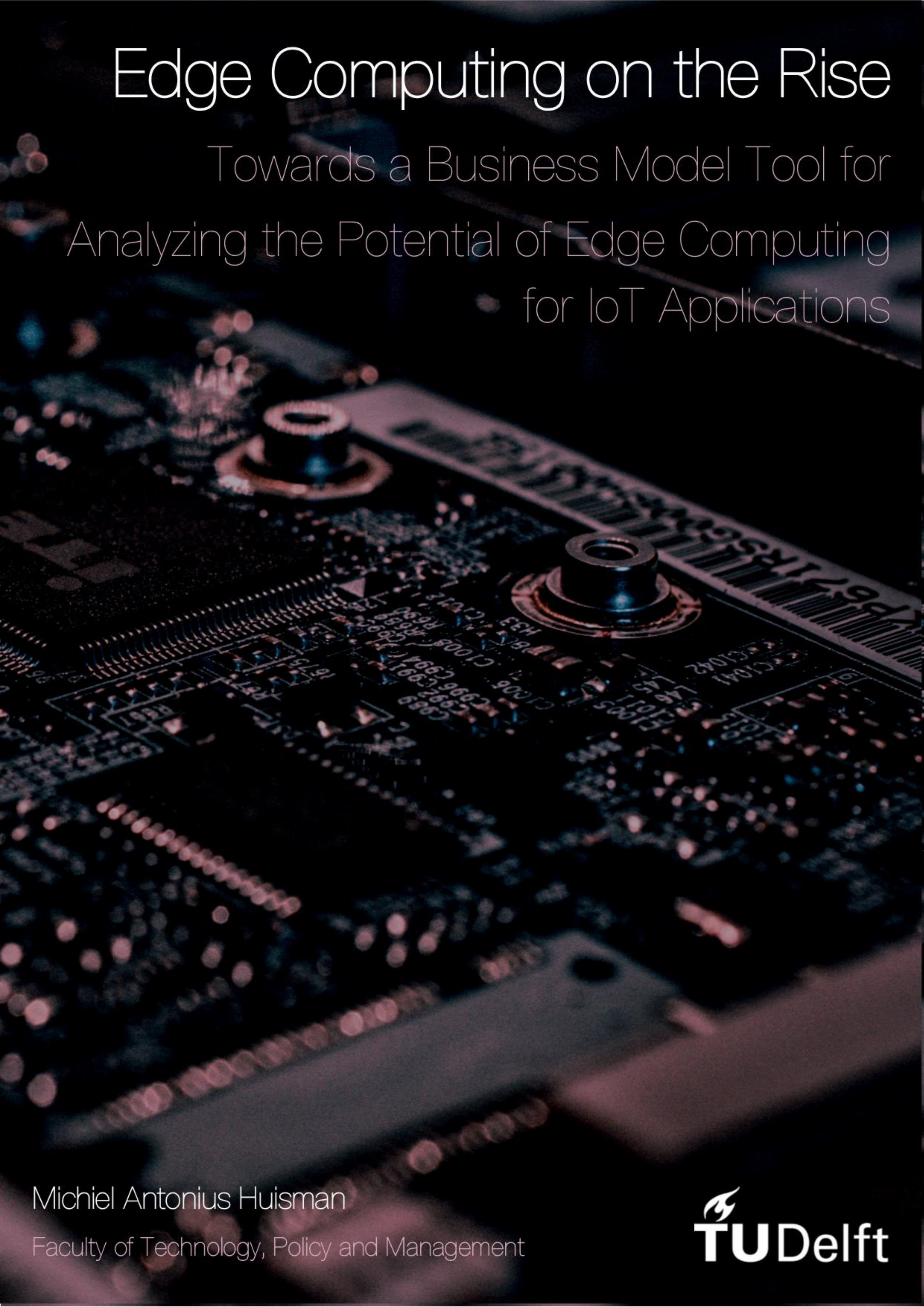
Edge Computing on the Rise

Towards a Business Model Tool for Analyzing the Potential of Edge Computing for IoT Applications



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Towards a Business Model Tool for Analyzing the Potential of Edge Computing for IoT Applications

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Acknowledgments

Friends have always told me that writing your Master thesis is the hardest part of studying. Whereas I can confirm that the previous period has been one of the busiest periods in my life, I would not say it was the hardest part of my academic career. It might have been the most difficult assignment I have had to fulfill yet, but because of my intrinsic motivation and interest for the subject, I was more than excited to work on this research project. Therefore, I would not say that this was the hardest part, as I have always enjoyed working towards the final result.

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Management summary

In the past decade, the cloud computing innovation has both transformed and dominated the IT discourse. In our current era, nascent technologies for the IoT are pushing computing towards decentralization. The advantages that cloud computing previously provided do not sufficiently meet the quality of service (QoS) that some IoT applications desire. Because of that, IoT applications such as autonomous vehicles, augmented reality, smart grid, distributed surveillance, and smart industry, among others, might not be feasible with a cloud computing offloading platform. A potential solution to this problem is brought with the edge computing paradigm. Edge computing is defined as: *an approach, which is aimed at solving the inherent problems of cloud computing regarding IoT, shifting the computing power away from the centralized data centers and envisioning a decentralized computing infrastructure, offering the same utility computing service, but with close proximity to the user and data source, which can be organized in a Cloudlet-, Fog computing- or Mobile Edge Computing IT solution.*

Within scientific literature it has become evident that edge computing can deliver substantial value to the general idea of IoT. However, literature on the financial and organizational domains of edge computing is scant. Whereas we have an understanding about the technical benefits, challenges, and solutions edge computing may bring, there is a lack of understanding about edge computing's business models. Additionally, there is a myriad of potential IoT applications for edge computing, but stakeholders are left with uncertainty about how the business potential of edge computing for these IoT applications can be identified. This leads to a deadlock situation where neither infrastructure providers, nor IoT providers are incentivized to engage in an edge computing ecosystem. In order to reduce this uncertainty, stakeholders need to be convinced that, for some applications, edge computing may constitute a viable and feasible business case. Scientific literature on business model tooling for assessing the business potential is however lacking behind. This implies that there is no business model tool that can be used to identify the business potential of edge computing in distinct IoT application areas, based on both business model viability and feasibility. Therefore, it is not possible to make informed decisions to target IoT application areas that hold substantial potential.

In order to solve the complexities mentioned in the previous paragraph, the main question has been formulated as: *How can technical-, business- and organizational factors be included in a tool, that can be used to identify the business model viability and feasibility of edge computing in distinct IoT application areas.* As this is the first research in this respective field, the tool cannot be expected to be mutually exclusive, nor collectively exhaustive. Hence, this research does not aim to design a comprehensive tool, nor does it aim to quantify the identified variables.

This research followed the six-step approach of the design science research methodology (DSRM). The first of these steps, identification of the main problems and related complexities, was formulated in the previous paragraphs of this summary. In the second step of the DSRM, the identified complexities were translated into design objectives that aim to formulate what solution would be desirable. Seven design objectives were formulated:

- O1. Business model variables should be contextualized towards the edge computing domain.
- O2. The tool's output should be an indication about the business potential of edge computing for the IoT application under analysis.
- O3. Edge service providers and IoT service providers should be able to use the tool.
- O4. By using the tool, edge providers and IoT providers should be able to formulate arguments that elaborate upon the business potential of edge computing for distinct IoT applications.
- O5. Use of the tool should clarify how edge computing creates value for potential adopters (i.e. IoT application providers).
- O6. In order to guide the process of informed decision making, an explicit description about how increase/decrease and presence/absence of the exogenous characteristics of an IoT application impact the business model viability and feasibility of edge computing should be elaborated in the tool.

O7. In order to enable accurate identification of the business potential, the relative importance of factors that influence the business model viability and feasibility of edge computing should be distinguished.

Then, in the third step of the DSRM, the artifact was designed. This research's design phase unfolds in two iterations. In the first design iteration, an extensive literature review was translated into a first draft of the tool. A distinction can be made between generic part of the tool and the contextualized part of the tool. In order to draft the generic part of the tool, the STOF ontology has been chosen as the guiding philosophy. The STOF model was adjusted to fit the design objectives. In order to do so, the general structure of the XLRM was used. The XLRM framework grouped variables into: IoT application characteristics as exogenous uncertainties (X), the choice of technology infrastructure for edge computing as policy lever (L), the conceptual model that explains the relations (R), and the potential of edge computing for the IoT application under analysis as the measure (M). Hereafter, the generic variables that were extracted from the STOF model, were contextualized towards the edge computing paradigm by means of literature review and informal talks. In the second design iteration, the input of eleven industry experts was used for refinement of the tool. First, the factors that have been drafted in the first design phase were validated on their relevance and applicability. Correspondingly, two variable groups were removed and 16 adjustments have been made in order to refine variables' definitions and interactions. Second, 27 new variable were identified. Third, by means of the Best-Worst Multi-Criteria Decision-Making Method, refinement was done by ranking nine generic variables; perceived value of the infrastructure, switching costs, customer base/revenue source, relative infrastructure cost, (financial) risk, IoT application's ecosystem (health), financial feasibility, technical feasibility, and organizational feasibility. These nine generic variables explain the business model viability and feasibility. This helps us understand the potential of edge computing for an IoT application under analysis. The output of the second design iteration is the final business model tool that is delivered in this thesis, which is displayed in Figure 1.

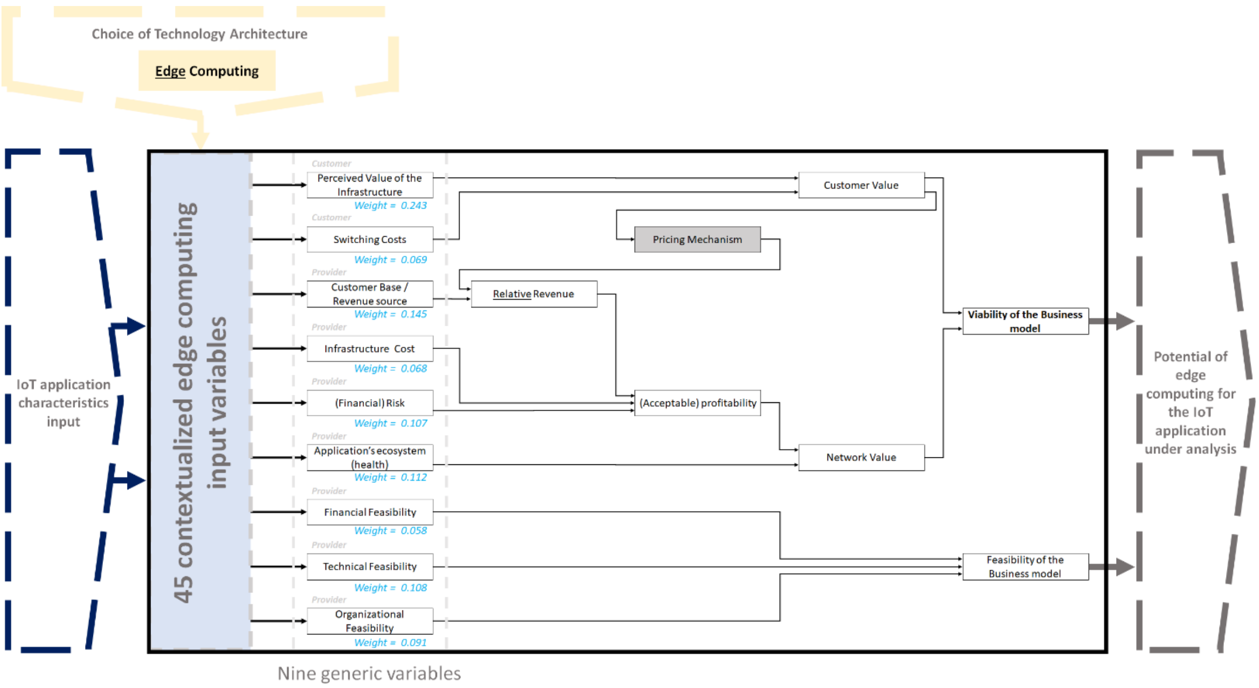

Figure 1: Simplified version of business model tool

The expert interviews confirmed the hypothesis that the 45 contextual input variables of the tool overloads industry practitioners with information. In order to mitigate this problem, the tool should be applied by means of ten constructive steps. The first nine steps of this 10-step method are aimed at explaining how the contextual variables interact with the individual nine generic variables. Users of the tool should provide a qualitative assessment of each contextual input variable's interaction with the corresponding generic variable. After assessing the interaction for all 45 contextual input variables, in the 10th step, the full tool used in order to derive to a final conclusion about the business potential.

In the fourth step of the DSRM, the tool was demonstrated on the IoT application; predictive maintenance in industry 4.0. In this demonstration, the utility that tool delivers was shown. After applying the tool on predictive maintenance in industry 4.0, it is concluded that there is currently no substantial potential for edge computing in this IoT application area. This results from the technical infeasibility of large-scale roll-out for a predictive maintenance solution. The technical infeasibility implies that, the major contributor of edge computing to predictive maintenance (i.e. pre-processing the big amount of data which mitigates band-width limits and reduces transmission cost of data), is of little use. Additionally, predictive maintenance requires a large-scale implementation in order to effectuate substantial cost savings. This requirement can however also not be met due to the technical infeasibility. Based on this, it is concluded that there is currently a lack of customer value. Moreover, it was identified that organizations in the industrial manufacturing domain are organizationally not ready for a shift towards the IoT domain. From the provider's side, it was identified that predictive maintenance in industry 4.0 constitutes an interesting potential market because; there is a major potential market size, the infrastructure cost is relatively low, the IoT application's ecosystem is relatively healthy, and no abundantly high risks have to be taken. Hence, if the technical and organizational complexities can be resolved, major potential gains await for both the customer (i.e. cost saving) as well as potential providers (i.e. revenue sources). It is recommended that providers start to make small investments in order to develop common standards and to make customer organizationally ready for implementation. Until these goals are reached, it is advised to search for another potential IoT application that may create value in the short-run.

In the fifth step of the DSRM, the designed artifact was evaluated by comparing the design objectives (drafted in step 2 of the DSRM), to the output of the demonstration phase. Based on this evaluation, it is concluded that the tool meets all seven design objectives. In turn, by meeting these seven design objectives, usage of the tool enhances the understanding about the business potential of edge computing in IoT application areas and thereby facilitates informed decision making.

- S1. The tool provides a set of 45 contextual input variables that explain 9 generic variables. These variables enhance our understanding about business models for edge computing.
- S2. Whereas the output of the tool does not provide a dichotomous answer, it's output is a formulated indication about the business potential of edge computing with respect to the IoT application.
- S3. The tool is targeted at edge providers and IoT providers. They should collaboratively apply the tool in order to get optimal results that contain minimum bias.
- S4. The qualitative assessment that is required for the tool's 10-step implementation, has as result that the conclusion which follows (in the 10^{th} step), represents a logical arguments that describe how the generic variables impact the business model potential.
- S5. By incorporating the business model variables *customer value*, the tool includes an assessment of the business value that edge computing brings for potential adopters.
- S6. The tool provides a description about how each variable's increase/decrease and presence/ absence impacts the respective generic variable.
- S7. The tool provides guidance in the prioritization of findings that are derived from the qualitative assessment of the tool's individual generic variables, by ranking their relative importance.

However, this research comes with limitations. More specifically, six limitations were identified. First, as interview data was collected in one point of time, the variables that have been added in the second design phase could not be empirically validated. Second, the identified weights contain a minor error, as interviewees have been asked to rank the relative importance of the generic factors as designed in the first design phase. However, as the philosophy behind these variables still holds, the ranking still provides utility. Third, in the demonstration phase, interviewees were asked about the interaction of the variables of the tool designed in the first design phase. This implies that tool as drafted in the second design phase could not be fully demonstrated. Fourth, a broad range of literature was covered in this research. This leads to a high-level analysis of the identified variables. Therefore, it cannot be guaranteed that the tool includes a comprehensive set of variables. Fifth, edge computing is interwoven with the concepts of Blockchain, Artificial Intelligence (AI), and 5G. Because of time and resource constraints, these concepts have however been excluded from the research scope. Sixth, the pricing mechanism that explains how customer value translates into a higher price, has not been researched.

Main findings of the designed tool can be generalized towards a broader field. First, the STOF model has guided identification of the nine generic variables. As the STOF model is focused on mobile service innovations, these generic variables apply to a broader field. Hence, we argue that the generic part of the framework is applicable to the field of mobile service innovations. In order use this, the generic variables should however be contextualized to these service domains. Two examples of mobile services for which the generic tool could be relevant are; cloud computing and 5G. The second generalization is that, the contextualized variables do not solely provide us with a tool that supports identification of the potential of edge computing for distinct IoT applications, but it also provides a better understanding of the edge computing paradigm in general.

The scientific contribution of this thesis research is explained in twofold. The first scientific contribution unfolds in the contextualization of generic business model variables towards the edge computing domain. The lack of understanding about edge computing business models has now been supplemented by describing how 45 edge computing variables explain nine generic business model aspects. To the best of the researcher's knowledge, no literature has described the totality of interactions for these contextualized variables. The second scientific contribution unfolds in the philosophy that an initial assessment of business model potential, prior to business model design, is beneficial. This is because the process of business model design, testing, and implementation, is time and resource consuming. This tool adds to existing approaches, as it is the first tool that indicates the business model potential based on both business model viability and feasibility, from both a customer and provider perspective.

The managerial contribution is explained by the utility that the designed tool brings to industry practitioners. For potential adopters, the tool provides contributions in their process of assessing if edge computing delivers advantages to their IoT service offering. With this, the uncertainty of edge computing's benefits to potential adopters are resolved. In turn, decreased uncertainty enhances adoption of the focal edge paradigm. Second, providers can use the tool in order to assess if they are technically, organizationally and financially ready for roll-out. If not, they can take actions accordingly. The tool also provides contributions in cases where customers and providers have already dedicated resources to edge implementation, but roll-out/utilization is staggering. The main managerial contribution to potential providers lays in the process of identifying for which IoT application areas edge computing hold substantial business potential. The tool's qualitative assessment results in logical arguments that explain the business potential. These arguments can be used to convince potential providers to invest in an edge computing ecosystem. Lastly, demonstration of the tool has answered the question whether edge computing has high potential for predictive maintenance in industry 4.0. This output contributes to the field of edge computing for predictive maintenance in industry 4.0, as it resolves the ambiguity that resided in the application area before.

Main recommendations (for future research) can be explained in threefold. First, potential edge providers, network providers, consultants, and IoT service providers, are recommended to apply the tool on other IoT application areas. Second, the tool should be improved by resolving limitations of this research as well as simplifying its use. Third, generic part of the tool should be contextualized to other mobile service domains in order to allow for identification of business model potential in those areas as well.

Keywords: *Edge Computing, Decentralized Computing, Internet of Things (IoT), Business Models, Business Model Tooling, Business Model Potential.*

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1 Problem identification

This Chapter elaborates upon the identified problem, which provides guidance for the remainder of this thesis research. First, a general background of the problem is delineated in section 1.1. Then, the managerial knowledge gap and its relevance are portrayed in section 1.2. Subsequently, the corresponding scientific knowledge gap and its relevance are augmented in section 1.3. Based on these knowledge gaps a problem statement (section 1.4) and research objective (section 1.5) are formulated. Lastly, the main research question and corresponding cope are expressed in section 1.6.

1.1 Problem background

In the ever-increasing web of interconnected devices, making up the Internet of Things (IoT) (Zhang et al. 2008), a proliferating amount of data will be generated, processed and stored. Where cloud computing was the past decade's answer for task-offloading of such resource-constrained IoT devices, our current era provides yet another valuable approach called edge computing. Aimed at solving the inherent boundaries revolving around the cloud computing paradigm, edge computing will allow an additional array of benefits to manifest (Shi et al. 2016).

1.1.1 From proprietary data centers to cloud computing

In the past decade, the cloud computing innovation has both transformed and dominated the IT discourse (Satyanarayanan 2017). In the process of doing so, cloud computing has extensively altered the way we live, work, and study (Shi et al. 2016). Cloud computing encompasses the model for ubiquitous, on-demand access to a shared pool of centralized resources (Mell and Grance 2011) and consists of both the application delivered as services to companies, as well as the hardware and system software that enable providers to deliver those services (Fox et al. 2009). In that sense, cloud providers can offer cloud computing capabilities through one of the three service models; Software as a Service (SaaS), Infrastructure as a Service (IaaS) and/or Platform as a Service (PaaS) (Mell and Grance 2011), which is usually offered in a pay-as-you-go manner (Fox et al. 2009). The value of cloud computing can be explained in threefold; First, through centralization, economies of scale presses down the marginal cost of system administration and operation. Second, businesses do not have to dedicate capital resources for creating a data center, but can instead consume computing power from large service providers (Satyanarayanan 2017). Third, the elasticity of cloud computing eliminates the risk of underprovisioning (underutilization) and overprovisioning (saturation) of customers' proprietary data centers by offloading in a pay-as-you-go manner (Fox et al. 2009).

1.1.2 The Internet-of-Things pushes towards a decentralized computing paradigm

However, the forces which have made the cloud computing paradigm the de-facto platform for computational offloading, are not the only ones at work. Especially nascent technologies for the IoT are pushing computing towards decentralization (Satyanarayanan 2017). In our increasingly interconnected world, a proliferating amount of physical objects are being connected to the Internet. These physical objects connect the outside environment to the Internet and in turn, realizes the idea of IoT (Al-Fuqaha et al. 2015). IoT is an enabler for physical objects to observe, think and perform jobs by having these objects share information in order to coordinate decisions (Al-Fuqaha et al. 2015). This means that, by merging underlying technologies such as sensing technologies, communication technologies, Internet protocols, pervasive computing, ubiquitous computing, and embedded devices together into one system, the IoT allows for a platform where the physical world can be digitalized. Lastly, by putting intelligence into the everyday objects (e.g. sensors), the objects in this ultra-largescale network can, next to collecting data, interconnect with each other (Borgia 2014). This then allows for unsupervised machine-to-machine (M2M) communication which is essential for delivering IoT applications such as smart cities, smart hospitals, and autonomous vehicles among others (Yu et al. 2018). In the article by Zhang et al. (2008), researchers empirically studied the Internet routing data (at a six-month interval) from December 2001 till December 2006. Based on their findings, they theoretically predict an accelerating trend with equal properties to Moore's law, where the Autonomous Systems (AS)-level connectivity structure of the Internet doubles every 5.23 years. Put more simply, every 5.23 years, the amount of interconnected devices is expected to double (Zhang et al. 2008). Not only will the number of interconnected devices (making up the IoT) grow, but it is estimated that by 2025, IoT will have a yearly economic impact of $11 trillion, representing a stunning 11% of the world economy (Dastjerdi and Buyya 2016). Industry leaders have acknowledged this. In 2015, an interview pointed out that 58% of the interviewed executives stated that the IoT is important to their business strategy (Cisco 2015).

Due to resource and power constraints of IoT devices, computation and data storage is often offloaded to the cloud through Machine-to-Cloud (M2C) communications (Premsankar, Di Francesco, and Taleb 2018; Yu et al. 2018). Unfavorably, in this ever-expanding web of IoT devices, there are countless data streams generated by sensors. When the data generated by the IoT devices is then sent to a geographically distant data center, real-time decision making is not possible due to serious latency issues (Varghese et al. 2016). This may especially have implications for applications such as: Autonomous vehicles, augmented reality, smart grid, distributed surveillance and network function virtualization (NFV). In these application areas short response time is non-negotiable and low latency is thus crucial (Morabito et al. 2018). Whereas the lack of proximity can be partially masked with sufficient resource dedication, there is an inherent limit. More specifically, the speed of light is the indisputable physical limit on latency, not to speak about the economic latency limit (Satyanarayanan 2017). With these limitations, it is not feasible to offload computation and data storage to a centralized cloud. Therefore, the earlier mentioned IoT applications might not be realizable with the current cloud infrastructure (Yu et al. 2018). Next to affecting latency, physical proximity also affects the economically viable bandwidth. Closer geographical proximity can increase the economically viable bandwidth (Satyanarayanan 2017). Adding to that factor, the proliferating amount of IoT devices will increase the volume of network traffic to the central servers, requiring a prohibitively high network bandwidth which, if not delivered, could even further increase latency issues (Ai, Peng, and Zhang 2018; Varghese et al. 2016).

Another worrying fact about centralized cloud computing can be found in the high energy consumption which is needed to keep the data centers, offering the cloud services, in operation (Varghese and Buyya 2018). In the next decade, it is expected that data centers will consume as much as three times the energy they consume today. With the increasing amount of devices making use of cloud services, it might be inevitable to adopt more energy efficient strategies in order to suppress the increasing energy demands (Varghese et al. 2016). Furthermore, as with any centralized computing model, cloud computing is susceptible to single point failures. One crucial internal failure can affect the entire cloud network (Varghese and Buyya 2018). Lastly, there are major issues regarding privacy protection requirements which might hinder centralized cloud computing for the IoT. To give an example, in some cases video images recorded by street cameras in public areas cannot be sent to the cloud due to privacy concerns (Shi et al. 2016). Building upon these privacy issues, as data centers are often located far away from its users, data might be transferred and stored in other countries than it originates from. As there are multiple regulatory and legislative constraints in this area, this increases concerns regarding the transfer of privacy-sensitive data (Varghese and Buyya 2018).

1.1.3 A potential solution: Edge computing

With the innovation of 5G around the corner, edge computing will prove to be a key solution for solving the issues of service providers to satisfy the Quality of Service (QoS) for many IoT applications (Yu et al. 2018). By bringing resources closer to the resource-constrained IoT devices, edge computing can possibly nurture a new IoT innovation ecosystem (Pan and McElhannon 2018). Edge computing describes the paradigm where data computation and storage is being performed at the network's edge. Correspondingly, the edge of the network is where it all starts, it is where the IoT devices allow for the real and digital world to meet.

First ideas on edge computing emerged in the late 1990s, when Akamai used edge nodes, close to the users, in order to accelerate web performance. This idea was however introduced in the light of content delivery networks (CDNs) which aimed to prefetch and cache web contents. Edge computing generalizes this concept and extends CDN by building upon the cloud philosophy and infrastructure. This means that, instead of being limited to web content, edge computing can run arbitrary code, similarly like in cloud computing. In 2012, the first real edge computing idea emerged when Cisco introduced the term fog computing to refer to a decentralized cloud infrastructure for IoT applications (Satyanarayanan 2017). In June 2015, the Open Edge Computing initiative, including Vodafone, Huawei, Intel, and Carnegie Mellon University was founded. Similarly, ARM, Dell, Cisco, Microsoft, Dell and Princeton University, initiated the OpenFog Consortium in November 2015. Since then, a couple of edge computing solutions for IoT have been proposed. Whereas these solutions are similar in their offering, they differ in their system architecture, background, and key techniques. Main solutions include: Cloudlet computing, Mobile Edge Computing (MEC) and Fog computing (Ai et al. 2018).

Going towards the core, the edge computing paradigm delivers a similar service as cloud computing, but by different means, enabling a range of new benefits to manifest such as; low latency, context awareness and mobility support among others (Premsankar et al. 2018). Furthermore, edge computing delivers the same utility computing service as cloud computing, delivering SaaS, IaaS and/or PaaS to its customers (Fox et al. 2009), but in a decentralized infrastructure, where computing power is brought to the network's edge (Michaela et al. 2017). Consequently, edge computing is an Information and Communication Technology (ICT) providing a service, delivered by software programs, to the user. This can be referred to as an electronic service. More specifically, Kar (2004) defines an electronic service as *"an activity or series of activities of intangible nature that take place in interaction through an Internet channel between customers and service employees or systems of the service provider, which are provided as solutions to customer problems, add value and create customer satisfaction"* (Kar 2004. pp28). Having identified edge computing as an electronic service, it is now possible to further define edge computing as a mobile service, which is a specific subset of electronic services. Mobile services, in turn, are electronic services being offered via mobile and wireless networks (Bouwman, De Vos, and Haaker 2008).

With its distinct infrastructure (further elaborated upon in section 3.1.3.3), edge computing solves numerous problems of service providers to satisfy the QoS for many IoT applications. First, the close physical proximity of edge nodes solves the inherent boundaries revolving from far located data centers, making it easier to achieve low end-to-end latency (Ai et al. 2018; Satyanarayanan 2017). Second, the cumulative bandwidth demand towards the cloud can be lowered because parts of the massive amounts of data generated by IoT devices can be processed at a lower level (at the edge). This means that not all data has to be sent to the cloud anymore, decreasing the stress on the limited bandwidth and thus mitigating the bandwidth requirements on the central network (Ai et al. 2018; Satyanarayanan 2017; Yu et al. 2018). Third, privacy-sensitive data can be processed at a lower level, relieving some of the problems revolving around privacy concern (Premsankar et al. 2018). Fourth, if the (large) cloud becomes unavailable, it can be partially masked by operating the essential processes in a local network (Satyanarayanan 2017). Fifth, edge computing can gather information about a device's location and environment at any given time, enabling the concept of context/content/location awareness. Based on this information, behaviors can be adapted according to the context of the device. For example, by means of location awareness, adequate data can be collected, processed and provided based on a device's geographic location, without being transported to the cloud (Shi et al. 2016). Sixth, edge computing can deliver mobility support to IoT applications. With mobility support, edge computing may facilitate mobility of devices mobbing around-, or falling outside the mobile network. For example, while moving around, a mobile node may keep its identifier and shift its attachment to the most suitable point to connect with the Internet (Ai et al. 2018).

Furthermore, it has been found that the nano-data centers, located at the edge, consume less energy than the centralized data centers. This means that edge computing can satisfy the QoS of IoT applications, while simultaneously saving energy due to offloading on the edge instead of centralized clouds (Jalali et al. 2016). Lastly, benefits due to energy savings can be observed with the energy expended in offloading queries. It has been found that energy consumption (Joule/query) can be significantly reduced by edge offloading compared to cloud offloading (He et al. 2017; Misra and Sarkar

2016; Premsankar et al. 2018). With these comparative benefits of edge computing over cloud computing, edge computing seems to be a promising innovation which could, with the increasing trend of IoT, transform the IoT discourse. Some scientists go as far as envisioning that edge computing will have as big an impact on our society as cloud computing had in the past (Shi et al. 2016). Figure 2 summarizes the main points of this section in a graphical manner.

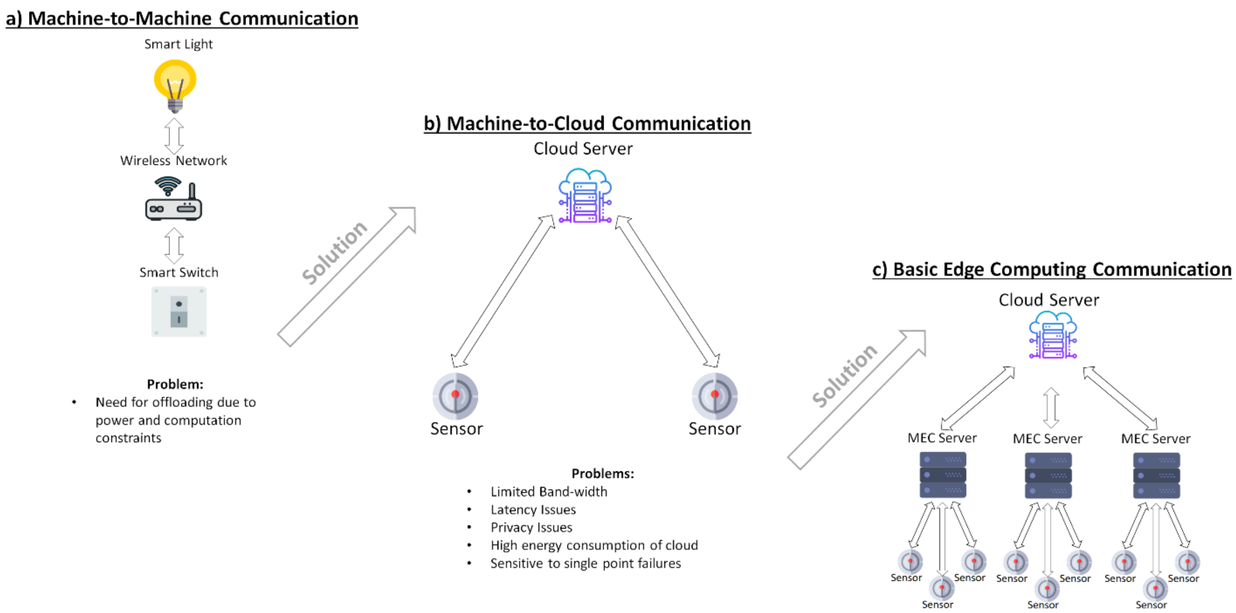


Figure 2: The evolution from simple M2M towards edge computing. Adapted from: *(Yu et al. 2018)*.

1.2 Managerial knowledge gap and relevance

As illustrated in the previous sections, edge computing can potentially deliver substantial value for IoT applications. With edge computing's value proposition, the general area of IoT has been identified as a key use-case. Along these lines, it is expected that edge computing will accelerate the development of IoT applications which require capabilities that cloud computing cannot deliver (Porambage et al. 2018). When exploring the literature, it becomes apparent that much literature has been dedicated to highlighting the technical advantages of edge computing compared to conventional cloud computing. Furthermore, the main technical challenges, opportunities, and prospects for edge computing have been widely explored (Ai et al. 2018; Dastjerdi and Buyya 2016; Jalali et al. 2016; Satyanarayanan 2017; Shi et al. 2016; Varghese et al. 2016; Yu et al. 2018). Whereas it has become evident that edge computing can indeed deliver value to the general idea of IoT, no papers provide guidance about how to analyze the value of edge computing for IoT application areas. Henceforth, ambiguity resides about which IoT applications will make a viable and feasible business case, and how this business case can be translated to economic outputs by means of a viable and feasible business model.

Multiple papers have highlighted potential application areas of edge computing, but these papers have solely selected use-cases in order to illustrate the boost of technical performance that edge computing can bring. The paper of Morabito et al. (2018) points out that edge computing can support IoT application areas such as autonomous drones, autonomous vehicles, augmented reality, and smart cities, but does not provide constructive argumentation about how much these application areas may benefit from the edge paradigm. Furthermore, the book of Bonomi et al. (2014) displays how edge computing can be deployed in a few potential case applications. The selection and evaluation of these cases have however not been guided by the ease of deployment nor by market considerations. Also, the paper of Shi et al. (2016) provides several case studies in order to display the technical value of edge computing. Whereas this paper provides insights about the value edge computing can deliver for cloud offloading, video analytics, smart home, and smart city, it does not provide a general understanding about factors that should be used in order to accurately analyze the business value of IoT use-cases (Shi et al. 2016).

More specifically, the paper of Pan and McElhannon (2018) identifies that application areas requiring low latency, high data bandwidth and with a large amount of IoT devices with low capacities will have the most benefit. The paper of Premsankar et al. (2018) also points out that low-latency communication and bandwidth-intensive applications will reap many benefits from edge computing. As third and fourth factor they explain that geographical distribution of devices and device mobility are increasing the benefit application areas will reap from edge computing (Premsankar et al. 2018). The aforementioned papers are however only focused on the technical benefits edge computing delivers to customers and thus do not include the business side (for consumers and providers). More technical literature has been dedicated to building and managing edge-based infrastructures for often mentioned applications such as smart grid (Samie, Bauer, and Henkel 2019), smart healthcare, industry 4.0 (Pace et al. 2019), augmented reality (Ren et al. 2019) and smart cities (He et al. 2017), among others. Lastly, the paper of Porambage et al. (2018) provides a holistic overview about the exploitation of edge computing for the realization of IoT application areas. This article analyzes the benefits edge computing may bring to the IoT applications; smart home, smart city, resource surgery, remote health consultancy, autonomous vehicles, augmented reality, virtual reality, gaming, retail, WIoT, farming smart energy and industrial Internet (Porambage et al. 2018). Whereas, this article provides an interesting insight about the technical requirements edge computing can fulfill for IoT application areas (as can be seen in Table 1), the business and organizational sides of these edge-enabled application areas are not included in the analysis.

Table 1: The (technical) benefits edge computing delivers to IoT application areas. Adapted from: (Porambage et al. 2018)

Required characteristics of edge computing and IoT *(Marked with X means application benefits from that specific edge computing characteristic)*	Description	Smart home	Smart city	Remote Surgery	Remote health consultancy	Autonomous vehicles	Augmented Reality (AR)	Virtual Reality (VR)	Gaming	Retail	Wearable IoT	Farming	Smart energy	Industrial Internet
Low Latency	Processing data with minimal delay		X	X	X	X	X	X	X		X	X	X	
Increased Bandwidth	Being able to move huge amounts of data	X	X	X		X	X	X	X	X	X	X	X	X
Content Awareness	Network characteristics can adapt to local service requirements	X	X	X			X	X	X	X	X	X	X	
Low Power Devices	Support for low power devices which has limited transmission power					X	X	X			X	X	X	X
Fixed wireless support	Operation of wireless systems used to connect two fixed locations with a wireless link	X	X	X			X		X	X	X	X	X	X
Fast Internet-RAT handoff	Speed up the handover takes place between different RATs	X	X	X			X	X	X	X	X			
Caching	Keeping frequently accessed information in a location close to the requester	X	X				X	X	X	X	X			
Edge analytics	Automated analytical computation on the sensor itself, network switch or another device instead of waiting for data to be sent back to a centralized datacenter	X	X	X			X	X	X	X	X			X
Application virtualization between edge and cloud	On-demand application and service migration from centralized cloud to the edge cloud		X	X		X	X	X	X	X	X	X	X	X
Private or local network	Limit the communication and data exchanges to a certain network segment	X	X	X		X	X	X	X	X	X	X	X	X
Security	Localized security		X		X		X		X			X	X	X
Privacy	Localized privacy		X	X	X	X	X		X		X			
Fast mobility	Enable the ability to move or be moved fast within the network or network coverable area		X	X		X	X		X		X	X	X	

The sole focus of edge computing research on the technical side leads to an inherent uncertainty about organizational- and financial factors. For edge computing, this uncertainty especially relates to the lack of mature business models and the unclarity about assessing the potential of edge computing for edge computing (Porambage et al. 2018; Satyanarayanan 2017). These issues have major implications in the IoT area, as research in this realm should give attention to- and include all the components that make-up the IoT ecosystem (Chernyshev et al. 2018). These uncertainties have implications on the side of the potential adopter (i.e. the companies that deliver IoT application areas) as well as the service provider (i.e. the companies that deliver an edge computing solution).

1.2.1 Implications on the adopters' side

The first implication from the adopters' side can be explained through the innovation diffusion theory of Rogers (2003). In his book Diffusion of Innovations, Rogers stipulates that innovation inherently comes with uncertainty. However, in order to propel wide-scale adoption, such uncertainties should be reduced. More specifically, he argues that one of the factors influencing the adoption of a new innovation is the amount of innovation-evaluation information accessible to potential adopters. When this innovation-evaluation information is not sufficiently present, potential adopters cannot answer questions such as: *What are the innovation's consequences* and *What advantages and disadvantages will the innovation in question bring to me specifically?* (Rogers 2003). Low availability of innovation-evaluation information thus leads to increased uncertainty which in turn leads to decreased adoption rates. Correspondingly, the paper of Heinle and Strebel (2010) builds upon this theory and empirically confirms that, in the case of IaaS adoption (one of the three cloud/edge computing service models), uncertainty revolving around the IaaS concept adversely affected adoption of the service (Heinle and Strebel 2010). Hence, adoption in the cloud paradigm was mainly driven by customers' support of the business model (Shirazi et al. 2017). This means that adopters' uncertainty revolving around technical and non-technical domains, as well as the business model benefit of edge computing, need to be resolved in order to accelerate its respective adoption rate.

1.2.2 Implications on the service provider's side

On the other side of the token, the biggest unknown for potential edge service providers relates to the analysis of the potential edge computing for IoT application areas. Potential service providers have no means of analyzing the business model viability for deploying an edge computing infrastructure for IoT application areas. With edge computing, the success is dependent on the support and involvement of multiple industries, organizations, and communities (Satyanarayanan 2017). Multiple players and stakeholders in the value chain and value net, need to actively contribute in order to turn the theoretical concept of edge computing into an implementable service (Bouwman, De Vos, and Haaker 2008; Pan and McElhannon 2018). In order to bring these actors to contribute their resources and capabilities, one must ensure that the business models are attractive to all actors involved in the ecosystem (Bouwman et al. 2008). Unfavorably, this results in a classic bootstrapping problem. Without killer applications and services that directly leverage the edge computing paradigm, there is no direct incentive for service providers to invest in the edge computing ecosystem and deploy the corresponding infrastructure (Satyanarayanan 2017). The players which could deploy such an infrastructure (current cloud providers, telco's, etc.), need to be convinced that edge computing makes for a better business case than the current cloud offering (Olaniyan et al. 2018). However, without initial investment in the infrastructure, there is no incentive for developers to develop services based on the edge computing paradigm (Satyanarayanan 2017). This means that, a major challenge resides in the difficulty to convince stakeholders of edge computing's business value for specific IoT application areas. Furthermore, as edge computing resources need to be placed in close proximity to the IoT application (Ai et al. 2018), specific (geographical) targeting of IoT application areas is a must. This is different from the centralized cloud computing paradigm, which can serve IoT application areas in different geographical locations. As a result, potential edge providers experience difficulties in determining efficient allocation edge nodes (Klas 2017).

1.3 Scientific knowledge gap and relevance

In order to solve the problems which have been stipulated in the previous sections, on the scientific side, there should be a model that enhances our understanding about adequate selection of IoT application areas for edge computing. Adequate selection is enabled by identifying the business potential of edge computing for these IoT application areas. Secondly, in order to drive the adoption process, our understanding of the business models of edge computing should be enhanced. As very limited literature has been dedicated towards the contextualization of business model variables towards the edge computing domain (Porambage et al. 2018; Satyanarayanan 2017), this part constitutes a major knowledge gap.

In the scan of state-of-the-art literature on the identification of the business potential, we start-off by referring to Chesbrough (2002), who stipulates that the business model mediates between technical inputs and economic outputs. A business model can provide companies with the capabilities to assess where their business model currently stands in relation to its potential. Based on that, companies may define the appropriate next steps (Chesbrough 2007). One of the main roles of the business model is to unlock the upper limit of the value potential that is embedded in a new technology (Zott and Amit 2010; Zott, Amit, and Massa 2011). Therefore, in order to formulate how the exogenous characteristics of edge computing and IoT applications translate into economic outputs and thereby provide an ample indication about the potential of edge computing for IoT applications, the shared language of business models should be the guiding design principle. This shared language is used in order to elaborate upon the business value of an IoT application under analysis, as well as the corresponding business model logic behind it.

Gordijn, Osterwalder, and Pigneur (2005) indicate a distinction in literature between business models as a taxonomies that enumerate a finite number of business model types and business models as ontologies which represent conceptual models that describe these business model types. Such ontologies outline what a business model actually is. The main aim of these ontologies is "to create a shared, formal and explicit conceptualization"(Gordijn et al. 2005. pp3). The conceptualization that these ontologies bring is relevant for assessing the business potential of edge computing for IoT applications. This is because we require an understanding of the way business is conducted with regards to edge computing, instead of a classification of distinct business model types (which is what taxonomies do).

Diving into the literature of business model ontologies, it becomes apparent that much effort has been dedicated towards their development (Bouwman et al. 2012). Major focus is on business model ontologies from a single firm perspective (Palo and Tähtinen 2011). Along these lines, ontologies such as the technology/market mediation model (Chesbrough 2002), the Business Model Canvas (Osterwalder and Pigneur 2013) and the Four-box business model (Johnson 2010), among others, have been introduced. However, an edge computing service needs to be delivered in a networked environment. Hence, it is more relevant to look at ontologies that take the perspective of services which are delivered in networks of companies instead of single firms. In this area of research, ontologies such as: the STOF model which explicitly focusses on mobile service innovations (Bouwman, De Vos, and Haaker 2008; Faber et al. 2003), the C-SOFT model which builds upon the STOF ontology (Heikkilä, Heikkilä, and Tinnilä 2008), the VISOR model which explicitly focusses on user experience and interface factors (El Sawy and Pereira 2013) and the networked business model which especially focusses on ubiquitous technology-based services (Palo and Tähtinen 2011), have been introduced.

The focus is however shifting from these theoretical ontologies towards more practical approaches of business model tooling. This is crucial, because business model thinking should contribute to practical solutions (Bouwman et al. 2012). The ontologies described above, often suffice as fundament for developing such tools (Gordijn et al. 2005). The increasingly popular scientific field of business model tooling is mainly focused on business model design (Anthanasopoulou, Haaker, and De Reuver 2018; de Reuver et al. 2016), testing, implementation (Anthanasopoulou et al. 2018). However, before we dedicate resources towards designing, testing, and implementing business models, the upper-bound potential should be assessed. This is because service design and development are still time-consuming tasks (Bouwman et al. 2008). Initial assessment of the upper bound limit has potential to safe time, as a quick-scan of the business potential may facilitate the decision whether to dedicate resources to design and development a business model. It has also been found that, a majority of the business model tooling approaches focus on financial evaluation (e.g. real option analysis, cost-benefit analysis, pricing, etc.), thus neglecting non-financial aspects (Heikkilä et al. 2016). Along these lines, Szopinski et al. (2019) indicated that researchers should explore new functionalities.

In order to deal with the managerial knowledge gap, a business model tool for informed decision making is required. More specifically, a tool that allows for informed selection of IoT applications domains for which edge computing contains substantial potential is needed. Some business model tooling literature focusses on evaluation (e.g. (Bouwman et al. 2008; Haaker et al. 2017; Heikkilä et al. 2016)) and informed decision making (e.g. (Bouwman et al. 2012)). However, scientific literature on these aspects is still lacking behind (Heikkilä et al. 2016; Tesch and Vrillinger 2017). More specifically, one of the under-researched areas of business models is the prescriptive way in which can be dealt with uncertainty (Bouwman et al. 2012). In this thesis, uncertainty relates to the potential of edge computing for distinct IoT applications.

One business model tool for assessing the business potential is represented in the book of Bouwman et al. (2008). They assess the business potential of eleven mock-ups. This assessment however solely focused on the business model viability. We argue that, for edge computing, technical, organizational, and financial complexities, play a prominent role in assessing the business potential. This implies that business model feasibility should be included for proper assessment. Business potential assessment by means of the value proposition canvas is also possible (Osterwalder et al. 2014). The value proposition canvas however solely focusses on creation of customer value, thus neglecting the value that is gained by the companies delivering the service.

To conclude, the scientific knowledge gap is explained in twofold. First, no research has been dedicated towards contextualization of the business model variables towards the edge computing paradigm. Second, there is no business model tool that can be used to identify the business potential of edge computing in distinct IoT application areas, based on both business model viability and feasibility. Therefore, it is not possible to make informed decisions to target IoT application areas that hold substantial potential.

1.4 Problem statement

Considering the problem background (1.1), the managerial knowledge gap (1.2) and the scientific knowledge gap (1.3) on the analysis of the potential of edge computing for IoT applications, and its implications on deployment and implementation of the corresponding infrastructure, the problem statement can be drafted as follows:

The lack of research on the business- and organizational factors of edge computing exemplifies itself in a lack of mature business models and uncertainty about how the potential of edge computing for IoT application areas can be analyzed. This especially relates to the uncertainty of potential adopters and service providers about the actual business value of edge computing for IoT applications. Together, this leads to a deadlock situation where neither infrastructure providers nor IoT providers are incentivized to invest in an edge computing ecosystem. In order to reduce the uncertainty and thereby break this deadlock, stakeholders need to be convinced that, for some applications, edge computing may constitute a viable and feasible business case. ***However, there is no business model tool that can be used to identify the business potential of edge computing in distinct IoT application areas, based on both business model viability and feasibility. Therefore, it is not possible to make informed decisions to target IoT application areas that hold substantial potential for both customers and providers.***

1.5 Research objective

In order to solve the identified problem area, the research objective is drafted as follows:

To design a business model tool, contextualized in the edge computing domain, that can be used to identify the business potential of edge computing in distinct IoT application areas, based on both business model viability and feasibility. The to-be designed tool should contribute in two main ways: First, for potential providers of edge computing infrastructures, it should allow informed decision making for targeting IoT application areas that constitute a viable and feasible business case. Second, the tool should facilitate potential customers in their estimation about the value edge computing may contribute to their IoT application area. These two contributions should in turn help in reducing the uncertainty revolving around the business model viability and feasibility for IoT application areas of edge computing, and thereby contribute to breaking the current deadlock situation.

1.6 Main research question

The main question, which aims to fulfill the specified research objective, is formulated as follows:

How can technical-, business- and organizational factors be included in a tool, that can be used to identify the business model viability and feasibility of edge computing in distinct IoT application areas?

The artifact that will be designed in this thesis is the first attempt to draft a tool that can be used to identify, and to provide arguments about the potential of edge computing for IoT applications. Therefore, it cannot be expected that the tool is mutually exclusive, nor that it is collectively exhaustive. This thesis does not aim to design a comprehensive tool, nor does it aim to quantify the identified factors. According to the best of the author's knowledge it is the first model that provides strategic guidance on informed decision making for targeting IoT application areas, based on technical, business and organizational factors, to the ones which are in a position (within the firm) to roll-out or adopt an edge computing infrastructure.

1.7 Conclusion

It is concluded that the problem identification constitutes five main complexities:

1. Literature on business models for edge computing is scant.
2. There is a myriad of potential IoT applications for edge computing, but stakeholders (i.e. edge service providers and IoT service providers) are unable to identify on which IoT applications they should focus their efforts.
3. Potential edge service providers need to be convinced that for some applications, edge computing may constitute a viable and feasible business case.
4. For potential adopters there is uncertainty about the actual business value of edge computing for their focal IoT applications, leading to decreased adoption rates of edge infrastructures.
5. There is no business model tool that can be used to identify the business potential of edge computing in distinct IoT application areas, based on both business model viability and feasibility. Therefore, it is not possible to make informed decisions to target IoT application areas that hold substantial potential for both customers and providers.

Together, these complexities lead to deadlock situation where neither infrastructure providers nor IoT providers are incentivized to invest in an edge computing ecosystem. These complexities can be solved by answering the main question: *How can technical-, business- and organizational factors be included in a tool, that can be used to identify the business model viability and feasibility of edge computing for IoT application areas.*

2 Research methodology

For rigorous research, it is required to follow a sound and structured research process. Therefore, this Chapter constitutes the description and elaboration of this thesis' research methodology. Section 2.1 elaborates the guiding research approach. Section 2.2 breaks down how the six sequential phases of the chosen research approach apply to this research. Section 2.3 then summarizes this into a research flow diagram, which delivers a graphical representation of the research approach. Lastly, section 2.4 formulates the overall research design.

2.1 Research approach

In this explorative study, a distinct advantage for using the Design Science Research Methodology (DSRM) (Peffers et al. 2007) has been found. This thesis research outsets from the problem-centered approach, (i.e. potential adopters and service providers are unable to estimate the actual business value of edge computing for IoT applications, leading to a deadlock situation), which is aligned with Design Science's (DS's) aim of creating and evaluating IT artifacts inherently with a problem solving process (Hevner et al. 2004). Furthermore, DS sets itself apart from other paradigms, as it attempts to create things that serve human purposes. DS research focusses on design and the proof of its usefulness. As industry practitioners (i.e. Edge providers and IoT providers) are the ones which should use the tool, the this is relevant in order to establish a practically relevant artifact (Peffers et al. 2007). DS should allow for a structured process of solving the focal problem in this research. In the realm of DS, the DSRM is the first commonly accepted methodology for carrying out DS for information systems. The DSRM provides a nominal process model for researchers aiming to do DS research in information systems. The strength of the DSRM can be found in the mental model it represents for presentation of outcomes (Peffers et al. 2007). The to-be designed tool aims to solve the problems revolving around application selection of edge computing enabled IoT applications (i.e. potential adopters and service providers are unable to estimate the actual business value of edge computing for IoT applications, leading to a deadlock situation). Consequentially, this research projects enters the DSRM approach at the problem-centered initiation (see Figure 3).

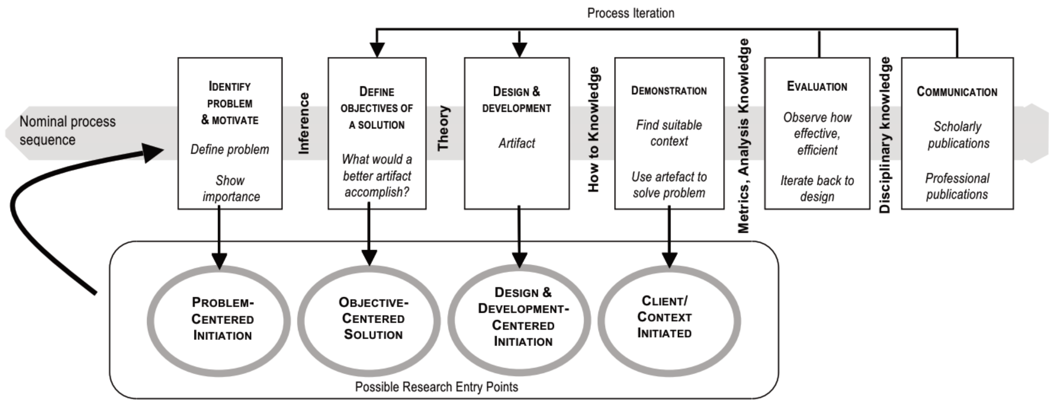


Figure 3: Design Science Research Methodology (DSRM) process model (Peffers et al. 2007).

2.2 Sub-questions answered by the six steps of the DSRM

Aimed at solving parts of the main question, and guided by the steps in the DSRM, the following three sub-questions have been drafted and will be elaborated upon in this section:

SQ 1: *How should concepts related to business modeling for IT services be used for identifying the potential of edge computing for distinct IoT applications?*

SQ 2: *How can the identified concepts be combined into a tool that indicates the potential of edge computing for distinct IoT applications?*

SQ 3: *To what extent does the designed tool facilitate informed decision making for selecting IoT applications in which edge computing delivers a viable and feasible business case?*

2.2.1 Identify problem & motivate

In this step, the research problem and the value of the solution that guides the research are identified and elaborated upon. Inherently, this step of the DSRM is used as a base to develop an artifact that can effectively provide a solution. Through literature review on edge computing, main knowledge gaps are identified (i.e. potential adopters and service providers are unable to estimate the actual business value of edge computing for IoT applications, leading to a deadlock situation) and the researcher's understanding of the problem is augmented. This step (1) of the DSRM has been discussed in Chapter 1.

2.2.2 Define objectives

Following from the problem definition in the previous step of the DSRM, this step aims to identify which solution would be desirable (i.e. what solution would be better than current ones). It has been identified that the artifact, which will be designed in this thesis, should lay the ground and provide initial insights on important factors for determining the potential of edge computing for distinct IoT application areas. Sub-question 1 should be answered in this step of the DSRM. This sub-question is aimed at identifying how concepts can be used in order to identify the business potential. Also, this step aims to further specify which factors are excluded from the tool. Main design objectives and a description of how the new artifact is expected to support solutions to problems hitherto not assessed are the output of this step. These design objectives in turn formulate how concepts related to business modelling for IT services should contribute to solving the complexities. The aims of this DSRM step are answered by providing an elaborate literature review about the relevant technical and theoretical domains of this thesis research. The technical domain constitutes an elaborate discussion about edge computing and its related domains. The theoretical domain consists of a thorough literature review about theories that may contribute in drafting the tool. Then, based on the output of this entire literature study plus the specified problem statement, design objectives for the tool are specified.

2.2.3 Design & development

Having defined the objectives of the solution plus the core concepts and ontologies of this research, the next step is to develop the tool itself. In this thesis, the tool's design is composed of two design phases. In the first design phase, the concepts and ontologies were described during the previous step of the DSRM are used to derive to the tool's variables. Furthermore, informal talks are used as additional input in this first design phase. This may provide valuable additional information as research on the contextual business model factors that influence the potential of edge computing for an IoT application is scant. Then, in the second design phase, by means of semi-structured expert interviews, a better contextual background about the identified factors is formulated and new factors, that have not been included in the first design phase, are unfolded. The output of this step is a tool, designed by two iterations, which should answer sub-question two. It should be noted that the second design phase is still exploratory in nature, intending to enhance the tool's capability to explain the real world. This implies that the tool is not tested on its comprehensiveness after the second design phase (i.e. only the variables which have been derived from the first design phase are validated and incorrect ones are removed).

2.2.4 Demonstration

In this step of the DSRM, the designed tool is demonstrated on an encompassing case. The selection of this case is guided by the earlier identified problem (step 1) and defined objectives of a solution (step 2). More specifically, a case can be defined as encompassing when it enables illustration of the extent to which the solution (i.e the designed tool) is desirable and thus answers the problems hitherto not addressed. Therefore, an encompassing case should be able to illustrate the extent to which the designed tool meets the design objectives that have been drafted in step 2. This suffices as main selection criteria for the demonstrating case. The second aim of the demonstration step is to provide industry practitioners with a real-life example about how the tool should be implemented. As literature on business model variables that impact edge computing's potential on an IoT application is scant, data is gathered through semi-structured expert interviews. due to time and resource constraints, one round of interviews is conducted (section 2.4 elaborates upon this data collection choice). Hence, the same interviewees provide input for the second iteration of the design phase and for the demonstration phase. Interviewees should have knowledge about the selected case and the value edge computing may contribute to that case. This section partially contributes in answering sub question 3.

2.2.5 Evaluation

Having demonstrated the tool on an encompassing case, this step evaluates the outcomes. More specifically, this step of the DSRM compares the objectives (identified in step 2) with the results of the case study (step 4). The tool's demonstration step should thus guide the evaluation of the designed tool. The research's outcomes and limits are thus evaluated in this step. Whereas researchers can usually decide whether to iterate back to step three (i.e. improve the artifact) of the DSRM or continue to step 6, because of time and resource constraints in this thesis, only one iteration of the DSRM is conducted. As the output of this step of the DSRM is the answer to sub-question 3.

2.2.6 Communication

Lastly, the sixth step of the DSRM aims to communicate the problem's importance and the artifact's novelty and utility. The communication should, display the rigor and effectiveness of the artifact's design. The communication phase of the DSRM is fulfilled by writing this thesis report. Therefore, in this thesis report, the relevance of the designed artifact's contribution to the problem (identified in step 1) is the main topic.

2.3 Research flow diagram

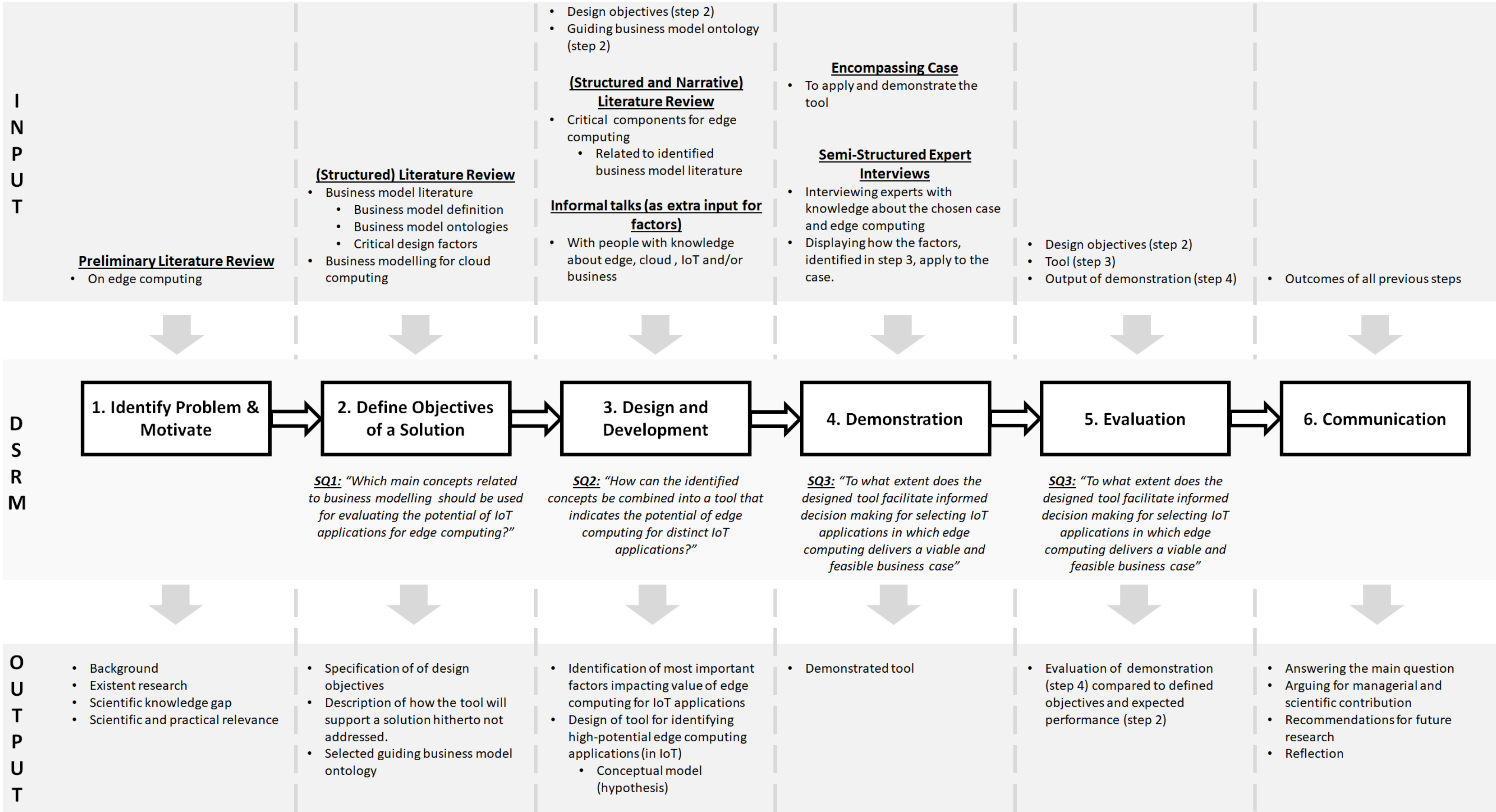


Figure 4: Research flow diagram

2.4 Research design

Having defined the main- and sub-questions, the next step is to conceptualize an appropriate research design. This research design should allow for a rigorous process in order to answer the main question (Sekaran and Bougie 2010).

As there is currently no theory that formulates how the potential of edge computing for IoT applications can be identified, a new theoretical tool should be developed. Whereas some facts are known on the technical side and on the business model side, more information is needed in order to develop a viable theoretical tool that is contextualized towards the edge computing paradigm. This implies that, this master thesis is exploratory in nature (Sekaran and Bougie 2010). Main advantages of such exploratory projects can be found in their adaptability, flexibility and their effectivity to lay the basis for future studies to build upon. Disadvantages are mainly related to its dependence on qualitative data. This, in turn, leads to higher vulnerability of the data being subject to bias, lower generalizability of the study's findings and decreased practicability in decision making (Dudovskiy 2018).

In order to guide the data collection methods and variables included in the tool, the level at which data will be aggregated for analysis is be determined. Defining this in scientific jargon, the unit of analysis is referred to as *"the level of aggregation of the data collected during subsequent data analysis stage"* (Sekaran and Bougie 2010. pp136). For this study, the aim is to establish a tool that can be used to identify the business potential of edge computing in distinct IoT application areas, based on bot business model viability and feasibility. Hence, the level at which data will be aggregated is at the application level, meaning the unit of analysis is IoT applications. Some examples of applications, which have been identified in the problem identification, are; autonomous vehicles, smart cities, augmented reality and smart grids among others. In order to make this systematic, the applications can be grouped in clusters (e.g. health based, surveillance based, etc.). Furthermore, with the inherent time and resource constraints within this study, for each step in the process, data will be gathered just once (though it will be over a period of several months). This means that the a cross-sectional data-collection method is used (Sekaran and Bougie 2010).

2.5 Conclusion

It is concluded that the Design Science Research Methodology (DSRM) is the most suitable research approach for this thesis research. This report is structured through the six steps of the DSRM. In order the main question, the three sub questions; *How should the concepts related to business modeling for IT services be used for evaluating the potential of edge computing for distinct IoT applications? How can the identified concepts be combined into a tool that indicates the potential of edge computing for distinct IoT applications?* And, to what extent does the designed tool facilitate informed decision making for selecting IoT applications in which edge computing delivers a viable and feasible business case? Should be answered. These sub-questions are fully answered in Chapter 4, 7, and9, respectively.

3 Literature review

Having identified the problem and research approach, this Chapter builds upon that and unfolds an extensive literature review on the technical domain (i.e. main concepts) and relevant theoretical frameworks and ontologies, in order to identify the design objectives for the tool. This Chapter partially contributes in answering sub-question 1, by enumerating the relevant concepts related to business modeling for IoT services. Put differently, the relevant concepts that are identified in this section will be the foundation for input of the first design iteration of the tool (Chapter 5).

3.1 Technical domain

This section describes the relevant technical concepts. The theoretical concepts: Internet of Things (section 3.1.1), Cloud computing (section 3.1.2) and edge computing (section 3.1.3) are unfolded in this section.

3.1.1 Internet of Things

A deep-dive into the Internet of Things (IoT) concept is required as this thesis focusses on identifying the potential of edge computing for IoT applications specifically. In order to do so, first, a working definition is adopted in section 3.1.1.1. Then, in order to get a more in-depth understanding of IoT, six key characteristics are identified in section 3.1.1.2. Section 3.1.1.3 is dedicated to unfolding IoT application areas. As identified in the problem statement, there is a myriad of potential IoT applications for edge computing. Hence, it is relevant to uncover the respective application areas as this provides us with increased insight in the types of IoT application to which edge computing may provide benefit. This will also help in selecting a concrete IoT application for demonstration of the tool.

3.1.1.1 A definition

Manifold definitions of IoT can be found in different research communities. This testifies the strong interest, as well as the vivacity of debates on it. The main reason behind the fuzziness regarding the definition if IoT, is the consequence of its respective name. The term Internet of Things is namely composed of two main parts. The first one refers to the network-oriented vision, whereas the second one shifts focus towards the generic objects to be integrated into one framework. The ambiguity in the definition then arises as researchers approach the IoT issue from either an Internet-, or a Things oriented perspective (Atzori, Iera, and Morabito 2010). This section aims to select a working definition. For a more in-depth discussion on the different definitions and the respective philosophies behind these definitions for IoT, one can consult the papers of Atzori et al. (2010), Gubbi et al. (2013) and Li, Xu, and Zhao (2015).

In 1999, the concept of IoT was first proposed by Kevin Ashton, which referred to the IoT as uniquely identifiable interoperable connected objects with radio-frequency identification (RFID) technology. At that time, however, the concept of IoT was still in its infancy and its definition was rather incomplete (Ashton 2010; Li et al. 2015). Atzori et al. (2010) extend this definition by mentioning that IoT refers to the network of all interconnected objects which communicate by means of standard protocols. This means IoT refers to much more than objects which are connected through RFID technology (Atzori et al. 2010). A more elaborate and encompassing definition has been formulated by Miorandi et al. (2012), who state that the IoT refers to *"both the resulting global network interconnecting smart objects by means of extended Internet technologies, the set of supporting technologies necessary to realize such a vision as well as the ensemble of applications and services leveraging such technologies to open new business and market opportunities"* (Miorandi et al. 2012. pp 1498). Simultaneously, Mazhelis, Luoma, and Warma (2012) define the IoT from a service perspective, where an ecosystem of companies is needed to deliver IoT solutions. This means that, when delivering IoT solutions, the unit of analysis should not be on single-firm level, but rather on a networked level. More specifically, they define the IoT as *"a global network and service infrastructure of variable density and connectivity with self-configuring capabilities based on standard and interoperable protocols and formats [which] consists of heterogeneous things that have identities, physical and virtual attributes, and are seamlessly and securely integrated into the Internet"* (Mazhelis et al. 2012. pp 1). The paper of Gubbi et al. (2013) takes a more user-centric perspective on the IoT and identifies that the IoT encompasses an information sharing platform. They extensively elaborate that technologies such as data analytics, information representation, seamless ubiquitous sensing and cloud computing are a must in order to unify the information sharing platform (Gubbi et al. 2013). Lastly, the ISO / IEC have formulated a standard definition for the IoT as: *"An infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and virtual world and react"* (ISO / IEC 2016. pp 9). In order to allow for rigorous discussion, the standardized ISO definition is adopted for the remainder of this thesis.

3.1.1.2 Key characteristics

Following key concepts from the definitions, as well as highly cited papers on IoT, it becomes apparent that the IoT is characterized by means of six characteristics:

1. **Sensing/actuation capabilities:** This characteristic of the IoT refers to the data collection of physical objects, digitalizing the real world. The Things in the network gather data and send it back to a data warehouse, data-base or the cloud (Al-Fuqaha et al. 2015).
2. **Interconnectivity and ubiquity:** IoT refers to the huge load of devices, all being connected to the Internet network (Patel et al. 2016). This interconnectivity is established by standardized protocols such as RFID, NFC, WiFi, LTE or RAN, among others (Al-Fuqaha et al. 2015). These communication protocols, in turn, allow for ubiquity, meaning the network can be accessed at any moment, at any place (Borgia 2014).
3. **Enormous Scale/scalability:** The number of devices that make up the Internet of things is enormous (Patel et al. 2016). More specifically, the number of devices can be counted in billions, making the IoT network an ultra-large-scale network of things (Ai, Peng, and Zhang 2018). Furthermore, this web of interconnected devices is dynamically scalable as everyday objects increasingly connect and disconnect (Miorandi et al. 2012).
4. **M2M communication:** This does not refer to any specific communication technology or specific protocol, but instead it refers the principle where two or more devices communicate (automatically) without the necessity of human involvement (Borgia 2014).
5. **Heterogeneous devices:** The devices which make up the IoT are heterogeneous, meaning they are based on different hardware platforms, software platforms, and networks (Patel et al. 2016). Furthermore, these devices will have different capabilities in the form of computational power and communication protocols (Miorandi et al. 2012).
6. **Storage- / Task-offloading:** The IoT results in the generation of enormous amounts of data. The devices that generate this data are however resource constrained in terms of computing power, storage capacity and in some cases battery lifetime (Pan and McElhannon 2018). Therefore a commodity model for processing and storing data is needed (Gubbi et al. 2013). This commodity model is currently called utility computing and can be executed in a cloud-, edge-, or other IT infrastructures.

3.1.1.3 IoT application domains and areas

This section elaborates upon the main application domains of IoT. This means that specific applications are not mentioned, but the application domains and areas are elaborated upon. In turn, each application domain contains numerous application areas. An application area contains a group of IoT applications that are used in the IoT application domain. Lastly, each IoT application area, contains specific IoT applications. Whereas an IoT application area describes a group of related IoT applications, an IoT application displays one specific case of the application area. It is relevant to provide an overview of these domains and areas, as it gives insights in the myriad of potential IoT applications for which edge computing may provide value.

Industrial:

- Intelligent logistics and transport: For the logistics sector, devices can be used to trace objects for supply-chain optimization, increased efficiency in warehouses and ensuring maximized utilization of storage facilities (Borgia 2014). Furthermore, integration between communication and computation can be used in order to monitor and control the transportation network (Al-Fuqaha et al. 2015).
- Smart Factory/industry 4.0: Based on the four elements; transportation, processing, sensing and communication, the concept of industrial automation can be extended from machine-line-automation towards automation of the whole process (i.e. from order to customization, to production), without direct involvement of humans. The machine's operations, functionality, and productivity can then be established by IoT (Al-Fuqaha et al. 2015). This application domain includes IoT application areas like Collaborative-robots (Co-bots), predictive maintenance, customized production, and other IoT enabled factory services.

Agriculture:

- Agriculture and breeding: In this domain, IoT applications for monitoring and tracing animals provide significant benefits. By means of sensor data, relevant events (e.g. diseases or separation of the herd) can be identified and subsequently acted upon. Similarly, data about soil conditions and other relevant agriculture metrics can be used as input to optimize the agriculture output (Borgia 2014).

Smart City:

- Smart grid: The smart grid refers to the intelligent electrical distribution system that is able to bidirectionally distribute energy flows between producers, consumers, and prosumers. Through devices such as smart meters, the traditional power grids can be upgraded into a smart grid which allows for optimized energy distribution and storage. Furthermore, the smart grid can give real-time feedback about the energy consumption of consumers, in turn helping in creating awareness of their individual consumption (Borgia 2014). The smart grid application is especially relevant when aiming to facilitate the distributed generation, cogeneration, and distribution of energy. This will become increasingly dominant with the rise of alternative energy sources (e.g. sustainable energy) (Farhangi 2010).
- Smart building and building automation systems: A myriad of sensors will allow buildings (i.e. homes, offices, etc.) to become smart and assistive environments. Instead of just being an empty shell, smart buildings allow for extended capabilities such as increased security, asset management/maintenance, energy saving, increased workplace utilization, and lightning/air quality optimization among others (Borgia 2014). It reduces the consumption of resources associated to the building, as well as increase the satisfaction level of the humans which populate the building. This has a positive impact on both economic as well as societal domains (Miorandi et al. 2012).
- Environmental monitoring: Environmental factors such as temperature, pollution, rainfall, wind, etc. can be actively monitored by means of IoT devices. This, in turn, allows for a solid platform to detect anomalies that can lead to endangering animal or human life (Miorandi et al. 2012). This is especially relevant when aiming to predict and anticipate on emergency situations such as floods, earthquakes, epidemics, tornadoes and electrical outages (Borgia 2014).
- Public safety: Lastly, the IoT can allow for real-time monitoring of public area's (i.e. by face recognition), which allows for increased crowd management capabilities, adequate detection of safety breaches and identification of malicious intentions/activities (Borgia 2014).

Smart Mobility:

- Mobility monitoring and planning: By connecting sensing devices to vehicles, traffic lights, camera's and other mobility-related objects, real-time traffic can be observed. This can help in getting insight into traffic density, road quality, and other relevant factors. Subsequently, this data can be used to optimize road utilization (without congestion) and plan future infrastructure projects. Furthermore, smaller applications like smart parking systems can be realized (Borgia 2014). Traffic control systems can offer services that mitigate congestion problems (Miorandi et al. 2012).

- Autonomous vehicles: encompasses the idea that vehicles (including cars, trucks, drones, etc.) can move without human involvement. This is built upon the IoT concept of V2X (Vehicle to Everything), which describes that the autonomous vehicle communicates with all 'smart' objects in its environment (Porambage et al. 2018).

Health/well-being:

- Smart healthcare: the IoT allows for real-time monitoring of medical parameters as well as vital functions of clients (e.g. blood pressure, temperature, cholesterol level, hearth rate). This data can then be used by doctors to continue monitoring patients while they are out of the hospital. On the other side of the token, IoT allows for increased inventory management as well as safety access systems within the hospital (Borgia 2014). The IoT can also be used to monitor if standard protocols (e.g. washing hands after seeing a patient – which reduces the chance of infection significantly) are actually followed (Al-Fuqaha et al. 2015). It also allows for more personalized health care (Miorandi et al. 2012).
- Independent living: By monitoring real-time psychological and physical factors of elderly people, active detection of falls, diagnosing and control of dementia and other serious health threats of these elderly can be actively monitored and acted upon. This could allow (some) people to live at home instead of nursing homes (Borgia 2014).

Wearable IoT (WIoT) and interactive gaming:

- Smart accessories: people are increasingly wearing smart devices such as step trackers, smart glasses, smart watches, etc. This trend is especially fueled by the development of low power wireless technologies (Porambage et al. 2018).
- Augmented Reality (AR): The concept of AR combines physical reality with computer-generated vision and data, allowing for augmented reality. Subsequently, this allows for virtual extension of the real world, providing a composite view. The connection of objects, characterizing the IoT, allows for even further extension of the AR capabilities (Porambage et al. 2018).
- Virtual reality (VR): VR describes the concept where the user interacts with a computer-generated simulation, which is seemingly real. VR is different from AR as it does not extend/manipulate real-world images but fully revolves around a computer-generated world.

3.1.2 Cloud computing

Edge computing provides a key solution for solving the issues of cloud computing for IoT, that service providers currently cope with. Because of that, edge computing may either compete or complement the cloud computing paradigm (Yu et al. 2018). In order to get a better understanding about the interactions of cloud and edge computing, a technical deep-dive into the cloud concept is required. In order to allow for rigorous discussion, section 3.1.2.1 adopts a working definition for cloud computing. Section 3.1.2.2 then further deepens into the key characteristics of cloud computing. This is especially relevant in order to outline the differences of cloud and edge computing later on. In section 3.1.2.3, the cloud service models are explained. This is relevant, as edge computing delivers the same three service models. Lastly, section 3.1.2.4 provides an overview about factors that influences firms' decision to adopt a cloud solution. As edge computing delivers the same service models (but with different characteristics due to its infrastructure), lessons may be learned from the adoption decision of firms' within the cloud paradigm.

3.1.2.1 A definition

In order to define the cloud computing paradigm, the NIST formulated a definition which describes the aspects of cloud they find to be of crucial importance. The NIST formulated this definition with the intention to be used as a baseline for discussion on what cloud computing is and how it can be best used. The NIST definition is currently the most cited and widely used one. Therefore, in order to follow the standards and guidelines which allow for rigorous discussion, the NIST's definition for cloud computing is adopter in this thesis, that is: "*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction*" (Mell and Grance 2011. pp 2). Before deep-diving into the key characteristics, following from this definition, one can observe that a closely interwoven concept, aligned with the service delivery part cloud computing, can be found in the overarching theme of utility computing. More specifically, utility computing describes the service of provisioning computing as a utility, similarly to utilities such as electricity, water and gas which are already widely known (Armbrust et al. 2010). Cloud computing then is the means by which this utility computing service is delivered to the end-user. Furthermore, a distinction can be made between private cloud, community cloud, public cloud, and hybrid cloud. The public cloud refers to the cloud infrastructure that can be used by the general public. In the community cloud, only a specified group of people is allowed to use the cloud. Then, in the private cloud, only one organization has access to the cloud system. The hybrid cloud encompasses a mix of public, private and/or community (Mell and Grance 2011).

3.1.2.2 Key characteristics

Following from the NIST's definition, cloud computing is described in terms of five key characteristics:

1. **On-demand self-service:** The consumer is provisioned with unilateral computing services. That is, the end-user can access computing capabilities such as network storage and computational off-loading at any moment required, but cannot provide any computing capabilities back to the server provider. Furthermore, this service should be provisioned automatically, meaning no human interaction is involved between the customers and the service providers (Mell and Grance 2011).
2. **Broad network access:** The computing services can be accessed over the (Internet) network by a range of heterogenous devices and with standardized communication protocols. Typical devices that can access the cloud computing capabilities include; tablets, laptops, mobile phones, workstations (Mell and Grance 2011) and other (sometimes) more resource-constrained IoT devices (Premsankar, Di Francesco, and Taleb 2018; Yu et al. 2018). As users can access the capabilities through the Internet, resources which are not locally available can be accessed at numerous locations which are geographically dispersed.
3. **Centralized Resource pooling:** A pool of resources is issued by the provider in order to serve numerous consumers. This is done in a multi-tenant model, where resources are dynamically assigned to real-time customer demand. This dynamic pooling allows for increased utilization of centralized computing sources. On the other side of the network, the user generally has little knowledge about the physical location of the location where the resources come from (i.e. they could only know the country, state or datacenter name) (Mell and Grance 2011). What typically characterizes cloud computing, is that the utility computing service is delivered in a centralized IT infrastructure (Satyanarayanan 2017).
4. **Rapid elasticity:** computing capabilities can be provided elastically and automatically (Mell and Grance 2011), meaning the scale at which a user consumes computing capabilities can be rapidly increased or scaled-down according to the consumer's demand. This rapid elasticity, in turn, reduces the risk of underprovisioning (underutilization) and overprovisioning (saturation) (Armbrust et al. 2010). The centralized cloud data centers allow for an almost unlimited pool of resources, meaning almost any appropriated quantity can be delivered at any time (Mell and Grance 2011).
5. **Measured service:** By means of a metering capability, cloud providers are able to automatically monitor, control and report resource usage, providing transparency for both the consumer as well as the provider (Mell and Grance 2011). This part enables the utility computing service, as it capacitates cloud providers to accurately offer these services to the user in a pay-as-you-go manner. This means the customer only pays for the computing capabilities that have actually been used (Fox et al. 2009).

3.1.2.3 Cloud service models

Cloud computing constitutes three service models, namely; Software as a Service (SaaS), Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) (Fox et al. 2009; Mell and Grance 2011). Figure 5 displays how the three service models relate to the technical cloud layers.

1. **Software-as-a-service:** SaaS refers to the service where the consumer uses the cloud's computing capabilities to run its applications. These applications can, in turn, be accessed from client devices and interfaces such as a program interface or web browser. In this service model, the user does not have any control over the underlying cloud infrastructure (e.g. servers, storage, network, etc.) (Mell and Grance 2011). This means that the application, which is used by the consumer, is being owned, managed and maintained by the service provider, but can be accessed by the consumer ubiquitously.
2. **Platform-as-a-Service:** This service model provides a platform that facilitates development as well as deployment of the customer's applications. Whereas the customer still has no control over the underlying cloud infrastructure, he does now have control over the focal application as well as the configuration settings for hosting environment. This means that, unlike in the SaaS model where standard plug-and-play applications are provided to the consumer, the PaaS model provides a model where customers can design, develop, test and deploy their own applications without managing the underlying infrastructure (Mell and Grance 2011).
3. **Infrastructure-as-a-Service:** In the IaaS service model, storing and processing capacity for off-loading are provided to the user. This means the consumer is able to use processing, storage, networks, and other computing resources without owning or controlling the cloud infrastructure (Mell and Grance 2011). These infrastructure capabilities, in turn, enable the user to use computing capacity from the service provider's data center in a pay-as-you-go manner, instead of dedicating capital resources towards buying it (Satyanarayanan 2017).

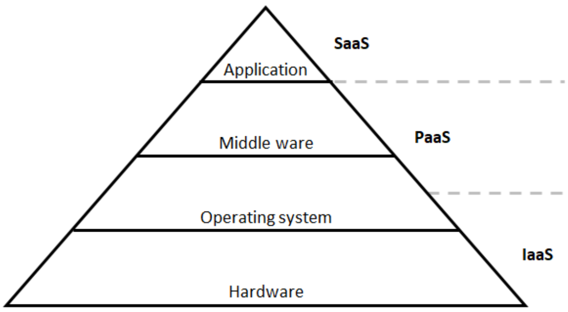


Figure 5: How the three service models relate to the cloud layers

3.1.2.4 Factors influencing the adoption of cloud computing

Multiple authors have attempted to identify factors which have a significant effect on the decision of single firms to adopt cloud computing technology (Alshamaila, Papagiannidis, and Li 2013; Hsu and Lin 2016; Low, Chen, and Wu 2011; Oliveira, Thomas, and Espadanal 2014). Whereas these researchers all used the Technology-Organization-Environment (TOE) framework for initial identification of factors, and thus have a similar set of factors which they hypothesized to have an effect on the adoption of cloud computing, they found conflicting results in the factors that were of significance. The TOE framework describes how a firm's context influences the implementation and adoption of innovations. It describes an organization-level theory that explains the adoption process by means of three different elements of the firm. These three concepts include; technological, organizational and environmental. In turn, these three contexts influence technological innovation (Baker 2012).

Table 2 displays an overview of the TOE variables respective researchers found to have a significant impact on the adoption of cloud computing for single firms. These contradictions indicate that there is no consensus on the factors that are of influence on the cloud adoption determinants for single firms. It does, however, indicate the relevance of the TOE framework in determining adoption factors.

Table 2: Cloud adoption factors, based on TOE framework, that found support in different studies

Paper	Theory used for proposition	Factors that found support	Effect
(Alshamaila et al. 2013)	Technology	Relative advantage	+
		Uncertainty	-
		Geo-restriction	-
		Compatibility	+
		Complexity	-
		Trialability	+
	Organization	Size	-
		Top management support	+
		Innovativeness	+
		Prior IT experience	+
	Environment	Market scope	Categorical
		Supplier computing support	+
		Industry	Categorical
(Hsu and Lin 2016)	Technology	Relative advantage	+
		Observability	+
		Security	+
	Organization	Financial costs	+
		Satisfaction with existing information system	-
	Environment	Competition intensity	+
(Low et al. 2011)	Technology	Relative advantage	+
	Organization	Top management support	+
		Firm size	+
	Environment	Competitive pressure	+
		Trading partner power	+
(Morgan and Conboy 2013)	Technology	Relative advantage	+
		Compatibility	+
		Complexity	-
		Triability	+
	Organization	Increased Collaboration	+
		Increased traceability and auditability	+
		Convincing IT managers	+
	Environmental	Security and Legal Issues	-
		Perception of the term cloud	-
(Oliveira et al. 2014)	Technology	Cost savings	+
		Relative advantage	+
		Complexity	-
		Technology readiness	+
	Organization	Top management support	+
		Firm Size	+

Another relevant contribution to the scientific body on cloud adoption, which identifies the main factors affecting the diffusion of cloud computing from a different perspective than the TOE framework, has been delivered by Tsai and Hung (2014). They found that service quality, infrastructure maturity, price, technology maturity perceived risk and economic situation are relevant cloud adoption determinants in a respective descending order (Tsai and Hung 2014). Table 3 displays the relative importance of the factors they found to be significantly influencing consumers' willingness to adopt a cloud computing solution.

Table 3: Factors influencing consumers' willingness to adopt cloud computing. Adapted from: (Tsai and Hung 2014)

Factor	Relative importance
Service quality	0.175570
Infrastructure maturity	0.147123
Price	0.145613
Technology maturity	0.145005
Perceived risk	0.080952
Economic situation	0.033573

Lastly, more recent research has been conducted by (Changchit and Chuchuen 2018), which specifically researches how the perception on cloud computing by the customer, influences the adoption process. This has especially been done in the light of laggards which are reluctant to adopt cloud, whereas its benefits have become apparent in many cases. They identified that; perceived usefulness, perceived ease of use, perceived security and perceived cost of usage, all had a significant effect on customers willingness to adopt a cloud computing solution (Changchit and Chuchuen 2018). For edge computing the adoption behavior of laggards is however not (yet) relevant, as it is still in initial stages of its diffusion.

3.1.3 Edge computing

This section is dedicated towards getting an in-depth understanding of this thesis' main topic, that is, edge computing. Getting an in-depth understanding about edge computing is especially relevant for the contextualization of generic business model variables towards the edge computing domain. Before deep-diving into the edge computing concept, section 3.1.3.1 formulates a working definition for edge computing. Then, in order to allow for structured comparison of edge computing with cloud computing, the characteristics of edge computing are drafted in section 3.1.3.2. Hereafter, in section 3.1.3.3, a more in-depth understanding about the edge computing infrastructure and process flow diagram is unfolded. Section 3.1.3.4 uncovers a new concept called; serverless computing. This concept may provide additional benefits to the edge paradigm and is therefore relevant to uncover. Lastly, the main technical (section 3.1.3.5) and business challenges (section 3.1.3.6) are enumerated. This is relevant in order to uncover complexities that may arise with edge roll-out in distinct IoT application areas.

3.1.3.1 A definition

Whereas definitions on previous concepts such as IoT and cloud computing have already been widely discussed in literature, on the definition of edge computing there is ambiguity. Researchers have proposed multiple definitions, sometimes aligned and sometimes conflicting. Many other papers do not even mention a specific definition of edge computing. In order to clear the fog, this section is dedicated to identifying definitions and formulating a proper working definition for this research.

The concept where the utility computing service is brought towards the edge devices (instead of the centralized cloud infrastructure), has been referred to by different names. Researchers and industry practitioners mention the terms of *fog computing*, *Mobile Edge Computing (MEC), cloudlets* or *edge computing* when referring to the decentralized computing paradigm that can either supplement or replace the current cloud infrastructure (Michaela et al. 2017). Whereas there is a consensus about the service types the aforementioned computing paradigms will offer (i.e. Saas, PaaS, and IaaS – similar to cloud computing), there is no consensus about the definitions of these concepts. The paper of Ai et al. (2018) states that there are typically three types of edge computing solutions, namely; fog computing, mobile edge computing (MEC) and cloudlet. This in then implies that edge computing is the overarching term for the fog, MEC, and cloudlet. Also, they state that cloudlet refers to a mobility-enhanced small-scale cloud data center which is closely located to the Internet's edge. A cloudlet then is a resource-rich, trusted computer (or computer cluster) that can be used by nearby mobile devices. The main aim of cloudlets is to support powerful computing to mobile devices. For MEC they state that it refers to a platform that is a key enabler for IoT and provides an IT service environment and similar capabilities as cloud computing, by providing computing power close to the edge of the network. These computing capabilities can be accessed within the RAN. Lastly, they state that fog computing delivers the same service as edge computing, but differs as the edge architecture places servers, applications and clouds at the edge (with exclusion of the cloud), whereas the fog jointly works with the cloud (Ai et al. 2018). The paper of Varghese et al. (2016) however states that edge computing is also known as fog computing or cloud computing, meaning that the three definitions refer to the same concept. The book of Cao, Quan, and Weisong (2018) partly confirms this, by stating that edge computing and fog computing are almost interchangeable. They, however, emphasize that edge computing is focused more on the Things side of the IoT and fog computing is more focused on the infrastructure side. However, when looking at the NIST formal definition for fog computing, these statements are completely contradicted. In the NIST's view, fog computing is often erroneously called edge computing. They state that edge computing differs from fog computing as it excludes the cloud. In contradiction, in their view, fog computing refers to the hierarchical infrastructure, where the fog layer works together with the cloud layer (Michaela et al. 2017).

Following from the multiple perspectives academics provide on definitions of edge computing, cloudlet, MEC, and fog computing, Table 4 aims to provide an overview of the highly cited definitions among them.

Table 4: List of definitions for cloudlet, fog, MEC and edge computing in highly cited papers

Type	Author	Definition
Cloudlet	(Satyanarayanan et al. 2009. pp 18)	*"Cloudlet can be defined as a trusted cluster of computers, well connected to the Internet, with resources available to use for nearby mobile devices."*
Fog	(Bonomi et al. 2012. pp 13)	*"Fog Computing is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network"*
Fog	(Vaquero and Rodero-Merino 2014. pp 30)	*"Fog computing is a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralized devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third parties. These tasks can be for supporting basic network functions or new services and applications that run in a sandboxed environment. Users leasing part of their devices to host these services get incentives for doing so."*
MEC	(ETSI 2014. pp 18)	*"a highly distributed computing environment that can be used to deploy applications and services as well as to store and process content in close proximity to mobile users."*
MEC	(Hu et al. 2015. pp 6)	*"Mobile Edge Computing offers an IT service environment at a location considered to be a lucrative point in the mobile network: the Radio Access Network (RAN) edge. Characterized by proximity, low latency and high bandwidth, this environment will offer localized cloud computing capabilities as well as exposure to real-time radio network and context information. "*
Edge	(Shi et al. 2016. pp 638)	*"Edge computing refers to the enabling technologies allowing computation to be performed at the edge of the network, on downstream data on behalf of cloud services and on upstream data on behalf of IoT services"*

Fog	(Michaela et al. 2017. pp 2)	*"Fog computing is a horizontal, physical or virtual resource paradigm that resides between smart end -devices and traditional cloud or data centers. This paradigm supports vertically-isolated, latency sensitive applications by providing ubiquitous, scalable, layered, federated, and distributed computing, storage , and network connectivity"*
Edge	(Satyanarayanan 2017. pp 30)	*"Edge computing is a new paradigm in which substantial computing and storage resources – variously referred to as cloudlets, micro datacenters, or fog nodes – are placed at the Internet's edge in close proximity to mobile devices or sensors"*
Edge	(Yu et al. 2018. pp 6901)	*"Edge computing encompasses data computing and storage that is being performed at the network edge"*
Edge	(Morabito et al. 2018. pp 1)	*"Edge computing represents a new trend to improve the overall infrastructure efficiency by delivering low-latency, bandwidth-efficient and resilient services to IoT users. Although this new approach is not intended to replace the cloud-based infrastructure, it expands the cloud by increasing computing and storage resources available at the network edge."*
Edge	(OpenFog 2018. pp 5)	*"Edge computing is a concept that places applications, data and processing at the logical extremes of a network rather than centralizing them. Placing data and data-intensive application at the edge reduces the volume and distance data must travel."*

Then, following from the definitions mentioned in Table 4, as well as the papers of (Satyanarayanan et al. 2009), (Guenter 2015), (Ai et al. 2018), and (Yu et al. 2018), which provide extensive discussions on definitions of cloudlet, fog, and MEC, Table 5 provides an overview of the main components of the three concepts and how they differ among each other. The first thing that we observe, is that the Cloudlet, Fog and MEC concept origin from different years, and have been founded by different research groups. Members of these research groups however always include major tech or telecom firms. Furthermore there is a distinction in main business interests. Where cloudlet focusses mainly on applications that are based on mobile computing, fog is targeted at facilitating the IoT. For MEC the scope is shifted towards edge's relevance for the 5G domain. Also on the characteristics of application drivers, cloud extension, means of access, and network creation, the three concepts show conflicts.

Table 5: Overview of differences between cloudlet, fog, and MEC

	Cloudlet	*Fog Computing*	*MEC*
Founding group	Research Group Carnegie Mellon University together with, Vodafone, Huawei, and Intel.	Researchers from Cisco, together with Dell, Intel, ARM, Microsoft, and Princeton University	The European Telecommunications Standard Institute (ETSI), supported by IBM, Intel, Huawei, Nokia, and Vodafone
Year	2009	2012	2014
Main business interest drivers	Applications which are based on mobile computing (e.g. video analytics and assistance applications)	Internet of Things & Wireless and Actuator Networks	5G requirements in the telco industry as well as the need for IT cloud providers and telco's to work together.
Main applications drivers	Enabling mobile applications which are latency sensitive as well as computing intensive.	Enable high-performance, secure and interoperable multi-vendor fog computing-based ecosystem	Enable an open RAN which can host applications of third parties as well as offload computing power and storage at the edge of the network.
Extends current cloud infrastructure	Yes	Yes	Not necessarily
Will be mostly accessed wirelessly	Not necessarily	Yes	Yes

Creates an architecture framework	No, cloudlets are can be an enabler that can be used to realize the MEC or Fog computing architecture	Yes	Yes

Whereas it has now become apparent that the three architectures differ among each other, they all share the same vision which is driven by an anticipated future where: Increasing amounts of data and computation will need to be processed and stored due to the IoT, Internet of Everything (IoE) and increasing interconnectedness of mobile devices (Guenter 2015). Table 5 has clarified the distinction between cloudlet, fog, and MEC, but the relation with the general term edge computing has not been discussed yet.

Following from the discussion in this section, as well as the extensive discussion of Ai et al. (2018), edge computing can be seen as the overarching term which contains the three edge computing solutions for IoT, i.e., cloudlet, fog, and MEC. This means that the general term edge computing does not give any remarks about the specific intentions or physical architecture, but rather illustrates the philosophy of the three edge computing solutions. Put more simply, edge computing refers to the delivery of cloud computing capabilities, close to the network's edge, in a decentralized infrastructure, with close proximity to the user. With this in mind, a new working definition for edge computing is formulated as;

an approach, which is aimed at solving the inherent problems of cloud computing regarding IoT, shifting the computing power away from the centralized data centers and envisioning a decentralized computing infrastructure, offering the same utility computing service, but with close proximity to the user and data source, which can be organized in a Cloudlet-, Fog computing- or Mobile Edge Computing IT solution.

3.1.3.2 Key characteristics

Based on the working definition that was formulated in the previous section, the following four key characteristics of edge computing are identified:

1. **Decentralized infrastructure:** In contrast to cloud computing, which relies on a centralized IT infrastructure, edge computing is characterized by its decentralized infrastructure, where the edge nodes are geographically distributed. Simultaneously this means, that a large number of edge nodes will be needed to deliver the edge network.
2. **Capabilities in close proximity to the user and data source:** Related to the decentralized infrastructure, with edge computing, data is processed near the edge (i.e. where the sensors translate the real world to the digital world). The edge devices simultaneously are the users of the systems, meaning the computing capabilities are being brought into close proximity to the user.
3. **Utility Computing:** Whereas the infrastructure and philosophy behind edge computing significantly differ from cloud computing, in its core, it delivers the same utility computing service. This means that with edge computing; SaaS, PaaS, and IaaS are delivered as a measured service, with rapid elasticity, my means of resource pooling, where capabilities can be accessed through broad network access and resources are automatically controlled and monitored, allowing for a pay-as-you-go service.
4. **Aimed at solving the inherent problems of cloud computing regarding IoT:** The main intention of edge computing then is to solve the problems of cloud computing regarding the IoT. Whereas some of the benefits (e.g. economies of scale presses down the marginal cost of system administration) which were delivered by cloud computing will be diminished by the decentralized edge infrastructure, it aims to solve the inherent problems of cloud computing regarding IoT, which previously hindered service providers to deliver the desired Quality of Service.

3.1.3.3 Explanation of the edge computing infrastructure and process flow

Figure 6 provides a graphical representation of how the layered architecture of edge-computing based IoT applications could look like. At the bottom of the pyramid, IoT devices collect data from the real-world environment. On these devices, as they have limited processing power, only the simplest and most crucial data is processed. The majority of the data processing and (short-term) storage is offloaded towards intelligent gateway edge computing layer. In this layer, real-time data analytics is done and real-time responses are provided back to the IoT devices requiring low-latency. It is important to note that the physical proximity between the IoT devices towards the edge computing stations is small. Lastly, only the heavy and long-term storage and computations, which are conducted on a larger level, are offloaded towards the conventional cloud servers, which are geographically distant from the edge network (Yu et al. 2018).

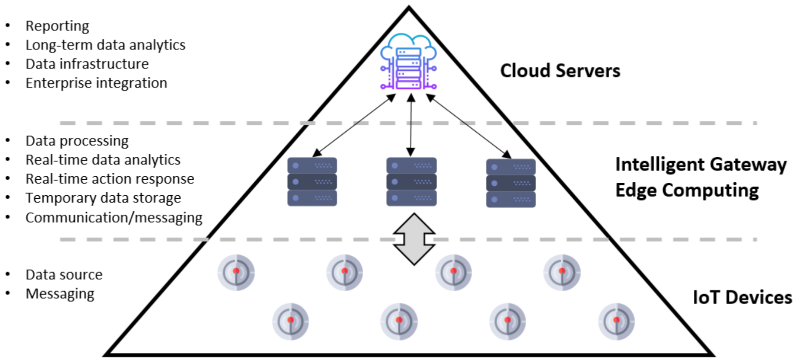


Figure 6: Layer architecture of edge computing-based IoT applications. Adapted from: (Yu et al. 2018).

Having explained a typical architecture for edge-computing based IoT applications, in Figure 7, a generic flow diagram is provided in order to illustrate how computation offloading can be done in a real-life application with the edge computing infrastructure. From the terminal node, the end-user requests a service. Then, the virtual cluster manager sends a request relay to the edge controller (in the image referred to as fog controller). Hereafter, in the decision making unit, a decision is made whether the service request is within the scope of the edge tier or cloud tier. Based on this decision, the service request is either executed in the edge (in close proximity of the user) or the cloud (in far proximity of the user). One should note that, when the service request is sent to the cloud, it has first passed the edge computing layer. This means that an extra layer is added between the device and the cloud which, if all services are offloaded to the cloud, could lead to increased latency (Misra and Sarkar 2016).

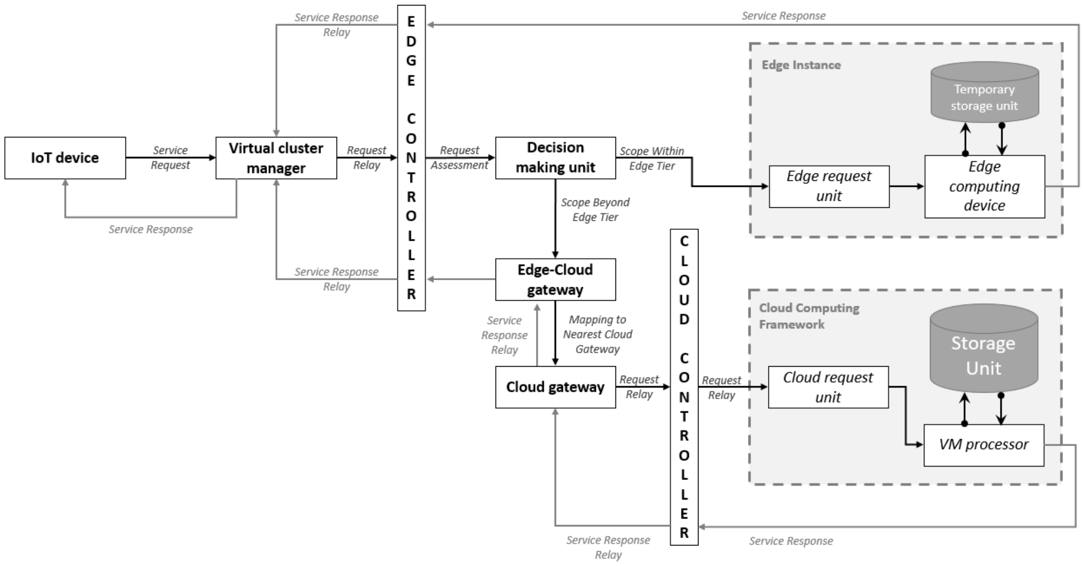


Figure 7: Example flow diagram for edge computing. Adapted from: (Misra and Sarkar 2016).

3.1.3.4 A serverless model for edge computing

Currently, most of the computing applications consist of two main elements; the interface that runs on a user device (e.g. PC, smartphone, etc.) and the server logic that is deployed on a cloud- or edge datacenter (Lara et al. 2016). This however has implications because, where cloud computing relieved customers with the difficulties of managing a physical infrastructure, it substituted this with a difficulty of virtual resource management (Jonas et al. 2019). Subsequently, while providers heavily promote cloud computing's key element of ease of use, this ease cannot be effectuated without mastering the configuration of the underlaying infrastructure layers, which can be a challenging task (Jonas et al. 2017). The manual task-specific server logic for computational offloading which users have to define consumes considerable time, is prone to error, and requires substantial knowledge of the underlying infrastructure. Subsequently, when resource pools for computational offloading increase in size, and as computation resources become increasingly heterogeneous, effective usage becomes inherently complex (Nastic et al. 2017). Therefore, the use of cloud computing still poses a major challenge for scientists as well as industry practitioners (Jonas et al. 2017). Even at some of America's most renowned universities, computer science students have never written cluster computing programs due to the inherent complexity of setting up the respective computational offloading platform (i.e. cloud or edge) (Jonas et al. 2017). Correspondingly, with the significantly more challenging management and overhead issues of edge computing (compared to cloud computing) (Olaniyan et al. 2018), these difficulties of use are expected to seriously increase.

The notion of serverless computing may resolve some of these increasing complexities. Serverless fosters the concept of stateless functions, which unifies abstraction for data processing and thereby simplifies programming and deployment for users (Jonas et al. 2017). Put more simply, with serverless computing, the provider virtually handles system administration and operation issues, meaning users do not have to manage the underlaying infrastructure, in turn facilitating an easy-to-use computational platform (Hellerstein et al. 2018; Jonas et al. 2019). Its origination can be found in the cloud computing domain, where it suffices as execution model in order to seamlessly execute user-defined functions in a transparently hosted and distributed platform (Nastic et al. 2017). Furthermore, the concept of serverless constitutes a partial realization of the philosophy that computing may be based on an event-driven approach, meaning applications are defined by events and actions. Subsequently, by means of the serverless approach, where programs are containerized, a function centric infrastructure may be leveraged (McGrath and Brenner 2017). Correspondingly, in the serverless model, a function is deployed once. Then, the function is invoked repeatedly whenever input arrives (Hellerstein et al. 2018; Jonas et al. 2017). Whereas serverless computing may be an oxymoron (i.e. the computational offloading paradigm is still constituted of servers), the name presumably arose because empowers programmers to simply write code and leave server provisioning tasks to the respective cloud- or edge provider (Jonas et al. 2019).

Serverless differs from serverfull computing (which is the de-facto standard as described before) on tree critical aspects: In serverless computation and storage are decoupled (i.e. generally storage is on the cloud and computation can be done on the edge, enhancing capabilities). Second, instead of requesting resources, with serverless code is executed without managing the allocation of resources (Jonas et al. 2019). Last, billing is associated to the execution dimension, meaning the user pays for the resources that he uses instead of the number of virtual machines that are allocated (Hellerstein et al. 2018; Jonas et al. 2019).

Subsequently, serverless can eliminate the difficulties of cluster management overhead and facilitate the elasticity of cloud computing, thereby effectuating more user-friendly distributed data processing systems (Jonas et al. 2017, 2019). The benefits of serverless seem to be even bigger for edge computing which inherently suffers from high complexity, labor-intensive lifecycle management and high cost (Glikson, Nastic, and Dustdar 2017). Subsequently, serverless computing may enhance the capabilities of a combined edge-cloud infrastructure, where the interaction of both paradigms seek to mitigate the inefficient and costly management of the corresponding infrastructure (Nastic et al. 2017).

In that sense, edge computing can facilitate the interaction- and integration between the edge and the cloud in a uniform manner (Glikson et al. 2017; Nastic et al. 2017). It does so by enhancing the uniform development and operation of edge and cloud, thereby diminishing some of the management and orchestration issues edge computing is currently coping with (Nastic et al. 2017). Additionally, serverless can enhance the edge capabilities as it can automatically migrate objects across a hierarchical layer architecture (for edge computing), meaning it can combine the benefits of edge with the computational storage capabilities of the cloud (Lara et al. 2016; Nastic et al. 2017). Because of these technological benefits, serverless computing concisely fits with IoT application's demands to utilize a decentralized computing infrastructure (most likely utilized in a hierarchical infrastructure) (McGrath and Brenner 2017).

For cloud/edge providers, serverless is potentially interesting as it promotes opportunity for business growth. It is expected that this growth is driven by the increased ease-of-use for the respective computation platform's users, which is effectuated by the serverless model. Furthermore, serverless computing may enhance the efficiency by which providers use their computational resources. On the other side of the token, customers benefit from increased programming productivity, cost saving due to more adequate billing, and increased software capabilities serverless delivers (Jonas et al. 2019). However, whereas serverless provides may potentially deliver aloft of benefits, it is still an active area in which research should be conducted (McGrath and Brenner 2017).

3.1.3.5 Technical challenges

Whereas edge computing solves a whole array of problems revolving from the centralized cloud infrastructure, it also comes with its challenges. In order to realize edge computing in the IoT, a static network will not allow for the dynamic scalability edge computing infrastructures require. The IoT involves a dynamically changing supply and demand of hotspots and devices along the edge (Olaniyan et al. 2018). As the amount of IoT devices in the edge is expected to increase exponentially (Zhang et al. 2008), the network should be extended in a dynamic way. Furthermore, due to the vast amount of end users, IoT devices and applications along the edge, a major challenge lies in the complex management that comes with it (Yu et al. 2018). Adding to that, the massive increase in the number of IoT devices will introduce an exponentially increasing management overhead for the edge network. This means one challenge is to reduce overhead (Olaniyan et al. 2018). Next to the dynamic expansion which should be managed, dynamic dropout of devices within the network should be managed as old devices might get replaced by new ones. Furthermore, when users are moving between edge nodes, these nodes need to collaborate in order to properly offload to the right edge node (Shi et al. 2016). Then, to efficiently offload tasks to edge nodes, partitioning of computational tasks is required. Computational offload should allow for flexibility to define a computation pipeline either hierarchically or over multiple edge nodes simultaneously (Varghese et al. 2016).

Another challenging task in the management of the edge network lies in supporting the heterogenous types of IoT devices each with varying service providers, applications and computation demands (Yu et al. 2018). The varying IoT applications (e.g. smart home, smart city, autonomous vehicles) will have different requirements and priorities, further complexifying the allocation of the edge computing power within the network (Shi et al. 2016). Furthermore, the network should be able to integrate heterogenous types of nodes from different generations into one edge network (Varghese et al. 2016). Due to the heterogeneity of such devices, allowed operations and data representation could vary among them, which in turn increases complexity (Shi et al. 2016).

In order to fully utilize the potential of edge computing networks, such management and orchestration challenges should be coped with (Olaniyan et al. 2018). This means that there is a need for a proper pooling and orchestration of available resources within the edge because otherwise much of the potential computing resources might go to waste (Olaniyan et al. 2018). To do so, a flexible and extensible design of the service management layer is a must (Shi et al. 2016). This should be executed in an automated discovery mechanism which finds the best-suited candidates for offloading (Varghese et al.

2016). Along these lines, direct human involvement in the edge computing process should be minimized (Shi et al. 2016). One solution which can solve the inherent complexities of this dynamically expanding network with millions of users and hundreds of different applications, is the Software Defined Networking (SDN) model. The SDN model centralizes control over the network in order to simplify and optimize the network management (Yu et al. 2018). SDN is interlinked with Network Function Virtualization (NFV), which enables edge devices to operate across different network functions by creating Virtual Machines (VMs) (Ai et al. 2018).

Another challenge resides in the difficulty to maintain security following from the distributed nature of edge computing. As computation power is brought to the smaller devices located near the edge, protection mechanisms for malicious activities are not as advanced as in the centralized infrastructure. This, in turn, makes the edge nodes more vulnerable than cloud servers. These vulnerable devices can then lead to increased issues in cybersecurity and privacy protection (Yu et al. 2018).

3.1.3.6 Business challenges

Having identified the technical challenges, also business challenges revolving around the implementation of edge computing enabled IoT applications can be identified. Whereas on the technical side much solutions have been offered to solve the challenges, on the business side there is more ambiguity. No mature business models for edge computing have been established, and the killer applications are still to come (Pan and McElhannon 2018). This means that on the nontechnical side, a big uncertainty revolves around developing a viable business model for deploying the edge computing infrastructure (Satyanarayanan 2017).

Whereas edge computing provides a service similar to cloud computing, and will thus need a similar pay-as-you-go business model, the decentralized utilization of resources complexifies this (Ahmed et al. 2017). The implication resulting from this, is that new cost-models need to be developed in order to guarantee profit for the stakeholders providing their resources, as well as acceptability of users (Shi et al. 2016). The involvement of multiple stakeholders such as; service providers (who own the edge servers), cloud service providers (which may or may not enter the edge market) , and end users/IoT devices that can act as client as well as server for edge services, results in a network of actors each trying to maximize their share of the pie. Consequentially, uncertainty resides in how fair sharing can be ensured among the edge players. In order to create a complete business model, the manner in which resources will be monitored and accounted for needs to be determined. More specifically, how edge players will divide resource utilization and monetary compensation among themselves has to be defined (Ahmed et al. 2017). Also, in the light of these additional stakeholders which were only involved to a limited extent in cloud computing services, new social, legal and ethical standards for using edge nodes have to be established (Varghese et al. 2016).

Lastly, as identified in section, 3.1.3.4, a huge amount of heterogenous devices needs to be integrated into one encompassing edge computing infrastructure. Whereas this involves a great deal of technical challenges, also on the business side this evokes a great challenge. In order to enable the seamless integration of these heterogenous components, social collaboration is needed. However, social collaboration is hindered by a lack of standardization and a presence of competition (Ahmed et al. 2017).

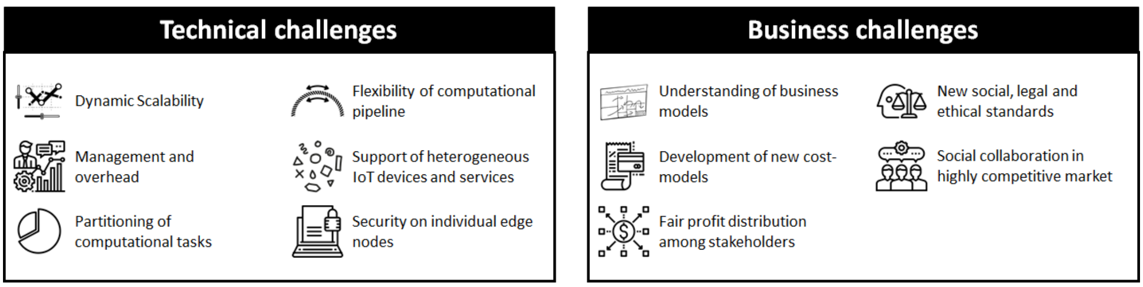


Figure 8: Summary of main technical and business challenges for edge computing

3.2 Theoretical domain

Whereas the previous section elaborated upon the relevant technical concept, this section dedicates its efforts to explaining the relevant theoretical concepts. This section elucidates platform theory (section 3.2.1), business ecosystems (section 3.2.2), and the business model (section 3.2.3).

3.2.1 Platform theory

Previously, the cloud computing technology enabled a new platform for personal and enterprise computing, competing against traditional proprietary desktops or handheld devices (Cusumano 2010a). Edge computing now aims to deliver the same platform capabilities as cloud computing, but then by means of different infrastructure, solving some of cloud computing's inherent problems regarding the IoT. Therefore, in order to get a better understanding of the edge computing concept and how users may switch from one technical architecture towards another, it is important to conceptualize the platform concept.

3.2.1.1 Types of platforms

The platform concept finds its most important feature in the conservation of a core component, which allows to achieve economies of scales, decreasing the cost, while allowing for a wide variety of complementary components (Gawer 2014). Diving into different forms in which platforms can manifest, one of the most widely known distinctions between platforms is the product platform vs. the industry platform (Cusumano 2010b). The product platform can be defined as *"The collection of assets that are shared by a set of products"* (Robertson and Ulrich 1998. pp 20). This relates to the creation of a new family of products that are easily adjustable into derivatives for a single firm (Wheelright and Clark 1992). Such a product platform can be established because most firm's production lines have a common or related underlying technology, set of basic components, customers and applications, application markets, manufacturing processes, geographical markets, channels and brand name (Sawhney 1998). The four main categories of such assets are; components, processes, knowledge & people and relations. The total collection of these groups of assets constitutes the product platform. In product platforms, most, if not all, of the production and development assets are shared (Robertson and Ulrich 1998). Whereas the product platform provides a core technology or shared foundation which can be used for multiple variations of the product within the firm, an industry platform provides the same function, but then as part of an ecosystem. This means that the industry platform is part of the technology system, where components originate from different companies, called complementors. Furthermore, without complementary products or services, the industry platform has low value (e.g. the processors of Intel are just an empty box without the software of Microsoft). Additionally, in an industry platform, there is no single firm which provides all the necessary applications to deliver a compelling product or service. Therefore, in order to make an industry platform attractive, multiple companies must complement each other in the same ecosystem (Cusumano 2010b).

Whereas the above provides us with a valuable distinction between product and industry platforms, the paper of (de Reuver, Sørensen, and Basole 2018) modernizes this concept by zooming out one more step. More specifically, they state that product and industry platforms, as mentioned above, can be described under the umbrella of non-digital platforms. Whereas the concept of non-digital platforms mainly describe that platforms encompass the modularization through a common design hierarchy, on the other side, digital platforms assume something else (de Reuver et al. 2018). One of the earlier definitions which refers to the digital platform concept has been stipulated by the paper of (Bresnahan and Greenstein 2003). In the realm of ICT they stipulate that a platform can be defined as a shared, stable set of hardware, software and networking technologies on which users build and run computer applications (Bresnahan and Greenstein 2003) More specifically, the digital platform concept is characterized by; homogenization of data, reprogrammability, self-referentiality (Yoo, Henfridsson, and Lyytinen 2010), editability and distributedness (Kallinikos et al. 2013). Building on the conceptualization of (Eisenmann, Parker, and Alstyne 2006) and (Gawer 2014), the paper of (Tiwana, Konsynski, and Bush 2010) describes a proper definition of digital platforms in the technical realm as *"The extensible codebase of a software-based system that provides core functionality shared by the modules that interoperate with it and the interfaces* *through which they interoperate"* (Tiwana et al. 2010, pp 676). On the other hand, instead of taking a technical perspective, the paper of (Tilson, Sorensen, and Lyytinen 2012) looks at digital platforms from the sociotechnical perspective and analysis how such factors affect the evolution of these platforms. From the sociotechnical perspective, a digital platform can be defined as: *"technical elements (of software and hardware) and the associated organizational processes and standards"* (de Reuver et al. 2018. pp127). In this thesis, the definition of (de Reuver et al. 2018) is taken. This is chosen because literature about edge computing on technical areas is around, but the literature on sociotechnical aspects is lacking behind. Hence, looking at an edge computing platform from a sociotechnical perspective may provide new insights.

3.2.1.2 Key characteristics

Taking a deep-dive into the characteristics such industry- and ICT platforms have, (Bresnahan 1999) describes five key characteristics of platforms. In turn, the dissertation of Ballon (2009) provides an insightful overview of these five characteristics.

1. **Network effects and backward compatibility:** The concept of network effects and -economics assumes that there are indirect network externalities that have an influence on the adoption process of technology. This pattern results from positive feedback; the value of membership to the platform of one user is positively influenced when another user joins the platform, and thereby enlarge the user-base. Put more simply, the more users a platform has, the higher the value it creates for users is. This concept applies to platforms that bring together multiple user groups (Katz and Shapiro 1994). Therefore, technologies that are characterized by strong network effects are usually subject to long lead times, followed by exponential growth. The exponential growth starts when a critical mass is reached, and a large number of people find adoption of the platform to be worthwhile. Externalities can be either indirect or direct. They are direct when the value of the platform depends on the number of users in the same user-group, and are indirect when the value depends on users in a different user group (de Reuver et al. 2018). One specific externality that is worth highlighting, is the backward compatibility (Ballon 2009; Bresnahan 1999). This concept refers to the extent that customers' sunk cost (i.e. the cost of training people, writing software, etc.) associated with the platform, lock them into what they currently have. By enhancing the standards and interfaces determine the platform's compatibility with previous and complementary systems, these sunk costs and related switching costs can be decreased. Therefore, a higher compatibility increases the platform's value to users. On the other side of the token, incompatibility of platforms that are competing can increase user's switching cost and thereby create a lock-in effect where users cannot or do not want to change platforms due to the high switching costs. Whereas incompatibility can considerably help in retaining customers, in initial stages of the platform, in order to create a critical mass of customers, the platform should follow a more open strategy with higher compatibility (Katz and Shapiro 1994).
2. **Economies of scale:** refers to the extent that platform operators obtain a cost advantage due to the sheer size of their operation or by operating on common concepts, models, standards. Larger adoption of the platform presses down the marginal cost of system administration and operation. Additionally, the platform operator's investments are characterized by positive feedback loops. As platform operators invest in the platform and thereby enhance its components, the platform becomes more attractive to users. Then, as the platform becomes more attractive to users, its adoption rate will increase, again leading to a higher value to the customer.
3. **Barriers to entry:** The lock-in effect which is created due to the network effects and potential backward incompatibility, together with economies of scale, present the platform operator with significant opportunities to create barriers to entry.
4. **Persistence over time:** Due to platform-specific investments that are made by both users and platform operators, platforms persist over time. This investment includes constant alignment of the technologies and markets to which the users and operators belong. Subsequently, it creates a vested interest for both parties, in turn leading to platform persistence over time.

5. **Hard to start, hard to stop, easy to maintain:** This characteristic can be explained by means of the previous four characteristics. Due to the network effects, it is hard to reach the critical mass of customers, however, when this is reached, due to positive feedback loops, the platform will see explosive adoption rates. Then, due to the barriers to entry and the vested interest for both parties, it is hard to create a competing platform, and thus the platform is easy to maintain.

3.2.1.3 Platform openness

In markets where user's interactions are subject to network effects and switching costs due to the strong platform characteristics, one major question arises. That is, how can firms overcome entry barriers? (Eisenmann, Parker, and Van Alstyne 2011). As described in the previous section, platforms are hard to start, but also hard to stop due to such network characteristics. Platforms often evolve into winner-take-all markets (Evans and Schmalensee 2001). One way to break through the hard-to-start chasm, is by opening up the platform and thereby enhancing adoption.

The concept of platform openness finds its roots in the broader question regarding technology development and commercialization. According to (Shapiro and Varian 1999), one can make the choice between opening up a proprietary technology, and thus allowing external parties to participate in development and commercialization, or to keep the system closed. These aspects especially become relevant when talking about systems which consist of multiple components which can individually be opened up (Katz and Shapiro 1994). The concept of platform openness is related to the governance model which in turn determines the degree to which the decision-making process revolving around a platform is open to the community of users (Laffan 2012). In more concrete terms, the openness relates to the extent to which restrictions on development, commercialization, and use of a technology are opened up (Boudreau 2010). This implies that a platform is deemed to be more open when it places fewer restrictions on participation, development, or use for either the developer or end user (Gawer 2014). Another way to enhance the openness is by vertically integrating platforms. On the extreme side, when a platform is completely open, there is no central control over the platform and it consists of fully unrestricted open standards (Parker and Van Alstyne 2018). Openness can be examined at three main levels; provider level, technology level, and user level. The provider level is related to the strategic involvement of partners and stakeholders. The technology level describes the interoperability of the platform. Lastly, the user level is concerned with the level on which the platform discriminates user groups or segments. Opening up a platform on either one, or multiple of these levels can enhance the market potential during the pre-ignition stage (Ondrus, Gannamaneni, and Lyytinen 2015).

More specifically, opening up a platform can enhance the growth by reducing lock-in fears and switching cost and by harnessing network effects (Parker and Van Alstyne 2018). By opening up the platform, the platform owners can allow third-party developers to contribute in enhancing and developing the software base, in turn enhancing the platform's value to users (Ghazawneh and Henfridsson 2013). On the other side of the token, platform openness reduces the owners' capability to control the platform, reap substantial profit and exclude competitors (Parker and Van Alstyne 2018). Therefore, for firms that create and maintain a platform, it is important to determine the optimal level of openness (Gawer 2014). The opening strategy for platforms is heavily dependent on the context in which it is rolled out (Boudreau 2010). For different markets, technologies or applications, there is a different suitable level of openness.

Whereas the concept of platform openness has been described in the paper of (Eisenmann et al. 2011), for digital platforms, openness goes one step further. Not only the organizational arrangements regarding the entrance and exit rules should be managed, but also the openness of technologies and standards such as the software development kids and APIs should be taken into consideration (Ghazawneh and Henfridsson 2015; de Reuver et al. 2018).

3.2.1.4 Cloud and edge computing as a platform

As stipulated in the paper of (Cusumano 2010a), SaaS and the more general cloud infrastructure that enables that offering (as well as PaaS, and IaaS offerings) encompass a platform for personal and enterprise computing. Defining cloud computing as an industry platform however comes with the premise that firms sufficiently open up their technology to third parties (Cusumano 2010a). In the ICT realm, cloud computing can however easily be defined as a digital platform. This is because it involves technical elements of both software and hardware that are standardized in order to utilize their potential (de Reuver et al. 2018). Furthermore, the core functionality of cloud computing's offerings are based on an extensible codebase that interoperate with it (Tiwana et al. 2010).

As far as cloud computing platforms have similar APIs or web services that encourage developers to tailor their applications to the cloud platform, or make it difficult for users to switch among platforms, the cloud exhibits direct network effects. Cloud platforms may however also exhibit indirect network effects to the extent that the popularity of one platform over another, results in a positive feedback loop, in turn enhancing the platform's attractiveness. Interoperability and use of common standards can enhance the perceived value by customers (Cusumano 2010a). This perfectly relates to the characteristic of digital platforms, which describes that not only the modularization through a common design hierarchy constitute the platform, but also the openness of technologies and standards, such as software development kids and APIs should be taken into consideration (de Reuver et al. 2018).

Following from the above, cloud computing can thus be defined as a digital platform. Then, as indicated in section 3.1.2.3, cloud computing can be operated on either one of the three service models: SaaS, PaaS, IaaS. Furthermore, as indicated in section 3.1.3, edge computing delivers the same service models as cloud computing, but then by means of a different infrastructure. Whereas cloud computing has its computing resources centralized, in edge computing the computing resources are decentralized, allowing for another array of benefits to manifest. Therefore, as cloud computing has already been identified as a digital platform it can be inferred that edge computing, which delivers the same service through a different technology infrastructure, is a digital platform as well.

3.2.2 Business ecosystems

The ecosystem concept is related to the previous platform concept (de Reuver et al. 2018), where the platform owner can be referred to as the ecosystem's key stone firm (Tiwana 2014). In order to get a better understanding about the relevant theoretical domains, the business ecosystem concept should be conceptualized.

3.2.2.1 A definition

The term business ecosystem has been first introduced in the paper of Moore (1993) and was based on two concepts which are relevant in both natural and social systems. The first concept is *co-evolution*, which describes how independent species evolve in an endless reciprocal cycle. This means that the evolution of species A will inevitably change both the natural selection and evolution of species B. The second concept is *natural ecosystems*, which describes that dominant combinations of species may shift and natural ecosystems might even collapse if they change to drastically. Following these two concepts, combined with his vision on strategy, Moore introduces the concept of business ecosystems. The business ecosystem concept describes that a company cannot be viewed as a member of a single industry, but should rather be viewed as part of a business ecosystem that crosses multiple industries. These business ecosystems are composed of a range of loosely connected entities and gradually moves from a random collection of organizations towards a structured system. Based on that philosophy, Moore states that in a business ecosystem, different companies *"Co-evolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations"* (Moore 1993. pp 76). A business ecosystem is considerably different from an industry, as it does not contain the whole population of the industry and the relation of the agents in the business ecosystem can be across multiple industries. The business ecosystem concept also differs from the value-chain concept as it illustrates a many-to-many relationship (instead of one-to-one) and because an ecosystem is not necessarily ordered according to the logical value-adding sequence (den Hartigh and Asseldonk 2004). It is impossible to draw a boundary of the business ecosystem, rather, one should aim to systematically select the organizations which are most needed to deliver future success (Iansiti and Levien 2004).

The business ecosystem concept has especially become relevant when companies' competitive orientation shifted from competition on efficiency and effectiveness, towards competition on innovation. As their innovative efforts accelerated, companies realized they can't realize the desired innovation results alone (Moore 2006). Perhaps one of the most widely known industries, which his characterized by extreme innovative efforts and is thus massively interconnected, is the computing industry. In such highly connected industries, the performance of organizations is for a large part driven by the structure and characteristics of the business ecosystem they partake in (Iansiti and Levien 2002). In order to form an effective business ecosystem, organizations must effectively collaborate, co-evolve their efforts around a certain innovation and align their visions so that their R&D investments are mutually supportive and their operating processes are synergistic (Moore 2006). A network of companies (business ecosystem) works together in order to gain advantage over another network of companies. Standalone strategies are therefore not sufficient when a company is highly networked and its technology's success is thus highly dependent on the network of organizations that has influence on the creation and delivery of the focal product or service (Iansiti and Levien 2004)

3.2.2.2 Main players in business ecosystems

As mentioned in the previous section, the term business ecosystems finds its roots in social and natural sciences (Moore 1993). Along these lines, a translation is made from the roles of species in biological ecosystems to the roles of players in business ecosystems. More specifically, the book of Iansiti and Levien (2002) provides a categorization of three members and their distinct roles in a particular business ecosystem. The presence, relations and interactions among these players in turn describes how the focal business ecosystem works.

- **Keystones:** These players fundamentally aim to improve the ecosystems overall health by providing predictable and stable assets. In business ecosystems, keystones have the advantageous position of providing a systemwide role, despite only being a small part of the total system. They serve as the hub in the network of interactions among members by simplifying the complex task of connecting other network participants to one another. Furthermore, they enhance the robustness of the ecosystem by providing a point of reference and by consistently incorporating innovations. Along these lines, keystones aim to ensure their own prosperity and survival by continually trying to improve the focal ecosystem. Subsequently, effective keystone strategies are focused at creating value within the ecosystem and sharing that value among players in the ecosystem. As a keystone player is foundational in forming a stable ecosystem, removing one, inherently leads to its collapse (Iansiti and Levien 2002).
- **Dominators:** This player mainly aims for vertical or horizontal integration, allowing him to own a large share of the network. This concept stems from biological systems, where the dominator overtakes a large part of their ecosystem by overtaking their functions or eliminating them. Along these lines, the dominator aims to be responsible for the majority of value creation and capture and eliminate other members or prohibit new players from entering. Once a dominator has secured his dominant position, due to the high level of control, it is hard to create a meaningful ecosystem. Consequently, a dominator can potentially damage an ecosystem's health (Iansiti and Levien 2002).
- **Niche Players:** The third player do individually not have big impact on the ecosystem, however, due to the big amount of players, their total bulk contributes significantly. Both in terms of total mass as well as variety they contribute, thereby shaping what the ecosystem is. This is different from keystone players, which shape what the ecosystem does (Iansiti and Levien 2002).

3.2.2.3 Measures of ecosystem health

As explained in section 3.2.2, business ecosystem does not look at the performance of a single firm, but rather looks at the dynamic interactions of the system as a whole. When analyzing the health of the ecosystem, we must therefore shift our view towards the collective impact of network interactions in the network. We then ask ourselves: *How can we assess the health of an entire business ecosystem of firms, products, and consumers*? The book of Iansiti and Levien (2002) proposes guidelines which can be used to measure an ecosystem's health. The measures they propose are related to the extent an ecosystem as a whole is *durably growing opportunities for its members and for those who depend on it* (Iansiti and Levien 2002. pp 32). In the light of that, and inspired by the biological metaphor from which the business ecosystem concept is derived, they propose three aspects which can measure the ecosystem health. In turn, each of these aspects have a number of metrics that should provide as a set of tools to assess these aspects. These metrics will however not apply in every circumstance, but should rather provide a rough guideline for assessing the ecosystem health.

1. **Robustness:** This refers to the extent the business ecosystem is capable of surviving and dealing with disruptions and perturbations. It has its main emphasis on the robustness of the ecosystem's with regard to disruptions that are considered to be destructive. This is aspect is especially relevant in the light of increasing technological change leading to discontinuous waves through industries.
    a. Survival rates: The extent that participants in the ecosystem have high survival rates over time, or compared to similar ecosystems
    b. Persistence of ecosystem structure: The extent that the structure of the ecosystem and relations among ecosystem participants are not affected by external change.
    c. Predictability: Next to persistence of the ecosystem, it is predictably localized as well. With some radical changes it is inevitable to change the ecosystem, however the predictable core of a robust ecosystem will generally not change.
    d. Limited obsolescence: Most of the investments and installed base of the technology will remain similar after disruptive changes in the ecosystem's environment.
    e. Continuity of use experience and use cases: With the introduction of new technologies, the ecosystem's consumers' experience will gradually evolve instead of being rendered obsolete.
2. **Productivity:** Next to sustaining a stable structure, the members of a business ecosystem must sufficiently benefit from their connections. The productivity then refers to the effectiveness of an ecosystem in converting raw materials into value for its members. Value can either be created through new products and functions or lowered costs.
    a. Total factor productivity: The productivity of an ecosystem's members units of input (e.g. labor, capital, etc.) into units of output (i.e. added value).
    b. Productivity improvement over time: The extent that the factor productivity of an ecosystem's members increases over time.
    c. Delivery of innovations: The extent that the ecosystem contributes in delivering new technologies, ideas or processes to its members. Furthermore, the ecosystem should lower the cost of implementing these innovations compared to employing them without the ecosystem. Delivery of innovations can also be measured by the extent the ecosystem propagates access to the innovations or propels adoption of the innovation.
3. **Niche creation:** Lastly, the business ecosystem health can be measured by the extent that it exhibits variety or diversity. Whereas variety of the ecosystem is important, it is not an adequate measure of the ecosystem's performance on its own. There are many examples of business ecosystems that are considerably diverse, yet lack performance. Therefore, what matters most, is that, through the creation of new valuable functions, the business ecosystem is able to increase the meaningful value over time.
    a. Variety: The number of new options, categories, technological building blocks, products, and/or business being created within the ecosystem.
    b. Value creation: The overall value of the created options

The paper of den Hartigh, Tol, and Visscher (2006), builds upon the first step that has been taken by Iansiti and Levien (2002) in defining and identifying the determinants and factors. Whereas Iansiti and Levien (2002) conceptualizes the business ecosystem health concept and give some advice on measuring it on meso-level, den Hartigh et al. (2006) take the next step by providing concrete operational measures of business ecosystem health at both business ecosystem- and company level. Managers should be able to readily use these business ecosystem health measures. From their drafted repository, den Hartigh et al. (2006) listed a range of ecosystem health measures which conform their four criteria; user friendliness (i.e. usable in management practice) , availability of data (i.e. data on the measure should be commonly available) , long-term usage (i.e. data on the measure should be usable over a longer term) and multi-level measurements (i.e. on individual company- and ecosystems level).

1. **Robustness:**
    a. Z-Score: A bankruptcy model, aimed at measuring the creditworthiness and solvency of a company.
    b. ZETA model: Mathematical bankruptcy classification score model that estimates the chances of a company going bankrupt within two years.
    c. Liquidity: Indication about the a company's assets that are cash or can be quickly transferred into cash, indicating the extent to which a company is able to make its short term payments.
    d. Connectedness: Number of relations among participants within the ecosystem
    e. Connectedness of company: Number of relations of a single actor (company level)
    f. Centrality of company: Higher centrality (i.e. the being the central touch-point of the ecosystem) of a company in a business ecosystem, means higher persistence of it.
2. **Productivity:**
    a. Asset buildup: An increase in financial assets (can be at company or ecosystem level), established through earnings, savings and investment returns.
    b. Network resources: which is measured by the centrality (calculated by Herfindahl index), solvency and return on assets (ROI).
3. **Niche Creation:**
    a. Variety within ecosystem and partners: Can be measured by the differences of ecosystem participants' company scale, performance, market activities, etc.
    b. Niche variety of partners: Different partners' proximity to the customer, and the novelty of their current knowledge.
    c. Solvency: The growth of equity over debts.

3.2.2.4 IoT ecosystems

As discussed in the previous section, an ecosystem revolves around a certain innovation (or a core). This core refers to the assets which are commonly used by the members in the business ecosystem. As the IoT refers to the interconnection of the physical world with the digital world, the hardware and software platforms and commonly used standards lay at the core of the IoT ecosystem.

Subsequently, the IoT ecosystem can be explained in terms of four parts:

- **Device:** This refers to the Things side of the IoT and includes the hardware and software platforms, as well as related standards such as gateway specifications related to the devices (i.e. sensors and actuators).
- **Connectivity:** This refers to the connectivity among the devices, and the communication through which this is established. This can include technologies such as RFID, WIFI, RAN, etc. Both hardware and software platforms should be included in this part of the ecosystem.
- **Application services:** This refers to the common software platforms and standards allowing for standards in developing IoT applications
- **Supporting services:** This refers to services needed for billing, assurance and provisioning of the IoT applications (Mazhelis et al. 2012).

Following from this, an IoT business ecosystem can be defined as: *"A special type of business ecosystem which is comprised of the community of interacting companies and individuals along with their socio-economic environment, where the companies are competing and cooperating by utilizing a common set of core assets related to the interconnection of the physical world of things with the virtual world if Internet."* (Mazhelis et al. 2012. pp 5).

When talking about the technical domains of IoT, related to the four parts of which the IoT ecosystem is composed, three domains can be identified; the device domain (identification and sensing technologies), connectivity domain (access and core network connectivity), service domain (application services). Based on these four domains, specific roles for players in the IoT ecosystem can be described (Mazhelis et al. 2012). A generic and simplistic version of the IoT ecosystem has been provided in the book of (Bertin, Crespi, and Magedanz 2013). They mainly distinguish between 5 types of actors. Figure 9 displays how they visualize the IoT ecosystem to look like. Whereas this model provides a generic view on the ecosystem structure for IoT applications, which is applicable to all IoT domains, it neglects the importance of cloud providers in its services.

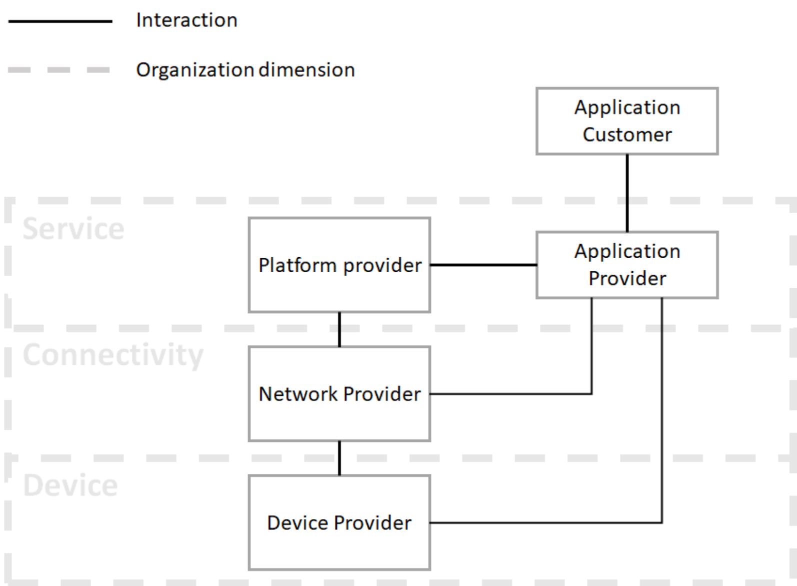


Figure 9: Simplified illustration of the IoT ecosystem. Adapted from: (Bertin et al. 2013)

A more comprehensive view on the IoT ecosystem has been drafted in the book of (Mazhelis et al. 2012). Whereas the ecosystem drafted in this book describes a detailed IoT ecosystem, it should be noted that the real IoT ecosystems are still unstructured and immature. This becomes apparent by the myriad of papers trying to identify ecosystems for IoT specific services, and by the difficulty to identify and exploit IoT business opportunities of the business ecosystems (Ikävalko, Turkama, and Smedlund 2018). Figure 10 displays how Mazhelis et al. (2012) foresee the technical IoT ecosystem to look like. Next to the technical players, which have been described in this model, they stipulate the ecosystem includes non-technical actors such as; standard development organizations, intellectual property holders, regulatory bodies and legislative bodies (Mazhelis et al. 2012). Whereas Figure 10 provides us a more comprehensive and elaborated version of what the roles in a technical IoT ecosystem could look like, and includes the important cloud providers in its scope, the model is not applicable to all IoT services. The players that enact in the ecosystem differ for each domain of IoT services. Furthermore, the maturity of the focal ecosystems can significantly differ per IoT application domain (Mazhelis et al. 2012).

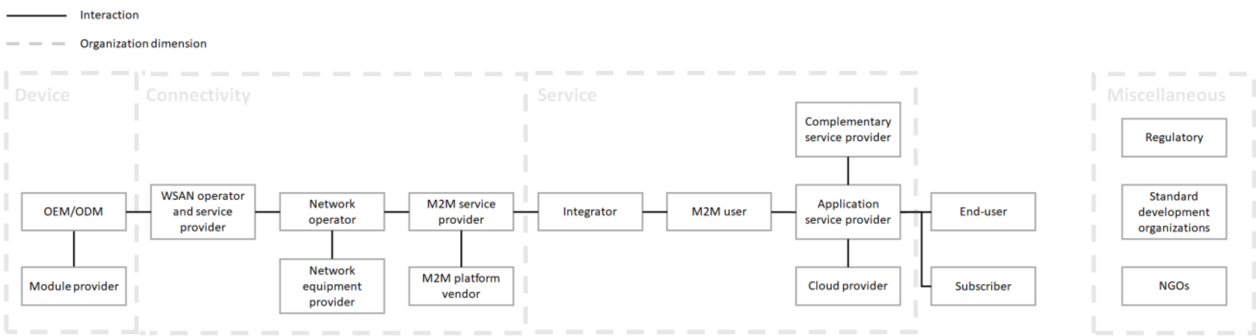


Figure 10: Simplified visualization of roles in the technical IoT ecosystem. Adapted from: (Mazhelis et al. 2012)

3.2.2.5 Cloud ecosystems

Over the past decade, the cloud computing ecosystems have rapidly evolved. Some of the key players in the cloud computing market include; Microsoft, Amazon, Google, Apache and Salesforce.com, which all have been able to form an ecosystem around their platform offering. Subsequently, these cloud providers create and capture the majority value of the cloud computing industry. It is expected that, as cloud computing and IoT are inherently interwoven, these cloud providers will create and capture a bight share of the IoT value as well. These players will be keystone players in both the cloud and IoT ecosystems (Mazhelis et al. 2012).

When analyzing the cloud computing ecosystem, first of all, in the competitive landscape, a distinction between provider types and architecture layers can be made. As identified in the NIST definition of cloud computing (Mell and Grance 2011), the three architecture layers include Infrastructure, platform and application. Furthermore, one can distinguish between three types of providers, namely; device providers, network providers and cloud providers. Subsequently, cloud providers create, run and distribute the cloud services from their datacenters. The network providers offer network access, in turn enabling the ubiquitous access to the cloud services. Lastly, the device providers offer the access devices which include PCs, tablets, smartphones, etc. and the operating systems which allow them to run. Figure 11 (A) provides an overview of the service type per provider type and architecture layer combination. On the right side of the figure (B), an example of major cloud providers' service-offering combinations is displayed. This image does not include the total cloud computing ecosystem, but rather a summary of service types and how major cloud providers position regarding these services (Kushida, Murray, and Zysman 2012).

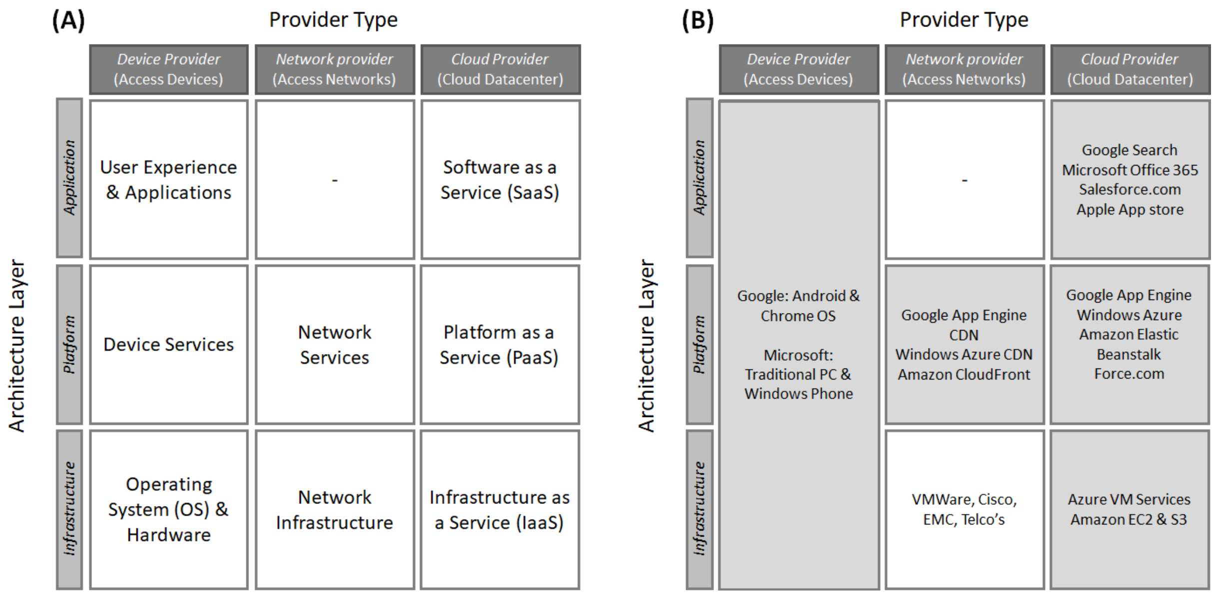


Figure 11: Cloud-, network- and device provider service framework. Adapted from: (Kushida et al. 2012).

Looking at a higher level of abstraction, the paper of Altmann and Rana (2010) identified the generic value network for cloud computing services. Using the E3-value method, they derived the total cloud computing ecosystem composed of; application providers, platform providers, infrastructure providers, aggregators, integrators, consultants and consumers. Figure 12 summarizes the main findings of the paper of Altmann and Rana (2010), describing the general cloud computing value network / ecosystem, including it's value- and monetary flows.

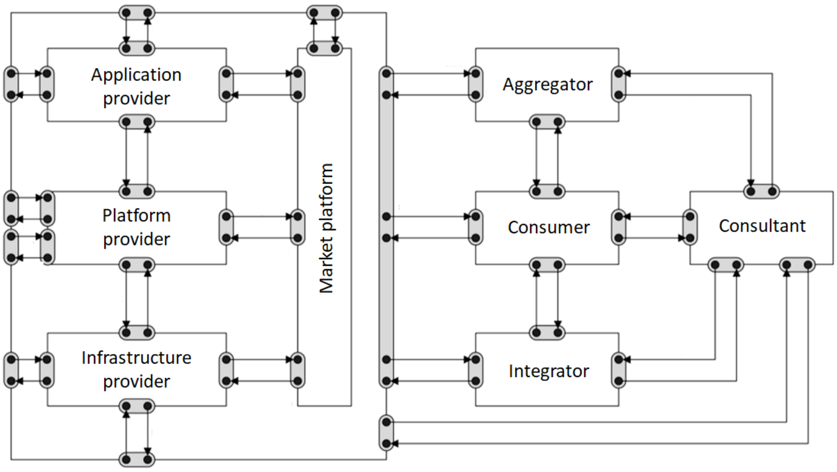


Figure 12: A generic value network of cloud computing. Adapted from: (Altmann and Rana 2010).

3.2.2.6 Edge computing ecosystems

The edge computing ecosystem will most likely be an extension of the current cloud-based ecosystem. The edge ecosystem will however not constitute a mandatory layer for the cloud comping ecosystem, but rather an optional layer (Michaela et al. 2017). Whereas the cloud- and IoT ecosystems have been described in academic literature, no literature has specifically been dedicated towards describing how a future edge computing ecosystem would look like. Therefore, this section uses information from the previous sections (3.1.3, 3.2.2.2, 3.2.2.3, 3.2.2.4 and 3.2.2.5) in order to identify players that would participate in a to-be-formed edge computing ecosystem.

The interaction of the respective cloud-, edge- and IoT ecosystems is the results from interdependency. Cloud computing, edge computing and IoT applications individually have weaknesses and incompleteness. However, the technical infrastructures can supplement each other in a three-layer logical architecture (Yousefpour et al. 2019). Subsequently, the three individual ecosystems generally need to interact in order to deliver a final solution. A graphical representation of how the ecosystems generally relate is based on how the three-layer logical architecture (drafted by (Yousefpour et al. 2019)) interacts and displayed in Figure 13.

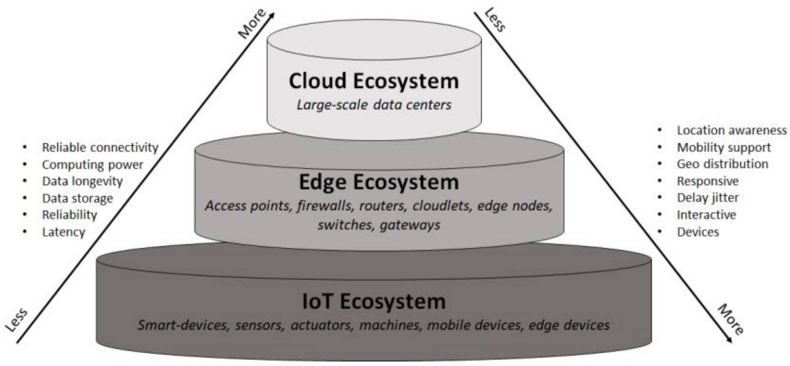


Figure 13: Positioning of edge computing ecosystem within relevant domains. Adapted from: (Yousefpour et al. 2019)

Looking at the cloud-, network- and device provider service framework which has been drafted in the paper of (Kushida et al. 2012), it becomes apparent that edge computing finds its interaction with cloud computing on the entire cloud provider spectrum and throughout the whole infrastructure level. This is aligned with the definition of edge computing, which has been formulated in section 3.1.3 as: *"an approach, which is aimed at solving the inherent problems of cloud computing regarding IoT, shifting the computing power away from the centralized data centers and envisioning a decentralized computing infrastructure, offering the same utility computing service, but with close proximity to the user and data source, which can be organized in a Cloudlet-, Fog computing- or Mobile Edge Computing IT solution."* This definition indicates that the edge computing differentiates from cloud computing on infrastructure level. subsequently, it is at infrastructure level that edge computing and cloud computing may compete or complement each other indicating the points of interaction. Figure 14 provides a graphical representation of the layer at which cloud and edge computing interact. The interaction throughout the whole cloud provider spectrum, meaning edge computing impacts SaaS, PaaS and IaaS is supported by (Michaela et al. 2017), whom state that those are the three respective service models edge may complement/substitute. Furthermore, as edge computing will deliver the same service models as cloud computing, but then by means of a different technical infrastructure, it can be expected that the respective value network of edge computing will be constituted similarly to the value network of cloud computing as has been drafted by Altmann and Rana (2010).

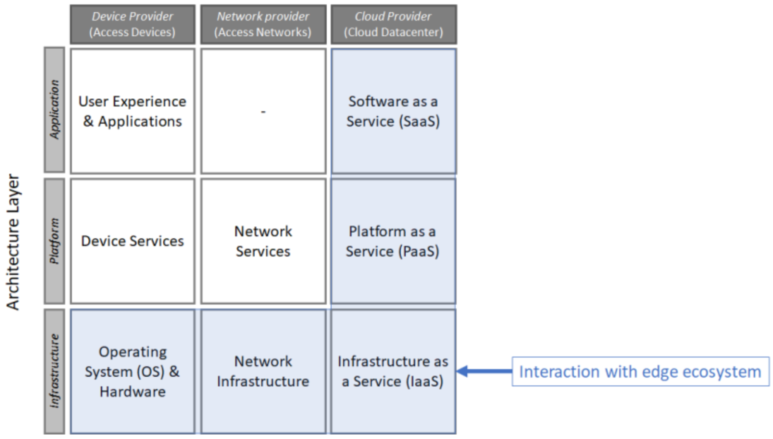


Figure 14: Level on which edge computing will interact with the cloud computing service framework. Adapted from: (Kushida et al. 2012).

The other interaction points of the edge computing ecosystem, which are with the IoT ecosystem, can be indicated based on the technical IoT ecosystem as drafted by (Mazhelis et al. 2012). Figure 15 graphically displays that the edge computing ecosystem is expected to interact with the network operator, the network equipment provider and the cloud infrastructure provider of the IoT application. Whereas some indirect interactions may occur, in order to keep oversight, only the direct interactions are displayed.

The WSAN (wireless sensor and actuator network) operator and -service provider ensures that a network of IoT nodes/devices can sense the environment and communicate the data from the monitored field towards a sink (can also be called a monitor or controller) which can either locally use the data or send it to other networks (e.g. the Internet) for usage (Mazhelis et al. 2012; Verdone 2008). Subsequently, the network operator is the one providing connectivity between the WSAN and the IoT applications. Network operators may deliver access network (i.e. mobile network of landline), the core network, and the transmission network. The network equipment provider then is the manufacturer of the network's elements and related services which it offers to the network operators (Mazhelis et al. 2012). Lastly, the IoT application provider interacts with the cloud provider in order to off-load storage and computation processes. As the edge paradigm will most likely be supplementary to a cloud infrastructure, the interaction between the IoT application service provider and the cloud provider will be impacted.

Furthermore, as edge computing allows for SaaS, PaaS and IaaS through a different (decentralized) infrastructure the practices of the WSAN operator and service provider, the network operator and the network equipment provider will be expected to change considerably. A graphical presentation of how edge computing is expected to interact with the IoT ecosystem is drafted in Figure 15.

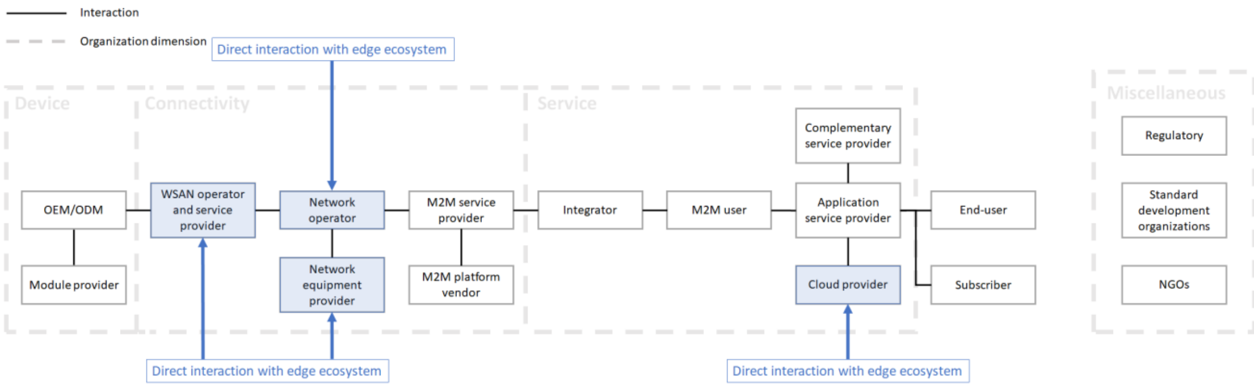


Figure 15: Level on which edge computing will interact with the IoT ecosystem. Adapted from: (Mazhelis et al. 2012)

Based on how the papers of Bertin et al. (2013), Mazhelis et al. (2012), Kushida et al. (2012) and Altmann and Rana (2010) drafted the IoT and cloud ecosystems, the insights that have been gathered from exploring the respective technical domains (section 3.1), and the positioning of edge ecosystems compared to the related cloud- and IoT ecosystems, a simplified draft of the players involved in an edge computing ecosystem, and their mutual interactions, has been visualized in Figure 16. Whereas it cannot be expected that this draft is comprehensive, it helps in understanding the players that constitute the edge ecosystem. Subsequently, when drafting the framework which suffices to identify the potential of edge computing for IoT applications, this can be taken into the back of our minds.

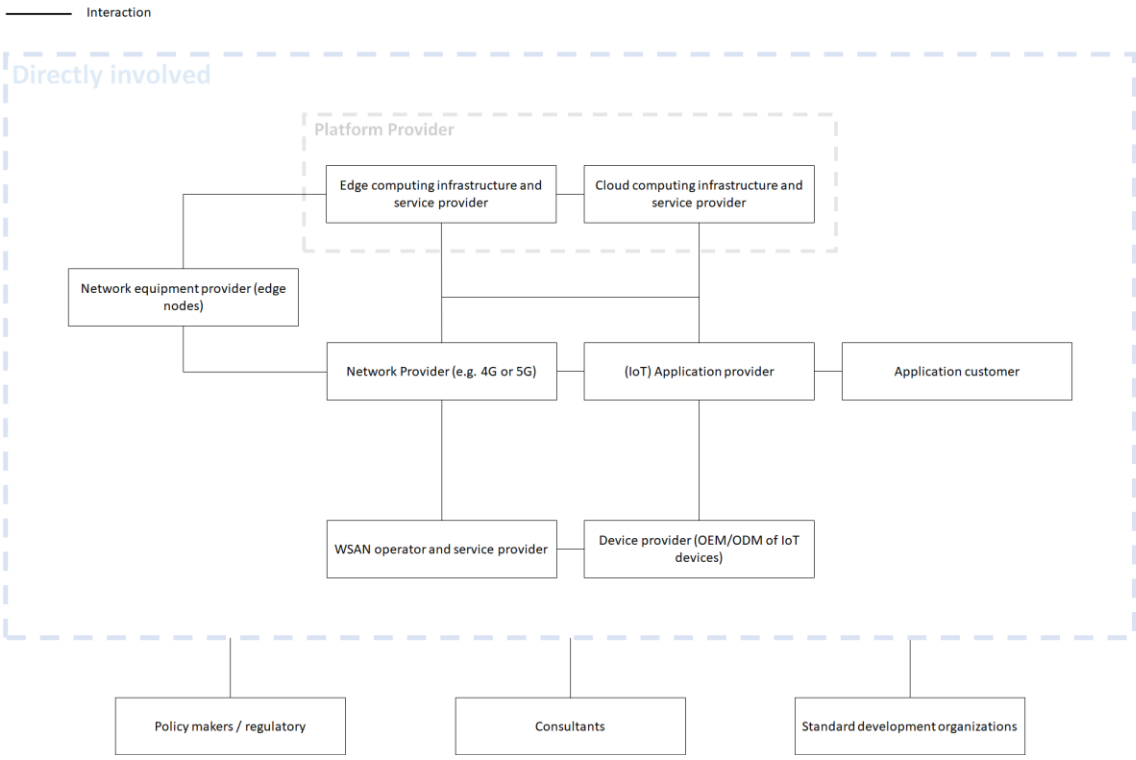


Figure 16: Simplified draft of edge computing ecosystem participants

3.2.3 The business model

As stipulated in Chapter 1, problem identification, there is a lack of understanding about the business models of edge computing. This leads to an uncertainty about the process that constitutes an adequate selection of IoT applications for edge computing. Before these complexities can be solved, we should get a better understanding about the business model concept. A better understanding about the general concept of business models should in turn facilitate a more rigorous selection and use of one of the ontologies. In section 3.2.3.1 a working definition for business models is selected. Section 3.2.3.2 then breaks down the general concept of business models into business model feasibility, viability, and sustainability. Definitions for business model feasibility and viability need to be clear, as the to-be developed tool will identify the potential of edge computing for IoT applications by assessing the business model feasibility and viability.

3.2.3.1 A definition of business models

The business model concept is still quite novel and ambiguity resides in how to formulate its definition. Many authors have previously proposed definitions, all focusing on different elements of the business model, but attempting to formulate a concise definition (Shafer, Smith, and Linder 2005). This Chapter aims to describe some of the relevant definitions mentioned in previous research, but does not strive to formulate an encompassing discussion. For more elaborate discussion about definitions for business models, the papers of Shafer et al. (2005), Bouwman, De Vos, and Haaker (2008) and Fielt (2011) can be consulted.

In the paper of Timmers (1998), one of the earlier attempts to formulate a definition for business models in electronic-commerce (e-commerce) can be found, that is; *"a business model is an architecture for the product, service and information flows, including a description of the various business actors and their roles, a description of potential benefits for the various business actors, and a description of the sources of revenues"* (Timmers 1998. pp 2). In this definition, Timmers envisions that the business model itself does not provide an understanding of how certain business goals of a focal firm can be realized. Instead, he states that the marketing model is of essential need to assess, among others, the commercial viability, competitive advantage and marketing mix. Furthermore, this definition displays that companies have to account for multiple actors when formulating their business model (Timmers 1998).

Based on the definition of Timmers (1998), in the dissertation of Osterwalder (2002), a more encompassing working definition for business models has been provided. *"A business model is a conceptual tool that contains a set of elements and their relationships and allows expressing a company's logic of earning money. It is a description of the value a company offers to one or several segments of customers and the architecture of the firm and its network of partners for creating, marketing and delivering this value and relationship capital, in order to generate profitable and sustainable revenue streams"* (Osterwalder 2002. pp 15). This definition intends to include the business and money earning logic of the company and highlights that the business model represents a layer between the business strategy and business processes. In this rather broad definition, Osterwalder captures the main elements which have increasingly gained attention over the past two decades.

Simultaneously, Chesbrough (2002) stresses the fact that technology by itself can only create little value. Instead, value of technology is created when the technology is properly commercialized through a business model. The following definition of a business model is mentioned in this paper: *"A business model is a description of how your company intends to create value in the market place. It includes that unique combination of products, services, image, and distribution that your company carries forward. It also includes the underlying organization of people, and the operational infrastructure that they use to accomplish their work"* (Chesbrough 2002. pp 6). This definition suggests that the role a firm chooses in a network is important.

Building upon the earlier mentioned definitions, in the book of Bouwman, De Vos, and Haaker (2008), the design aspects of the business models are emphasized. Furthermore, their definition of a business model reflects the fact that business models can be both described for a single company's perspective, or from a networked perspective. This means that, Instead of describing the position a single firm can have in a network, they describe business models from a network perspective. In their book, the following definition is provided; "*A business model is a blueprint for a service to be delivered, describing the service definition and the intended value for the target group, the sources of revenue, and providing an architecture of the service delivery, including a description of the resources required, and the organizational and financial arrangements between the involved business actors, including a description of their roles and divisions of the cost and revenues over the business actors*" (Bouwman et al. 2008. pp 33). It is important to note that the concept of service is essential in their definition. Furthermore, this definition focusses on the fact that a network of companies is needed to deliver a desired service and thus referring to a networked business model. Along these lines, Palo and Tähtinen (2011) infer that "*a networked business model defines the way a strategic business net creates value*" (Palo and Tähtinen 2011. pp 378), meaning the unit of analysis shifts from a focal firm towards a business net.

The definition of Bouwman et al. (2008) is aligned with this thesis' research objective, as this thesis project revolves around the service delivery of edge computing enabled IoT services. Furthermore, Bouwman's definition focusses on IT as central enabler of the business model, which perfectly aligns with the main subject of edge computing (as IT enabler for IoT). Third, this definition highlights the importance of networked service delivery and allows for identifying a more holistic view, from the total network of companies rather than a single firm. Therefore, for the remainder of this thesis, when referring to business models, the definition of Bouwman et al. (2008) is used.

3.2.3.2 Business model feasibility, viability and sustainability

A distinction between business model feasibility, -viability and -sustainability can be made. Whereas feasibility and viability are mainly important in order to evaluate new business models in its initial stages, sustainability is mainly relevant in order to determine if it is possible to sustain the competitive advantage the drafted business model delivers, over a longer extend of time (Bouwman et al. 2008). Subsequently, one must first identify whether a business model is feasible and viable, before assessing if the benefit it brings can be sustained over time.

First of all, the feasibility of the business model mainly relates the feasibility of deployment of the technical architecture that should enable the business model (Timmers 1998). Put more simply, it explains to what extend the business model is technically achievable (Bouwman et al. 2008). Secondly, the viability of a business model is mainly related to the commercial part of the business model, and explains how the relationship between technical inputs and economic outputs are related (Chesbrough 2002; Sharma and Gutiérrez 2010; Timmers 1998). In a viable business model, all participating players, both in the value- and consumer network, are able to run a profitable business which sufficiently incentives them to sustain the value network (Sharma and Gutiérrez 2010). Subsequently, the business model viability is can be influenced by design variables which influence the value that is created to customers and organizations in the business ecosystem (Bouwman et al. 2008).

Whereas business model literature often refers to the concepts of feasibility and viability, no formal definition is provided. In order to formulate a working definition for business model feasibility and -viability in this thesis research, the definitions from the dissertation of Kräussl-Derzsi (2011), which are explained from the perspective of innovative value constellations, are translated towards the business model language. (Kräussl-Derzsi 2011) first identifies the concept of economic feasibility, which is translated into the concept of business model viability for this research: "*business model viability of business ecosystems refers to the question of whether all stakeholders, such as service providers and consumers, participating in a constellation, gain significant with respect to their roles they fulfill. It is then important to address substantial economic effects in terms of cost and benefits of the service provision*." (Adapted from: (Kräussl-Derzsi 2011. pp 15). Secondly, the concept of technological feasibility is combined with the STOF vision which state that, in order to realize a service, the technology, organization and finance domain should be feasible (Bouwman et al. 2008). Subsequently business model feasibility can be defined as: *"business model feasibility of business ecosystems refers to the question of whether one can find a technologically, organizationally and financially achievable solution to provide the innovative service, thus to put the value constellation into operation by deploying information and communication technology."* (Adapted from: (Kräussl-Derzsi 2011. pp 15). Subsequently, the two identified concepts are mainly driven by value requirements and system requirements respectively (Kräussl-Derzsi 2011).

Lastly, after having identified a business model is both feasible and viable, one should look if the competitive advantage the business model delivers can be sustained. In that sense, the business model sustainability refers to the extent that a business model can deliver long-term, sustained competitive advantage of a firm or a value network. In order to keep a business model sustainable, it should be constantly aligned with the external factors that are of importance for the focal business. Furthermore, the business model components should demonstrate consistency both in terms of an internal- and external fit (Morris, Schindehutte, and Allen 2005).

3.3 Conclusion

For this thesis, the working definition of edge computing is formulated as; *an approach, which is aimed at solving the inherent problems of cloud computing regarding IoT, shifting the computing power away from the centralized data centers and envisioning a decentralized computing infrastructure, offering the same utility computing service, but with close proximity to the user and data source, which can be organized in a Cloudlet-, Fog computing- or Mobile Edge Computing IT solution.* From the literature review, it becomes apparent that edge computing delivers the same service models as cloud computing (i.e. SaaS, PaaS, and IaaS), but then by means of a different infrastructure. The characteristics that edge computing infrastructures exhibits are especially relevant for IoT application areas.

Cloud computing and IoT applications were previously not directly interlinked. Whereas IoT applications can use cloud computing services, the cloud computing domain stretches further. Edge computing is however very interlinked with both cloud computing (i.e. it complements or supplements cloud computing) and IoT (it solves problems of IoT computational offloading). This means that future edge computing ecosystems are positioned between cloud computing ecosystems and IoT ecosystems. As edge computing can be defined as a digital platform, the openness of technologies and standards, such as software development kids and APIs, as well as other platform characteristics, should be taken into consideration. This especially applies when looking at the customer value that edge computing delivers.

In order to identify the business potential of edge computing in distinct IoT application areas, the business model feasibility and business model viability should be assessed. Business model viability is defined as; *whether all stakeholders, such as service providers and consumers, participating in a constellation, gain significant with respect to their roles they fulfill. It is then important to address substantial economic effects in terms of cost and benefits of the service provision.* Business model feasibility is defined as; *whether one can find a technologically, organizationally and financially achievable solution to provide the innovative service, thus to put the value constellation into operation by deploying information and communication technology.* Hence, in order to draft a tool that can identify the business potential, answers to these concepts should be answered.

The understanding about IoT, cloud computing, and edge computing (technical domain), combined with the understanding about platforms, business ecosystems, and the business model concept, will be used in further sections to draft the tool.

4 Identification of design objectives

Having identified the main problems, and having clarified the relevant technical and theoretical domains, this Chapter takes the next step by drafting the guidelines for the tool's design. First, the selection criteria for the business model ontology are drafted in section 4.1. These characteristics are used to compare the business model ontologies in section 4.2. In section 4.3 the best fitting ontology is chosen based on a multi-criteria analysis of these selection criteria. Lastly, based on the complexities that have been identified in Chapter 1, design objectives are formulated in section 4.4. These design objectives should guide the design phases of the tool so that it addresses the complexities hitherto not addressed.

4.1 Selection criteria for business model ontology

In the process of selecting a state-of-the-art method as guiding principle for the first design iteration of the to-be designed tool, it is essential to draft selection criteria in order to ensure a transparent and objective selection process. Along those lines, six selection criteria were drafted. Table 6 displays these selection criteria and the desired characteristic that the business model ontology should exhibit.

As identified in chapter 1, in order to assess the potential of edge computing for an IoT application, the business model feasibility and business model viability should be assessed. Hence, the first criteria is that the chosen business model ontology focusses on both the feasibility and the viability aspects. The second selection criteria is that the ontology covers technological, organizational, and financial areas. The technological domain should be included because technical complexity of edge computing varies among IoT applications. The organizational and financial domains are crucial to include because they constitute the gap in scientific literature on edge computing that currently result in uncertainty about its potential. Thirdly, as edge computing is delivered by a network of firms rather than by a single firm, the business model ontology should take a networked firm perspective. Fourthly, it is desirable that the chosen ontology unfolds concrete variables and describes their causal relations. Causal relations are important since the to-be designed tool aims to identify which variables result in viable and feasible business models. A detailed ontology is relevant because this provides tangible guidelines for identification of variables. Fifth, it is desirable that the ontology is drafted in the environment of ubiquitous mobile services or in the environment of digital platforms. In its essence, edge computing is an ubiquitous mobile service. In section 3.2.1.4, edge computing was defined as a digital platform. Hence, focus of the selected ontology on either one of these research areas allows for identification of variables that are specifically applicable within the edge computing paradigm. Lastly, the model's use in academia is relevant in order to assess the extent to which the model is generally accepted in scientific research. High adoption of the ontology in scientific literature allows for increased rigor of the to-be designed tool as rigorous research involves a sufficient theoretical base (Sekaran and Bougie 2010).

Table 6: Desired characteristics of business model ontology

Selection criteria	Focus on business model aspects	Covered areas	Perspective of the tool	Level of detail	Environment	Use of ontology in academia
Desired characteristic	Feasibility and viability	Technological, organizational, financial	Networked firm perspective	Detailed ontology that indicates causal relations among individual variables	Ubiquitous mobile services or digital platforms	High number of citations

4.2 Business model ontologies

This section describes the characteristics of the identified business model ontologies in terms of the six selection criteria that were drafted in Table 6. In section 4.3, these characteristics are compared to the desired characteristics.

4.2.1 The Business Model Canvas (BMC)

The business model canvas (BMC) finds its early roots in the dissertation of Osterwalder (2002), which describes the business model in terms of four pillars; customer interface (building block 1, 3 and 4 of the BMC), product (building block 2 of the BMC), infrastructure management (building blocks 6, 7 and 8 of the BMC) and financial aspects (building blocks 5 and 9 of the BMC). Based on the main findings of this dissertation, Osterwalder and Pigneur (2013) wrote the book 'Business Model Generation', which aims to support visual thinking of the business model design in terms of nine building blocks. This model supports individual firms in how to position their business model within the competitive landscape, as well as redesign these focal firms' business model with a design- and innovation-oriented approach. The nine building blocks of the BMC aim to provide a shared language for describing, assessing, visualizing and changing business models. Industry practitioners can use the BMC to design viable business models. The BMC is not focused on any specific industry environment (Osterwalder and Pigneur 2013). The BMC has no specific focus on the technology domain. Limitations of the model can be found in the absence of cause-and-effect linkages between the components and its enterprise perspective instead of networked perspective. These limitations also refer to the BMC's internal focus on what the company should deliver and how this can be established. The main strengths of the BMC are found in its ease of use and high usage in academia.

4.2.2 The STOF model

The STOF business model was introduced in the conference paper of Faber et al. (2003). More elaborate illustration of the philosophies behind the STOF model, it's implications as well as illustration has been exemplified in the book of Bouwman et al. (2008). The STOF model sees a business model as the way a network of companies (instead of a single firm) intends to create and capture value from employed technologies. This viewpoint intents to provide an perspective on the cross-company collaboration in complex value networks. Furthermore, this model is mainly focused at structuring design choices in this networked perspective. More specifically, the STOF model aims to guide industry practitioners in designing viable and feasible, networked business models for mobile services (Faber et al. 2003). By comparing definitions on business models from the papers of Slywotzky (1996), (Timmers 1998), Weill and Vitale (2001) and Rappa (2001), they identified four common elements, which they called the service-, organization-, technology- and finance domains. This implies a networked business model can be designed by making blueprints for these four interrelated domains. The STOF model stresses the fact that any business model should have its starting point at the customer value of a product or service that a single company or network of companies will offer. Therefore, the STOF model starts from the service domain. Although technology is often the main driver for high-tech services, in the STOF model this is only seen as an enabler and is thus the second domain which is tackled. As third domain, the organizational domain should be described. This domain explains how the resources will be made available. Lastly, the finance domain focusses on investments, pricing strategies and other related financial concepts (Bouwman et al. 2008). One of the main strengths of the STOF model is it's level of detail and its concrete indication of causalities among factors.

Critical design Issues & critical success factors

The Critical Design Issues (CDIs) and Critical Success Factors (CSFs) shift the scope of the STOF model towards the understanding of causalities that influence the viability and feasibility of business models. Along those lines, Bouwman et al. (2008) argue that, in order to realize a viable business model, the interests and requirements of the involved actors need to be balanced. Furthermore, they argue that it is important to understand the CDIs, their interdependencies, and how they are interlinked to the CSFs with regard to the business model viability, in order to realize a balanced design. These CDIs and CSFs should help organizations in gaining insight in how a 'balanced' business model can be designed. The CDIs and CSFs are value-creating elements, meaning they provide customer value or network value. Finally, these factors are exemplified in a causal model that provides an understanding of the business model viability.

4.2.3 VISOR

From the perspective of design theory for digital business ecosystems, The VISOR model represents a conceptual framework that consists of five main categories, each representing one letter of the name; Value proposition (V), Interface (I), Service Platform (S), Organizing Model (O) and Revenue Model (R). For each of these domain it provides a moderately detailed identification of related components. The VISOR model aims to integrate multiple business model approaches while addressing components such as user experience and interface factors which are not addressed in many other approaches, yet prominently present in innovation diffusion theories. In the realm of digital businesses, this model sets itself apart by integrating the service platform part, which describes the IT platforms that enable, shape and support the business. Hence, the service platform part partially describes the technology domain. In this respect, the model illustrates how the focal firm can create the greatest customer value for digital businesses in a profitable and sustainable manner, thereby designing a viable business model. Put more simply, a successful digital business model, from the VISOR perspective, should align the 5 components in such way that the value proposition maximizes the wiliness to pay, while minimizing the real cost (El Sawy and Pereira 2013). The advantage of VISOR is that it takes both a service platform and digital business ecosystem perspective, which is perfectly aligned with the edge computing domain. However, the VISOR model has a strong focus towards the user interface, which is not especially relevant in this study. Moreover, VISOR solely focusses on business model viability, thus neglecting the feasibility aspect.

4.2.4 The C-SOFT model

The C-SOFT business model is introduced in the paper of Heikkilä, Heikkilä, and Tinnilä (2008) and aims facilitates an iterative design of viable and feasible business model as the firm grows. This business model ontology is inspired by the models provided of Osterwalder (2002) and (Faber et al. (2003). The C-SOFT illustrates similar domains as the STOF model (Bouwman et al. 2008; Faber et al. 2003), but has the customer relationship as focal point of attention. Furthermore, the C-SOFT ontology focusses on long term service models for Business-to-Business (B2B) markets. Heikkilä et al. (2008) state that the C-SOFT model is characterized on long lasting business relationships between customers and suppliers, hence it's focus is on long-term services. The central distinguishing element of the C-SOFT model can be found in the nature of the customer relationship, which plays a major role in the view of Heikkilä et al. 2008) and is often neglected in other business model ontologies. The C (Customer relationship) of the C-SOFT model is the focal point of the C-SOFT ontology. This domain mainly revolves around customer relationships and joint development of products and services with customers. Similarly to the STOF model, the C-SOFT framework emphasizes that products or services, in global markets, are delivered in a networks rather than by single firms. Therefore, the C-SOFT model focusses on a joint business model for collaborative networks (Heikkilä et al. 2008). The model does not illustrate the dynamics of their designed tool, nor does it illustrate the relationship between important design variables of the five indicated domains. The C-SOFT ontology solely gives a description of the importance of the customer relationship domain, but does not provide a conceptual framework. Therefore, the practical relevance of this model is hard to gauge.

4.2.5 Networked business model development for emerging technology-based services

The Networked business model for emerging technologies was introduced by Palo and Tähtinen (2011), builds on business model research of Timmers (1998), Osterwalder (2002) and Shafer et al. (2005) and combines this with the theories of (Möller, Rajala, and Svahn (2005) and Parolini (1999) which describe the value- and strategic-net approach. This business model ontology is specifically focused on design of viable business models. It does so in the environment of ubiquitous services, which is aligned with the edge computing- and IoT based services. Main emphasis is placed on the customer, service, technology, revenue model and business net. Similarly to the STOF model and the C-SOFT model, this business model ontology employs the concept of a networked business model. Furthermore, this business model ontology is focused technology-based services. Similarly to the C-SOFT model, the networked business model development for emerging technology-based services highlights additional importance on the customer's needs when developing the service (Palo and Tähtinen 2011). Whereas this model provides a theoretical contribution on the elements of the networked business model (on different actors in the value net, the service itself, as well as the value exchanges and activities between actors), it only identifies a set of generic core elements. This means that the model itself lacks theoretical depth and might be too generic to be used for design.

4.2.6 Summarized overview of business model ontologies

Based on the descriptions of the previous sections, Table 7 summarizes the characteristics of the business model ontologies.

Table 7: Summarized overview of characteristics of the identified business model ontologies

BM Ontologies / Characteristics	BMC	STOF model	VISOR	C-SOFT	Business models for emerging technology-based services
Source	(Osterwalder and Pigneur 2013)	(Bouwman et al. 2008; Faber et al. 2003)	(El Sawy and Pereira 2013)	(Heikkilä et al. 2008)	(Palo and Tähtinen 2011)
Focus on business model aspects	Viability	Feasibility and viability	Viability	Feasibility and Viability	Viability
Covered areas	Customer interface, product, infrastructure management, financial aspects	Service, Technology, Organization, Finance	Value proposition, Interface, Service Platform, Organizing Model, Revenue Model	Customer relationship, Service, Organization, Finance, Technology	Customer, Service, Technology, Revenue model, Business net.
Perspective	Single firm perspective	Networked firm perspective	Networked firm perspective	Networked firm perspective	Networked firm perspective
Environment	Generic	Mobile services	Digital platforms	Long-term services	Ubiquitous services
Level of detail	Describes nine generic building blocks and their important aspects. Does not describe the causal relations	Very detailed identification of variables and their causal relations for each domain.	Moderately detailed description of five respective domains and their relevant elements. Does not describe the causal relations.	Generic description of the five domains. No identification of concrete variables	Generic framework of the elements of a networked business model and their interactions. No identification of concrete variables.
Use of ontology in academia	9035	417	142	25	98

4.3 Selecting the guiding business model ontology

Table 8 evaluates how the identified characteristics of the business model ontologies that were summarized in Table 7 are aligned with the desired characteristics as drafted in Table 6. This evaluation was done by describing the fit in terms of: - = negative fit, 0 = neutral fit, + = positive fit , and, + + = distinct advantage. A characteristic has a negative fit if it conflicts with the desired characteristic. A conflict with the desired characteristic has negative effect on the suitability of the ontology. When a characteristic is not specifically aligned, but does not negatively affect the ontology's suitability, a neutral fit is specified. A positive fit is identified if the tool's characteristic is aligned with the desired characteristic and thereby enhances its suitability. Lastly, in cases where the ontology has a unique characteristic so that other ontologies do not exhibit and where it is perfectly aligned with what is desired, a distinct advantage is indicated.

Based on Table 6, Table 7, and Table 8, it is concluded that the STOF model best fits the desired characteristics. Firstly, STOF and C-STOFT are the only ontologies that specifically focus on both the business model feasibility and viability. Secondly, STOF encompasses the three desired areas of technology, organization and financial (only BMC does not meet this requirement). Fourthly, similarly to VISOR, C-SOFT and Business models for emerging technology-based services, the STOF model takes a networked firm perspective. Fifthly, STOF provides a positive fit on the environment as it focusses on mobile services and edge computing falls under this category. VISOR was identified to have a distinct advantage on this aspect as it is the only ontology that is specifically focused on digital platforms. However, VISOR is not suitable as it does not focus on the business model viability and as it lacks in its level of detail. On the other side of the token, the STOF model has a distinct advantage in its level of detail as it is the only ontology that provides a very detailed description of variables and their causalities. Lastly, the STOF model is has a high citation rate and can therefore be seen as a generally accepted ontology in scientific literature. As STOF was identified to provide a positive fit on all six criteria, it will be used as guiding philosophy in the first iteration of the design phase. The results of this comparison are represented in Table 8.

Table 8: Comparison of criteria-fit of business model ontologies

BM Ontologies / *Characteristics*	BMC	STOF model	VISOR	C-SOFT	Business models for emerging technology-based services
Focus on business model aspects	-	+	-	+	-
Cover areas	-	+	+	+	+
Perspective	-	+	+	+	+
Environment	0	+	+ +	0	+
Level of detail	-	+ +	-	-	-
Use of ontology in academia	+	+	0	-	0

4.4 Design objectives

In the previous section, the STOF model displayed to be the most suitable business model ontology to guide the design phase. The STOF model should however be adapted in two main ways. First, the theoretical STOF ontology should be transformed into a practical tool that can be used in order to make informed decisions for selecting IoT applications in which edge computing constitutes a viable and feasible business case. Second, the generic variables should be contextualized towards the edge computing domain, so that it is directly applicable to this respective domain. In order to make these adaptations in a way that the complexities that were identified in Chapter 1 are solved, design objectives are drafted. The to-be designed tool should thus meet the design objectives that have been drafted in Table 9, in order to address the complexities hitherto no addressed.

Table 9: Design Objectives

Complexities derived from the problem identification in Chapter 1	Design objectives resulting from the complexities
Literature on business models for edge computing is scant.	O1. Business model variables should be contextualized towards the edge computing domain.
There is a myriad of potential IoT applications for edge computing, but stakeholders (i.e. edge service providers and IoT service providers) are unable to identify on which IoT applications they should focus their efforts.	O2. The tool's output should be an indication about the business potential of edge computing for the IoT application under analysis. O3. Edge service providers and IoT service providers should be able to use the tool.
Potential edge service providers need to be convinced that for some applications, edge computing may constitute a viable and feasible business case.	O4. By using the tool, edge providers and IoT providers should be able to formulate arguments that elaborate upon the business

	potential of edge computing for distinct IoT applications.
For potential adopters there is uncertainty about the actual business value of edge computing for their focal IoT applications, leading to decreased adoption rates of edge infrastructures.	O5. Use of the tool should clarify how edge computing creates value for potential adopters (i.e. IoT application providers).
There is no business model tool that can be used to identify the business potential of edge computing in distinct IoT application areas, based on both business model viability and feasibility. Therefore, it is not possible to make informed decisions to target IoT application areas that hold substantial potential for both customers and providers.	O6. In order to guide the process of informed decision making, an explicit description about how increase/decrease and presence/absence of the exogenous characteristics of an IoT application impact the business model viability and feasibility of edge computing should be elaborated in the tool. O7. In order to enable accurate identification of the business potential, the relative importance of factors that influence the business model viability and feasibility of edge computing should be distinguished.

4.5 Conclusion

Now, having analyzed the relevant concepts to business modelling in chapter 3, having selected a guiding business model ontology, and having drafted design objectives that aim to solve main identified complexities, the sub question; *How should the concepts related to business modeling for IT services be used for identifying the potential of edge computing for distinct IoT applications?* can be answered.

First, the STOF model exhibits desired characteristics and therefore is the most suitable ontology to guide generic design of the tool. Hence, STOF should be the guiding philosophy in order to identify relations among business model variables. In order to make STOF suitable for the identifying the potential of edge computing for distinct IoT applications, it should however be adapted and contextualized towards the edge computing paradigm. It is concluded that, the identified concepts related to business modelling for IT services should be used in order to solve seven design objectives:

- O1. Business model variables should be contextualized towards the edge computing domain.
- O2. The tool's output should be an indication about the business potential of edge computing for the IoT application under analysis.
- O3. Edge service providers and IoT service providers should be able to use the tool.
- O4. By using the tool, edge providers and IoT providers should be able to formulate arguments that elaborate upon the business potential of edge computing for distinct IoT applications.
- O5. Use of the tool should clarify how edge computing creates value for potential adopters (i.e. IoT application providers).
- O6. In order to guide the process of informed decision making, an explicit description about how increase/decrease and presence/absence of the exogenous characteristics of an IoT application impact the business model viability and feasibility of edge computing should be elaborated in the tool.
- O7. In order to enable accurate identification of the business potential, the relative importance of factors that influence the business model viability and feasibility of edge computing should be distinguished.

Meeting these seven design objectives results in a tool that adequately solves the complexities related to identifying the potential of edge computing for distinct IoT applications.

5 Design Phase 1 - based on literature review and informal talks

This Chapter describes the first design phase of the tool. The tool should be designed so that it fulfills the design objectives as drafted in section 4.4. The STOF ontology will be used to draft the generic tool. The other identified technical- and theoretical domains are used in order to contextualize the generic business model variables towards the edge computing domain. In order to allow for structured organization and assembly of the tool, the general structure of the XLRM framework as drafted in the book of Lempert, Popper, and Bankes (2003), is used. This choice was made because the XLRM structure helps in designing a visualized decision support system that can be used to navigate through scenarios and formulate rigorous arguments about actions to take based on the model. The main aim of this research is to design a tool that facilitates informed decision making and argumentation for the potential of edge computing for distinct IoT applications. Hence, the XLRM framework's intention is perfectly aligned with this thesis' aim. The XLRM framework groups variables into exogenous uncertainties that are outside the control of decision makers (X), policy levers which are near-term actions that the decision maker wants to explore (L), relationships which describe how factors relate to each other (R), and measures that indicate the performance standards decision makers want to measure (M). Groups of variables for the to-be designed tool can be drafted as: IoT application characteristics (Exogenous uncertainties – X), the choice of technology architecture for edge computing (Policy lever – L), the conceptual model that explains the relations between the choice of technology and the IoT application characteristics (relationships in system – R), and the potential of edge computing for the IoT application under analysis (Measure – M). Section 5.1 elaborates upon the variables that have been extracted from literature and how they are relevant for the tool. The first version of the tool (i.e. the outcome of design phase 1) is displayed in section 5.2.

5.1 Drafting the tool

In the DSRM, the identified problem, the main research question, and the corresponding design objectives, should be guiding the design phase. In section 1.6, the main research question was drafted as: *How can technical-, business- and organizational factors be included in a tool, that can be used to identify the business model viability and feasibility of edge computing in distinct IoT application areas?* In section 3.2.3.2, business model feasibility was defined as the extent to which a technically-, organizationally- and financially achievable solution can be found in order to effectuate the desired service. The business model viability in describes the extent to which the business model can deliver value for all stakeholders that are involved in the value constitution. As displayed in Figure 17, in order to determine if there is substantial potential for edge computing in an IoT application, the business model should be both feasible (i.e. technically-, organizationally, and financially, achievable) and viable (i.e. deliver enough value for the entire value constellation).

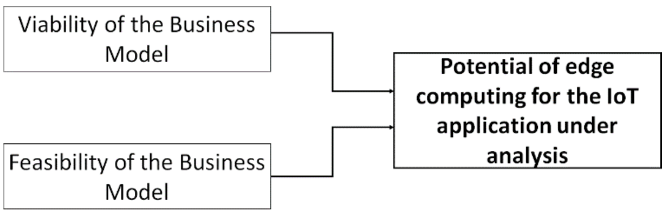


Figure 17: The potential of edge computing for an IoT application is impacted by business model viability and feasibility

5.1.1 The design process

From the starting point that business model viability and feasibility explain the potential of edge computing for an IoT application, this section elaborates the design process. In Chapter 4, the STOF ontology was selected to guide generic design of the tool. All variables that are part of the STOF model (i.e. service, technology, organization, and finance domain, as well as CDI and CSFs) are evaluated on their relevance for assessing the potential of edge computing for an IoT application. A variable, is deemed to be relevant for the to-be designed tool if:

- It explains how a characteristic of an IoT application area impacts the customer or network value that is delivered by an edge computing infrastructure.
- Or it explains how a characteristic of an IoT application area impacts the complexity of edge computing roll-out or utilization

Therefore, variables that are not dependent on the IoT application area are not included. This is because these variables do not help us understand for which IoT application areas edge computing may deliver a viable and feasible business case. These variables apply to edge computing in all application areas in general. Therefore, they do not provide us with means to distinguish among the business potential of distinct IoT application areas. Hence, these variables do not contribute to solving the main question.

For assessing the business model viability, first the CDIs and CSFs are evaluated on their relevance (Appendix A.1 displays this process). Hereafter, interactions of the CDIs with the service, technology, organization, and finance, domains were assessed. For the business model feasibility, these CDIs and CSFs are however not relevant. This is because they describe the business model viability. It is deduced from the definition of business model feasibility, that it is relevant to look at the technology, organization, and finance domains (i.e. not looking at the service domain). This is confirmed by Bouwman, De Vos, and Haaker (2008), who state that the technology, organization, and finance, domain enable the service domain.

After having analyzed the variables of STOF, the theoretical domains of business ecosystems and platform theory are consulted in order to see if the STOF is missing relevant variables for edge computing. Lastly, technical and organizational domains are used in order to contextualize the generic variables of STOF towards the edge computing domain. In this first design iteration, a hypothesis is formed about variables that are of influence. As no theory explicitly formulates which contextual variables are relevant, all variables that are hypothesized to be relevant in order to explain the generic variables are included. In the second design iteration, interviewees validate these variables. Hence, irrelevant variables can be removed at a later stage. As this research constitutes a broad theoretical domain, it cannot be expected that all relevant variables are identified in this first design iteration. The second design iteration helps to identify new variables that were not found in literature.

5.1.2 Business model viability

Zooming in on the business model viability, the book of Bouwman, De Vos, and Haaker (2008) indicated that there are several critical design issues (CDIs) and critical success factors (CSFs) which should be addressed in order to design a viable business model. Going to the core, Bouwman et al. (2008) stipulated that a designer should address the design-oriented CDIs, which influence the CDFs, in turn generating customer value or network value. Finally, when a business model adds sufficient customer and network value, it can be seen as viable. Therefore, as displayed in Figure 18, a business model can only be viable if it delivers both enough customer- and network value.

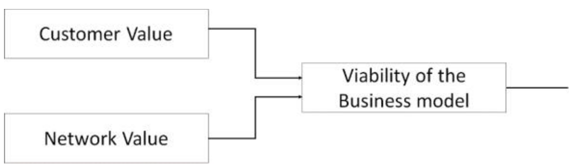


Figure 18: Viability of the business model is impacted by customer- and network value

As displayed in Table 10, the generic variables *perceived quality of service* and *switching costs* are expected to impact the *customer value*. By diving into the CSFs that explain customer value, it is argued that the CSF *acceptable quality of service* is the only variable that is of relevance for assessing the potential of edge computing for distinct IoT application areas. First, the *value proposition* that edge computing delivers is the same value proposition as cloud computing (it's alternative), augmented through a different infrastructure. Therefore, it is expected that the perceived quality of service more adequately describes the difference in technical infrastructures and how potential adopters may gain value from that. Unobtrusive customer retention refers to the mechanisms by which customers are retained, which is not a characteristic of IoT application areas. Lastly, a clearly defined target group enables companies to focus stay focused on their customers. This does however not explain a characteristic of an IoT application that influences the potential of edge computing.

Whereas (Bouwman et al. 2008) indicate that switching cost can be considerable in mobile service innovations, they do not explicitly include this variables in the service design. They do however state that the compatibility of a service with people's daily context (i.e. which influences the switching cost) impacts the variable *effort*. Effort in turn impacts the perceived value. Based on literature from Eisenmann et al. (2011, Farrell and Saloner (1985), and Rogers (2003), it is argued that switching cost is a major determinant that influences customer's perceived value of edge computing and thereby influences their adoption behavior. Hence, this variable should be named separately.

Table 10: Generic variables that explain the customer value

Variable Name	Source	Explanation
Perceived quality of service	(Bouwman et al. 2008)	The quality of service relates to the performance of the technical architecture in delivering the desired functionality. The extent to which an acceptable quality of service is delivered by the infrastructure in turn has a profound impact on the customer value that is generated. The perceived quality of service is impacted by the match between the demanded quality of service and the delivered quality of service.
Switching costs	(Eisenmann et al. 2011; Farrell and Saloner 1985; Rogers 2003)	When a company decides to switch from service X to service Y, it incurs switching cost. If these costs are substantial, switching between the services will require a high resource commitment. The benefit gained by the new service should exceed the switching cost a customer incurs. Hence, the switching costs may have a profound impact the customer value.
Pricing	*(Bouwman et al. 2008)*	*In order for a service to generate customer value and thereby be adopted, the perceived customer value must exceed the respective price a customer has to pay for the service. For this tool, pricing is considered to be a design variable that may be used to reduce customer value and enhance network value. The price may thus be used to divide the customer surplus and provider surplus. Hence, the price is dependent on the relative customer value that is created by implementing an edge infrastructure.*

Table 11 displays the generic variables that are relevant for explaining the network value that is created with edge computing in distinct IoT application areas. From the CSFs and CDIs, a couple of variables can be extracted. First, the CSF *risk* is relevant, as distinct IoT application areas provide different levels of risk for potential edge providers. Second, the *level of profitability* is relevant as different IoT application areas may provide different levels of profitability. However, the variable *profitability* can be broken down into the more specific generic variables: *Revenue, cost,* and *risk*. This means that the earlier identified CSF *risk*, impacts the level of profitability. The variable revenue can be further broken down into the variables *pricing* and *customer base.* As identified in the previous table, *pricing* is dependent on the created customer value. Therefore, it is stated that pricing is a design variable that can be used to divide the customer surplus and provider surplus. The *customer base* is a relevant characteristic of distinct IoT application areas that explains the network value. The CSF *sustainable network strategy* is not an characteristic of IoT application areas. Instead, it describes the strategy by which companies can secure access to resources and capabilities. Also the *acceptable division of roles* is not a characteristic of IoT application areas, instead it describes how firms divide profits and resources among each other. Hence, these two variables are not included.

Lastly, it is argued that the IoT ecosystem health is relevant for assessing the business potential of edge computing for distinct IoT application areas. A healthy ecosystem provides *durably growing opportunities for its members and for those who depend on it* (Iansiti and Levien 2002. pp32). This implies that for potential providers, an IoT application area that is delivered in a healthy ecosystem, provides additional value. Different IoT application areas are delivered in distinct ecosystems, hence the healthiness of these ecosystems can partially determine the attractiveness of an IoT application area (from the provider's perspective). STOF recognizes the relevance of organizational variables. STOF does however not indicate that the healthiness of an ecosystem may play a role in the network value. Based on literature from (Iansiti and Levien 2002), it is hypothesized that the ecosystem health plays a role in assessing the business value of edge computing for IoT application areas.

Table 11: Generic variables that explain the network value

Variable Name	Source	Explanation
Customer base/ revenue source	(Bouwman et al. 2008) + informal talks	For an edge service provider it is important that the IoT application under analysis, for which efforts and investments will be done, and competencies will be developed, constitutes a substantial customer base and corresponding revenue source. The edge infrastructure provider wants to build upon his competencies, standards and platforms in order to drive down the marginal costs and reproduce similar architectures over multiple customers. Hence, the extent to which an IoT application constitutes an acceptable customer base has a profound impact on the extent to which an acceptable profitability may be effectuated.
Relative cost	(Bouwman et al. 2008; DeMarzo 2013)	Next to the revenue, the relative cost which are incurred by building and maintaining an edge infrastructure for the IoT application under analysis, will directly impact the extent to which an acceptable profitability can be effectuated.
(Financial) risk	(Bouwman et al. 2008; DeMarzo 2013)	Next to the relative revenue and relative cost, lastly, what determines if there is an acceptable profitability, is the risk the service provider takes by focusing on- or rolling-out an edge architecture for a specific IoT application.
IoT application's ecosystem health	(Iansiti and Levien 2002)	The health of an ecosystem refers to the extent to which it is durably growing opportunities for its members and for those who depend on it. Translating this to the realm of edge computing, the different IoT applications edge service providers may target, have different ecosystems. The health of the respective ecosystems can differ. Therefore, the focal IoT application's ecosystem health may or may not enhance the network value, depending on the IoT application.

Acceptable profitability	*(Bouwman et al. 2008)*	*One of the critical success factors driving the network value, and ultimately the business model viability, is an acceptable profitability. The network of companies that may potentially deliver an edge computing service should be able to realize sufficient profitability.*
Revenue	*(Bouwman et al. 2008; DeMarzo 2013)*	*De revenue an edge service provider can potentially generate has influence on the extent to which an acceptable profitability can be reached with a certain IoT application.*

Based on the assessment of STOF's CSFs (and corresponding CDIs) and the other relevant theoretical domains, it is argued that there are six generic variables that are relevant for assessing the viability of an edge computing business model in a specific IoT application area. As graphically displayed in Figure 19, the variables; perceived quality of service, switching costs, customer base/revenue source, relative cost, (financial) risk, and IoT application's ecosystem health, are expected to impact the viability of the business model. Any further break-down of these variables unfolds in contextualization towards the edge computing domain (i.e. these variables cannot be adequately explained in generic definitions). In the second design iteration, the comprehensiveness of this set of generic variables needs to be tested, in order to ensure that they are sufficient to answer the main question.

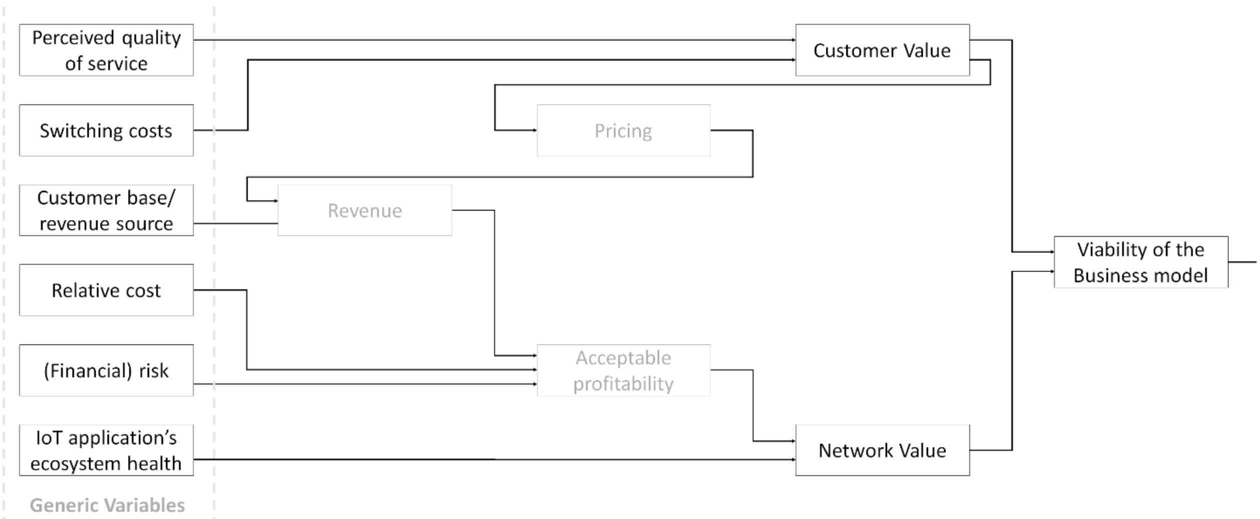


Figure 19: Six generic variables impact the business model viability

5.1.2.1 Perceived Quality of Service:

As explained in Table 13 and graphically displayed in Figure 20, the generic variable *perceived quality of service* is impacted by the match/mismatch between the *demanded quality of service* and the *delivered quality of service*, and the *potential additional functionalities* that edge computing may bring. These interactions have been extracted from the STOF model and informal talks. In the contextualization of these variables, it becomes apparent that the demanded quality of service is dependent on the *infrastructure requirements: Latency, raw amount of data, privacy, security, context awareness, mobility support, connectivity,* and *energy constraints of devices.* Additional functionalities of edge computing envelop in the functionalities that *serverless computing* can deliver. The concept of *serverless computing* can provide additional benefits by increasing edge computing's *ease of use* and by enhancing it's *technological functionalities*.

Table 12: Contextual variables that explain the perceived quality of service

Variable Name	Source	Explanation
Demanded/expected quality of service	(Bouwman et al. 2008)	The perceived quality of service is impacted by the expected quality of service. The STOF model describes the expected value as the value a customer or end-user expects from a service. These expectations are based on their requirements for the infrastructure and on their experience with previous versions. Hence, the infrastructure requirements influence the expected quality of service.
Service/infrastructure requirements	(Bouwman et al. 2008)	A user has certain requirements in the service domain. The service requirements a customer has for their computational offloading platform may be translated into a demanded quality of service in the technology domain.
Latency requirements	(Ai, Peng, and Zhang 2018; Satyanarayanan 2017; Shi et al. 2016; Yu et al. 2018)	An edge computing infrastructure can effectuate lower end-to-end latency due to close physical proximity of edge nodes to the users (devices). Therefore, one of the requirements that could drive the preference on the customer side to go for edge computing is the latency requirements the IoT application demands.
Raw amount of data	(Ai et al. 2018; Satyanarayanan 2017; Yu et al. 2018)	Edge computing has the potential to decrease the ingress bandwidth into the cloud by (pre)processing data intensive processes at decentralized level in close proximity to user. Data transfer can be done by local RAN, WiFi, Cable, etc. Therefore, the raw amount of data that needs to be processed, leading to higher bandwidth requirements, may increase the value of a customer to go for an edge infrastructure. Furthermore, as data is processed locally, the user may incur less cost on the transition of data through the mobile network.
Transmission cost of data	(Shi et al. 2016; Shi and Dustdar 2016; Zhang et al. 2017)	Depending on the amount of data an IoT application requires to transmit towards the cloud, a certain cost for data transmission is incurred. By (pre)-processing data in close proximity to the user, data transfer towards the cloud might be reduced, thus lowering the transmission cost of data. A lower cost may increase the perceived value of the infrastructure.
Privacy requirements	(Premsankar, Di Francesco, and Taleb 2018; Satyanarayanan 2017; Yu et al. 2018)	An edge computing infrastructure can relieve some of the privacy concerns by (pre-)processing privacy sensitive data at lower (decentralized) level, before sending it to a centralized location. This means that IoT applications that are constituted contain of privacy sensitive data, might gain value from an edge computing infrastructure.
Security	(Ai et al. 2018; Satyanarayanan et al. 2009; Shi and Dustdar 2016; Yu et al. 2018)	Security on the edge is a double edged sword. Whereas on the one hand edge computing delivers better security as data processing is done closer to the source, on the other hand, the security on the edge nodes their selves is less advanced. This makes it easier to hack individual edge nodes, but makes it harder to breach the whole network of nodes. Therefore, for an IoT application, requirements on the level where security is needed could drive or block the choice for an edge infrastructure.
Context awareness	(Ahmed et al. 2017; Dolui and Datta 2017; Perera et al. 2014; Ren et al. 2015; Shi et al. 2016)	An edge computing infrastructure facilitates context awareness. Context awareness refers to additional data of sensors' context (e.g. location, environment, user, etc.). Whereas real-time context aware information is not sufficiently supported when data has to be sent to the cloud, an edge infrastructure could facilitate this. This especially relates to three main aspects: First, edge computing's capabilities to respond to context changes faster. Second, the possibility of context aware communication. Third, the analytics and the added contextual information that edge nodes can contribute. Therefore, for IoT applications that have benefit from this context-aware data, an edge infrastructure might be beneficial

Mobility Support	(Premsankar et al. 2018)	Edge computing can enhance the mobility support for IoT devices. IoT devices can either dynamically switch their task-offloading to the most suitable access point while mobbing around the mobile network, or an edge node could dynamically move with the IoT device in order to deliver constant task-offloading possibility. This is different from a static cloud computing data center which can only be accessed through a stable network.
Connectivity stability / reliability	(Ahmed and Ahmed 2016; Satyanarayanan 2017)	Unavailability of cloud offloading due to network failure, can be masked by operating crucial tasks at decentralized edge level. This may especially provide benefits in hostile environments, where proper end-to-end network quality is rather a luxury than a standard.
Energy constraints of devices	(Ha et al. 2014; Misra and Sarkar 2016; Premsankar et al. 2018; Taleb et al. 2017)	It has been found that the energy expended (Joule/query) for transmission of data to an edge node is significantly lower than for transmission to the cloud. This leads to lower energy consumption at the end-devices. This means that IoT applications that contain devices that are battery constrained could benefit from an edge infrastructure.
Delivered quality of service	(Bouwman et al. 2008)	The demanded value refers to the value that the service delivers towards the customer. For edge computing, the infrastructure's characteristics may be translated into technological functionalities. These technological functionalities then determine the delivered value.
Potential additional functionalities of edge that bring benefit to the target group	Informal talks	Next to the alignment of the perceived quality of service with the delivered quality of service (i.e. dependent on customers' infrastructure requirements), edge computing may deliver additional. More specifically, there are additional functionalities of edge computing that may not be directly linked to customers' infrastructure requirements, but have impact on the perceived quality of service, of the infrastructure .
Added value of Serverless	(Glikson, Nastic, and Dustdar 2017; Jonas et al. 2017, 2017, 2019; Lara et al. 2016)	Depending on the IoT application, substantial additional benefit may be generated by means of severless computing in the edge paradigm. This especially relates to the increased ease of use and the enhanced technological possibilities it may deliver.
Ease of Use	(Bouwman et al. 2008; Glikson et al. 2017; Jonas et al. 2017, 2019) + Informal talks	Serverless can enhance the ease of use. In turn the ease of use has a profound impact on the utility experienced by the users. Put differently, the ease of use is eventually related to the value as experienced by the customer. As the concept of serverless can deliver distinct value in an edge infrastructure, this could potentially impact the choice to go for edge vs. cloud.
Technological functionalities	(Bouwman et al. 2008; Jonas et al. 2017, 2019; Lara et al. 2016; Nastic et al. 2017) + Informal talks	Technological functionalities are directly delivered by the technical architecture. For edge computing, the concept of serverless may extent the edge-cloud interaction, delivering increased technical functionality. This benefit can be effectuated by combining the benefits of edge with the computational storage capabilities of cloud. The value that it delivers however depends on the respective IoT application.

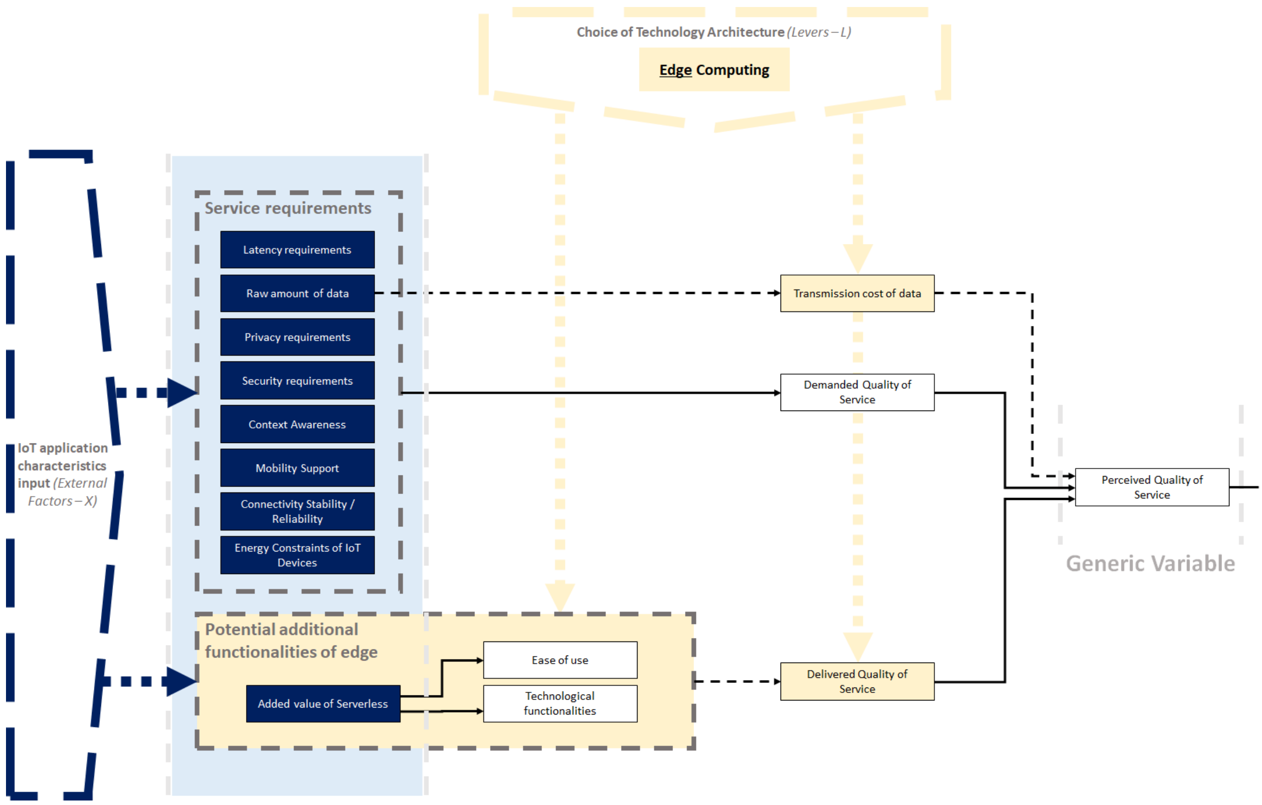


Figure 20: Graphical representation of variables that explain the perceived quality of service

5.1.2.2 Switching Costs

In section 3.2.1.4, edge computing was defined as a platform. Based on the identified literature of platform theory, two *platform characteristics* that vary per IoT application area, were then found to influence the customer value. More specifically, the *possibility of system integration with the previous offering* (i.e. with what customers currently have) and the *easiness of platform openness* influence the switching cost a customer incurs. These variables are explained more in-depth in Table 13. Figure 21 graphically displays the interactions of these variables.

Table 13: Contextual variables that explain the switching costs

Variable Name	Source	Explanation
Platform characteristics	(Bresnahan 1999)	An edge computing platform exhibits certain economic characteristics. These characteristics may impact the switching costs when a customer plans to migrate from the current service offering towards an edge computing infrastructure.
Possibility of system integration with previous offering	(Alshamaila, Papagiannidis, and Li 2013; Bouwman et al. 2008; Morgan and Conboy 2013)	The adoption of a service, which is in this case the edge computing service, can be partially determined by the extent it is- or can be integrated with the existing technical infrastructure. Subsequently, the extent to which an IoT application's current infrastructure can be integrated with the new edge infrastructure may impact the switching cost, in turn impacting the customer value.
Easiness for platform openness	(Benlian, Hilkert, and Hess 2015; Ondrus, Gannamaneni, and Lyytinen 2015) + informal talks	Platform openness is important for developers when they are considering to contribute to a platform or not. Therefore, it has substantial effect on complementors' satisfaction for the platform. It is expected that different IoT applications allow for different levels of openness on provider level and on technology level. Furthermore, enhanced platform openness could reduce the switching costs for users and foster innovation.

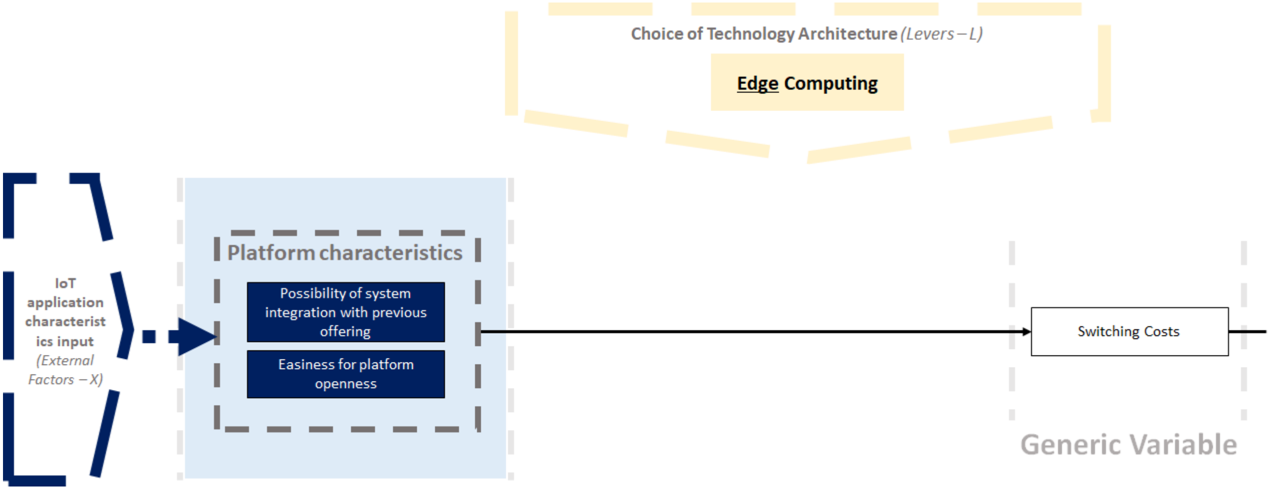


Figure 21: Graphical representation of variables that explain the switching costs

5.1.2.3 Customer base/revenue source

Based on literature from Bouwman et al. (2008), it is identified that a *market segment* has distinct properties. These properties in turn affect if there is an acceptable customer base (which provides the revenue source). They further state that the size of the maximum potential market and the current installed base are relevant market segment properties for assessing the customer base. Based on literature from Ai et al. (2018 and Yousefpour et al. (2019) it then becomes apparent that, in order to assess the potential customer base, it is also relevant to look at the % of data that is processed on the edge vs. cloud. Table 14 describes these variables more in-depth. Furthermore, the interactions explained in this section are graphically displayed in Figure 22

Table 14: Contextual variables that explain the customer base/revenue source

Variable Name	Source	Explanation
Market segment	(Bouwman et al. 2008)	Within consumer- and business markets, it Is possible to separate between market segments. Each market segment in turn has different properties and desires. Whereas on the one hand it is important to distinguish between market segment's needs, wishes and preferences, on the other hand the qualities of the market segment can be looked at. The market segment properties influence the extent to which an IoT application constitutes an acceptable customer base.
% of data on edge vs. cloud	(Ai et al. 2018; Yousefpour et al. 2019)	A typical edge architecture is hierarchical and thus collaborates/ federates with the cloud. One can understand that the cloud still has its own distinct advantages. Therefore it can be expected that the cloud paradigm will stay relevant as edge emerges. In order to determine the market size for edge computing in a certain IoT market, one should look at what percentage of data that will be processed at the edge vs. the cloud.
Size of maximum potential IoT market	(Bouwman et al. 2008)	One of the properties of the market segment is the size of the maximum potential of the market. For service providers of edge computing, it is mainly related to the potential of the IoT application that may use an edge computing infrastructure.
Current installed base of IoT application	(Bouwman et al. 2008)	Another one of the properties of the market segment is the current installed base. This includes customers that already have or use similar services or earlier versions of the service. In this case, the installed base is the part of the IoT application that may directly gain benefit from an edge computing infrastructure.

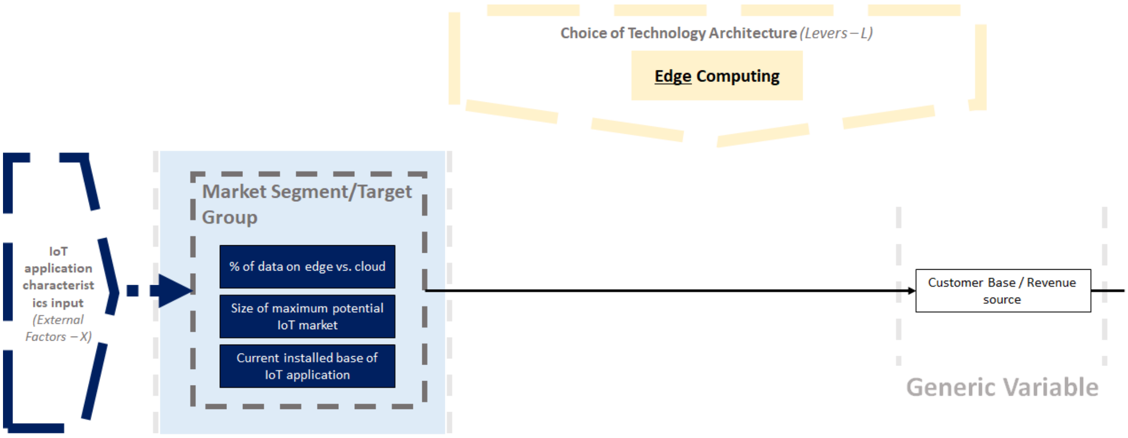


Figure 22: Graphical representation of variables that explain the customer base/revenue source

5.1.2.4 Relative cost

Literature on the cost generating mechanism for edge computing is scant. The only determinant that was explicitly stated in literature, is the *geographical coverage needed*. In informal talks it then became apparent that the geographical coverage has a non-linear effect on the relative cost. Initially (i.e. in small-scale solutions), edge computing can be delivered with a low relative cost. However, when edge computing is scaled up to larger solutions, the large amount of edge nodes results in a high relative cost. This hypothesis needs to be confirmed in the second design iteration in order to make it substantive. Table 15 and Figure 23 display how this translates to the tool.

Table 15: Contextual variables that explain the relative cost

Variable Name	Source	Explanation
Architecture cost generating mechanism	informal talks	The geographical coverage that is needed for roll-out, impacts the relative cost through the architecture cost generating mechanism. This mechanism describes the process how geographical coverage is translated in cost. No exact measure is given, however based on the explanation of geographical coverage needed, one can expect a higher cost will be incurred with large-scale roll-out.
Geographical coverage needed	(Beck, Werner, and Feld 2014) + Informal talks	One of the drivers behind the relative cost is the geographical coverage that is needed. Edge computing is distributed and localized. Therefore, a larger geographical coverage leads to more data centers that need to be placed in close proximity to the users and thus a higher cost. Furthermore, as the decentralized infrastructure expands, the system might get significantly more complex, thus increasing the relative cost. Lastly, the scale of implementation impacts the difficulty and cost of maintaining and operating the infrastructure. Different IoT applications might require different geographical coverage and thus the edge provider will incur different relative costs for rolling out the architecture.

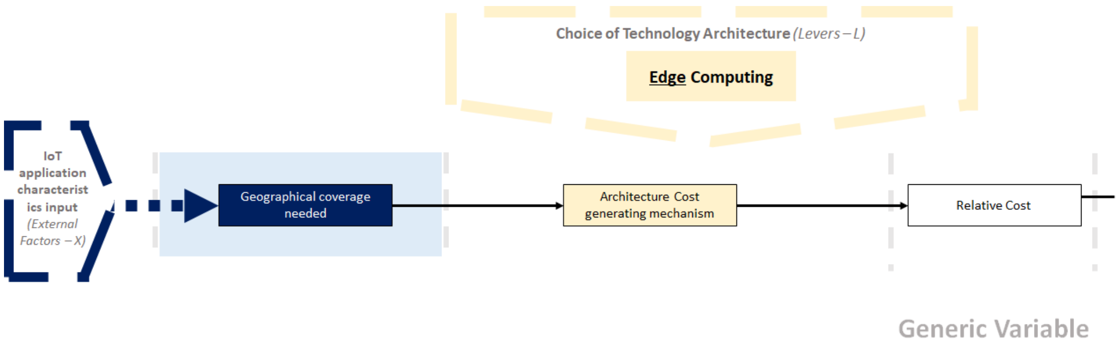


Figure 23: Graphical representation of variables that explain the relative cost

5.1.2.5 (Financial) risk

As indicated by Bouwman et al. (2008), risk is generated by *risk sources*. Currently, no explicit literature that describes risk sources for edge computing in distinct IoT application areas was found. Hence, variables that can be deduced from Bouwman et al. (2008) and from basic financial theory are used in order to draft initial hypothesis about relevant risk sources. It is important to validate the relevance of these variables as their relation with edge computing has not been described before. Furthermore, it is relevant to use the interviews in order to identify variables that are specifically applicable to edge computing. As explained in Table 16 and graphically displayed in Figure 24, it was found that the *maturity of the IoT application area* impacts financial risk. Furthermore, from basic financial theory, it was derived that a higher needed initial investment leads to higher capital commitment, in turn also impacting the risk. Lastly, based on informal talks it was deduced that the needed initial investment is mainly driven by the *geographical coverage* that is needed (i.e. a large scale roll-out requires potential providers to make large initial investments).

Table 16: Contextual variables that explain the (financial) risk

Variable Name	Source	Explanation
Risk sources	(Bouwman et al. 2008)	Risk sources are the generators of the respective financial risk. The variables underneath represent potential risk sources.
Maturity of IoT application	(Bouwman et al. 2008) + informal talks	Whether a business model contains acceptable risk or not is related to the uncertainty revolving around it. This uncertainty mainly relates to return on investment. One kind of uncertainty is generated by innovation and its related maturity. Technologies which are still a long way from maturity contain a lot of uncertainties about their potential trajectories. Subsequently, the maturity of an IoT application may impact the risk that edge providers take when targeting it.
Needed initial investment	(DeMarzo 2013) + Informal talks	A higher initial investment is related to higher capital commitment of a company. High capital commitment can be risky for the edge providers as it could put undue strain on their (other) financing activities and alternative investment. A higher initial investment and the related higher resource dedication, leads to a higher financial risk.
Geographical coverage needed	Informal talks	A bigger demanded geographical coverage leads to a higher amount of edge nodes that need to be installed on order to support it. A bigger demanded geographical coverage leads to a higher initial investment, thus increasing the needed initial investment.

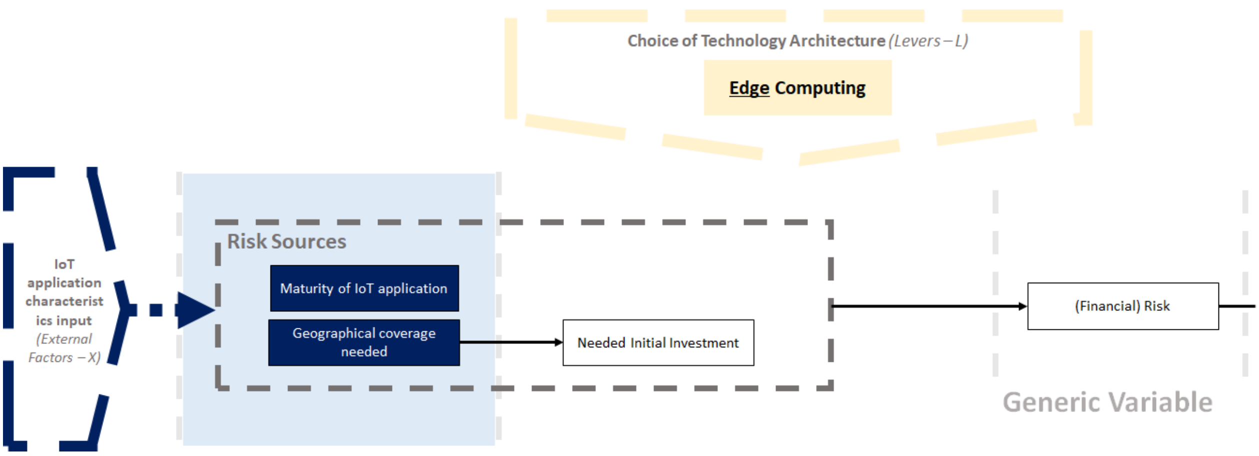


Figure 24: Graphical representation of variables that explain the (financial) risk

5.1.2.6 IoT application's ecosystem health

Based on theory from den Hartigh et al. (2006) and Iansiti and Levien (2002), specific ecosystem health measures are defined in Table 17. More specifically, Iansiti and Levien (2002) explain that ecosystem health can be measured by the three concepts; *diversity, productivity,* and *robustness*. den Hartigh et al. (2006) then argue that these concepts are not directly measurable. Building upon that, they conceptualize these concepts in measurable (financial) variables. They state ecosystem diversity is explained through the *variety of partners* (which can be measured by comparing company scales, reference value, etc.). *Productivity* can be measured by the *return on assets* and *total asset growth*. Lastly, *ecosystem robustness* is measured by the *liquidity ratio, amount of connections among partners,* and *creditworthiness*. Figure 25 graphically displays these interactions.

Table 17: Contextual variables that explain the IoT application's ecosystem health

Variable Name	Source	Explanation
Ecosystem health measures	(den Hartigh et al. 2006; Iansiti and Levien 2002)	There are several measures which can be used to indicate an ecosystem's health. Tracing these measures gives an estimate of the ecosystem health. The variables underneath display these measures.
Diversity / Niche creation	(Iansiti and Levien 2002)	The ecosystem participants should exhibit diversity, meaning it's participants should vary among each other. This characteristics allows ecosystems to enhance and develop their capabilities through innovation and integration. This would not be possible without a diverse subset of players. Diversity then enhances the value an ecosystem can bring.
Variety of partners	(den Hartigh et al. 2006)	In order to determine the diversity of an ecosystem, the variety of partners can be measured by comparing company scales, reference value or other related measures on which companies within an ecosystem may differ.
Productivity	(Iansiti and Levien 2002)	This concept relates to the efficiency of the ecosystem to convert inputs into valuable outputs. Furthermore, it is important that the productivity is not a one-time opportunity, but rather improves over time. For service providers of the edge this is an important indicator for ecosystem health, because it provides some hints about the future prospects for the IoT application.
Return on assets	(den Hartigh et al. 2006)	One of the factors that may indicate an ecosystem's productivity is the return on assets the ecosystem's participants enjoy. Generally speaking, the return on assets is a company's net income divided by their total assets.
Total asset growth / asset buildup	(den Hartigh et al. 2006)	Indicates how much the assets, on the balance sheet total, relatively grow. By comparing the total asset growth of multiple ecosystems, we can formulate an indication about their relative productivity.
Robustness	(Iansiti and Levien 2002) + informal talks	A healthy ecosystem will allow for survival for the firms populating it. The ecosystem robustness does not focus on the firms competing in similar markets, but rather focusses on firms that share common nodes. Ecosystems with higher robustness will generally exhibit a higher likelihood of surviving over time. Each IoT application has it's distinct ecosystem. For edge provider it may be important to look at the robustness of the IoT ecosystem in order to determine if he/she wants to enter this market. Furthermore, the robustness of an ecosystem may impact the (financial) risk an edge provider takes when focusing on an IoT application, as it partially describes the likely hood the ecosystem is able to pay for the infrastructure (i.e. based on the liquidity ratio and creditworthiness).
Liquidity ratio of participants	(den Hartigh et al. 2006)	This variable indicates the extent to which a company is able to meet its short term obligation. If companies in an ecosystem do not have sufficient liquidity, it could impact the overall robustness.
Amount of connections among partners	(den Hartigh et al. 2006)	Generally speaking, companies that have less connections throughout the ecosystem are less committed. This could result in companies leaving or switching between ecosystems. This could impact the overall robustness.

Creditworthiness of partners	(den Hartigh et al. 2006)	This indicates the likelihood of company participants within the ecosystem to default, and can be measured by the Z-score or Zeta model. If many companies in the ecosystem are likely to default, there is a potential of many participants leaving the ecosystem and thus a lack of robustness. This could lead to an unhealthy ecosystem.

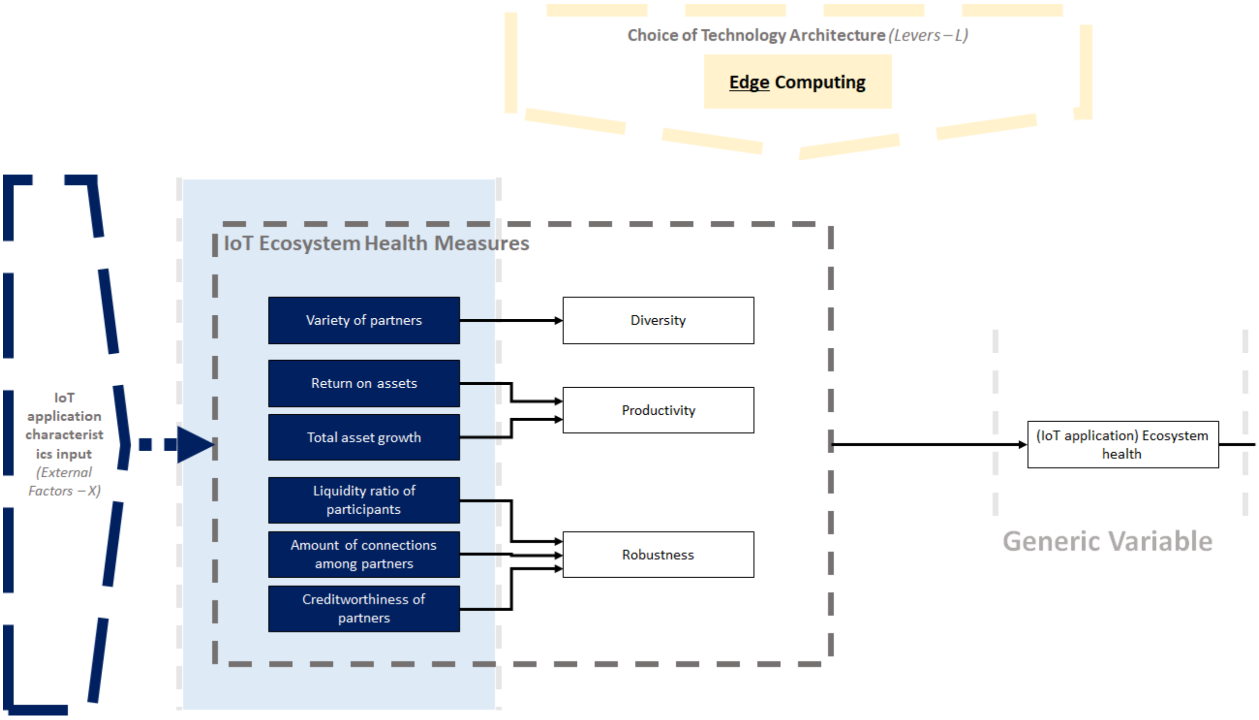


Figure 25: Graphical representation of variables that explain the IoT application's ecosystem health

5.1.3 Business model feasibility

Having derived which characteristics of IoT applications impact the business model viability of edge computing, the next step is to determine the variables impacting business model feasibility for rolling out an edge infrastructure for those IoT applications. As discussed in 3.2.3.2, whereas the business model viability relates to the question: *is there enough customer- and network value to make the service attractive?*, the business model feasibility is mainly related to the question: *is there a technically-, organizationally- and financially achievable solution to deliver the service?*. This description is aligned with the dimensions of the STOF model, which state that in order to deliver a service the technology, organization and financial domains should be feasible. In turn, the feasibility question that we ask ourselves *can we do it?*, is related to the complexity of their respective domains, meaning that in order to have a feasible service offering, one should look at the technological complexity, organizational complexity and the financial complexity. Table 18 provides an explanation about the three generic variables technical complexity, organizational complexity, and financial complexity impact the business model feasibility.

Table 18: Generic variables that explain the business model feasibility

Variable Name	Source	Explanation
Technical complexity	(Bouwman et al. 2008; Kräussl-Derzsi 2011)	In order to deliver the desired edge computing service, there should be a technologically achievable solution. Technical complexity impacts the extent to which an achievable solution can be effectuated. This implies that technical complexity has a profound impact on the business model feasibility.

Organizational complexity	(Bouwman et al. 2008; Kräussl-Derzsi 2011)	In order to deliver the desired edge computing service, there should be a organizationally achievable solution. organizational complexity impacts the extent to which an achievable solution can be effectuated. Hence, it impacts the business model feasibility.
Financial complexity	(Bouwman et al. 2008; Kräussl-Derzsi 2011)	In order to deliver the desired edge computing service, there should be a financially achievable solution. Financial complexity impacts the extent to which an achievable solution can be effectuated. This implies that financial complexity impacts the business model feasibility.

As displayed in Figure 26, in order to assess if a feasible business model of edge computing in an IoT application area can be established, one should analyze the *technical complexity*, *organizational complexity*, and *financial complexity*. Further explanation of these variables cannot be done in generic terms (i.e. it is dependent on contextual edge computing variables). Furthermore, these three variables are aligned with the vision of the STOF model, which explains that; in order to realize a service offering, the technical, organizational ,and financial domains, should be feasible. Hence, these variables constitute the generic variables that explain business model feasibility. Contextualization of these variables is done in the next sections.

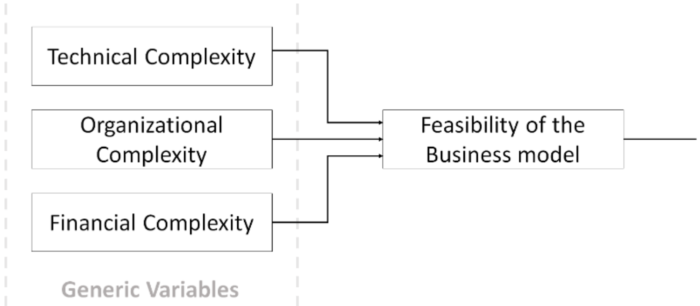


Figure 26: Feasibility of the business model is impacted by the technical-, organizational- and financial complexity

5.1.3.1 Technical Complexity

Based on literature review on edge computing, three main drivers for technical complexity were identified. As displayed in Table 19, the *geographical coverage*, *heterogeneity of devices and services*, and *standards in IoT application* impact the technical complexity. For geographical coverage, especially the increasing overhead, management, and orchestration issues, translate in technical complexities. Secondly, the heterogenicity of devices and services complexifies edge roll-out as allowed operations and data operation can vary, making integration of systems hard. Lastly, without standards, there is no means to integrate the heterogenous devices, in turn even further complexifying roll-out. These interactions are graphically displayed in Figure 27.

Table 19: Contextual variables that explain the technical complexity

Variable	Source	Explanation
Geographical coverage needed	(Beck et al. 2014; Olaniyan et al. 2018)	Larger edge computing infrastructures, with many distributed nodes, generally have to cope with exponentially increasing overhead, management and orchestration issues. Subsequently, the geographical coverage/scale of implementation affects the technical complexity involved with rolling-out an edge architecture.

Heterogeneity of devices and services	(Ahmed et al. 2017; Shi et al. 2016)	Due to the heterogeneity of IoT devices, allowed operations and data representation could vary. This could in turn increase technical complexity. The heterogeneity of devices and services can vary among different IoT applications and therefore the complexity related to that as well.
Standards in IoT application	(Ahmed et al. 2017; Bouwman et al. 2008)	In order to enable a properly working edge computing infrastructure, seamless integration of these heterogenous components is a prerequisite. In turn, standards can shield this complexity by simplifying communication between providers and requestors. Standards enhance the potential of collaboration and interoperability between systems. Therefore, a lack of standards could significantly impact the technical complexity for roll-out of an edge infrastructure.

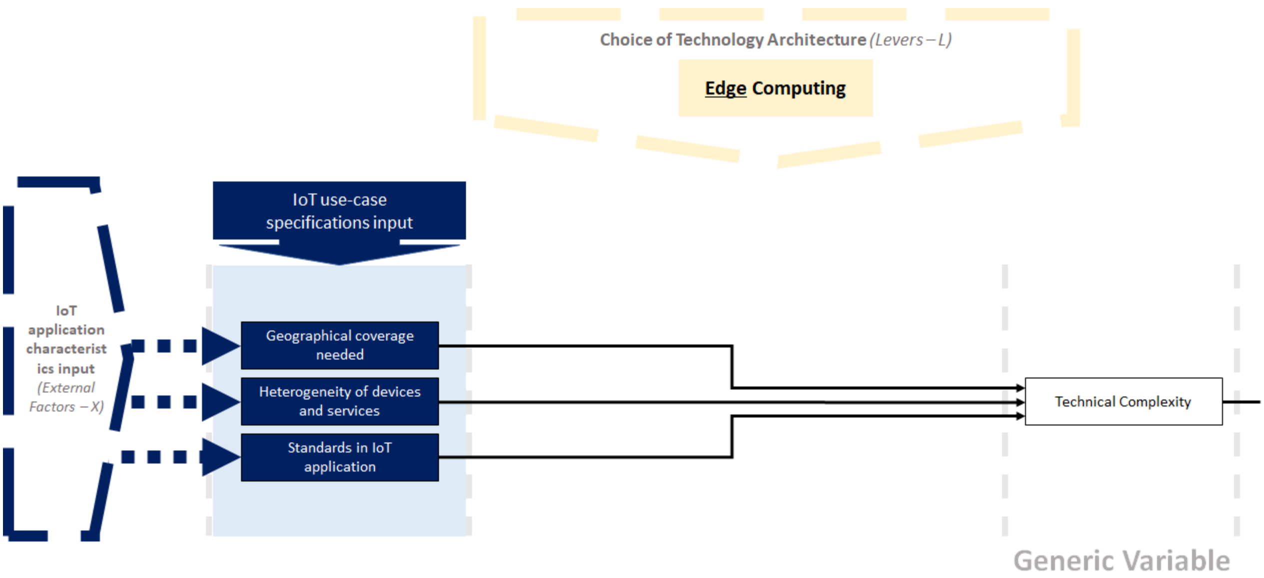


Figure 27: Graphical representation of variables that explain the technical complexity

5.1.3.2 Organizational complexity

No literature on contextual edge computing variables that influence the organizational complexity was available. Therefore, generic variables from the STOF model were translated towards the edge computing domain. Based on the STOF model, the *number of external partners* that are needed to roll-out the edge computing infrastructure in the focal IoT application area, and the *prior IT experience in the market segment* have been identified to influence the organizational complexity. As the relevance of these variables for edge computing has not been stated in literature, they should be validated. Also, it can be expected that the definitions of these variables need to be refined and that new variables will be found in the interviews. Table 20 provides a more elaborate explanation of these variables and Figure 28 graphically displays their interactions.

Table 20: Contextual variables that explain the organizational complexity

Variable	Source	Explanation
Number of External partners	(Bouwman et al. 2008)	The organizational complexity may increase because of the number of relationships a service provider has to sustain in order to roll-out an edge infrastructure. If, in order to roll-out of an edge infrastructure for a certain IoT application, the service provider has to sustain a huge number of relations, the stakeholder management might get difficult. On the other hand, if only a few connections are needed, the complexity is only moderate. Therefore, the number of external partners may impact the organizational complexity, depending per IoT application.

Prior IT experience in market segment	(Alshamaila et al. 2013; Bouwman et al. 2008)	The prior experience of customers for the IoT application may affect the organizational complexity. If the customer (which delivers the IoT service) does not have sufficient resources and capabilities, which can be; knowledge, people and systems, the roll-out of an edge infrastructure might get complex because these resources either have to be acquired or be built from scratch. Therefore, the prior IT experience in the market segment may impact the organizational complexity.

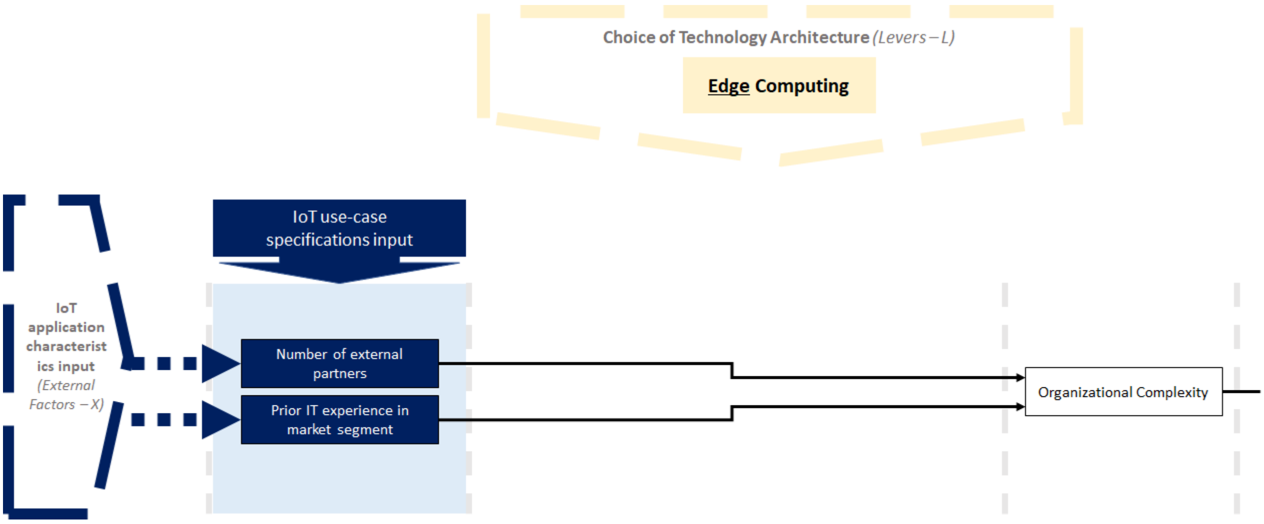


Figure 28: Graphical representation of variables that explain the organizational complexity

5.1.3.3 Financial complexity

Also for the financial complexity, no literature specifically indicates which edge computing variables are relevant. Therefore, the STOF model, basic financial theory, and informal talks were used in order to draft initial hypothesis on this behalf. This also implies that variables need to be validated in the interviews. Furthermore, it is expected that interviews will deliver new insights on financial complexity. As displayed in Table 21, a higher *needed initial investment* makes roll-out financially complex. This is because high initial investment makes it difficult to acquire the amount of money that is needed. The needed initial investment in turn is dependent on the *geographical coverage* of the edge infrastructure which an IoT application area requires. However, if the network of companies that roll-out the infrastructure can get *access to resources* of the IoT providers, the financial complexity can be decreased, as external monetary resources can be accessed. The amount of resources that can be accessed is however dependent on the *resources these IoT partners* have. These interactions are graphically displayed in Figure 29.

Table 21: Contextual variables that explain the financial complexity

Variable	Source	Explanation
Needed initial investment	(DeMarzo 2013) + Informal talks	A higher initial investment is related to higher capital commitment of a company. The larger the lump sum of money needed for the initial investment, the more complex it gets to arrange the financial activities . The department rolling-out the edge infrastructure may not get sufficient funds, or the company in general may not have enough fund to cover the full initial investment. Therefore, the needed initial investment may impact the financial complexity.
Geographical coverage needed	Informal talks	A bigger demanded geographical coverage leads to a higher amount of edge nodes that need to be installed on order to support it. A bigger demanded geographical coverage then leads to a higher initial investment.

Access to resources	(Bouwman et al. 2008) + informal talks	In partner selection, it is important to consider if it is possible to gain access to external resources. As different IoT application consists of different ecosystem player, the financial resources that can be accessed may differ considerably. Co-investment and co-ownership financing structures are part of the potential financial arrangements. These arrangements can however only be attained if the IoT application's ecosystem players have sufficient resources. Therefore, the access that is gained through this ecosystem may impact the financial complexity.
Resources of IoT partners	(Bouwman et al. 2008) + informal talks	In order to get access to resources, the first prerequisite is that these partners are in possession of sufficient financial resources. Therefore, the IoT ecosystem's players and their corresponding resources may impact the potential access to resources for a service provider.

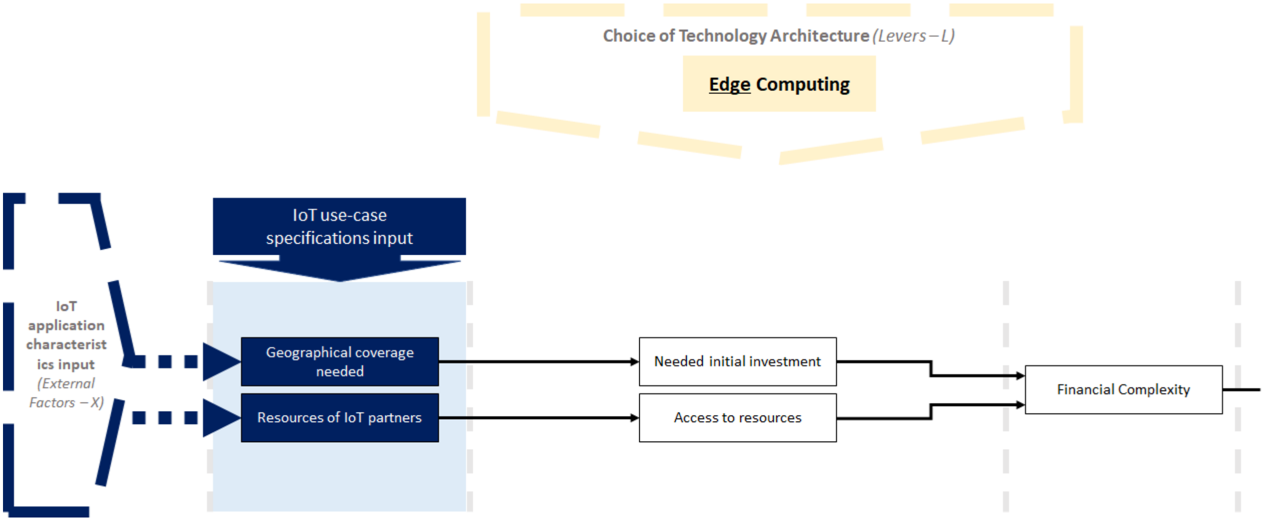
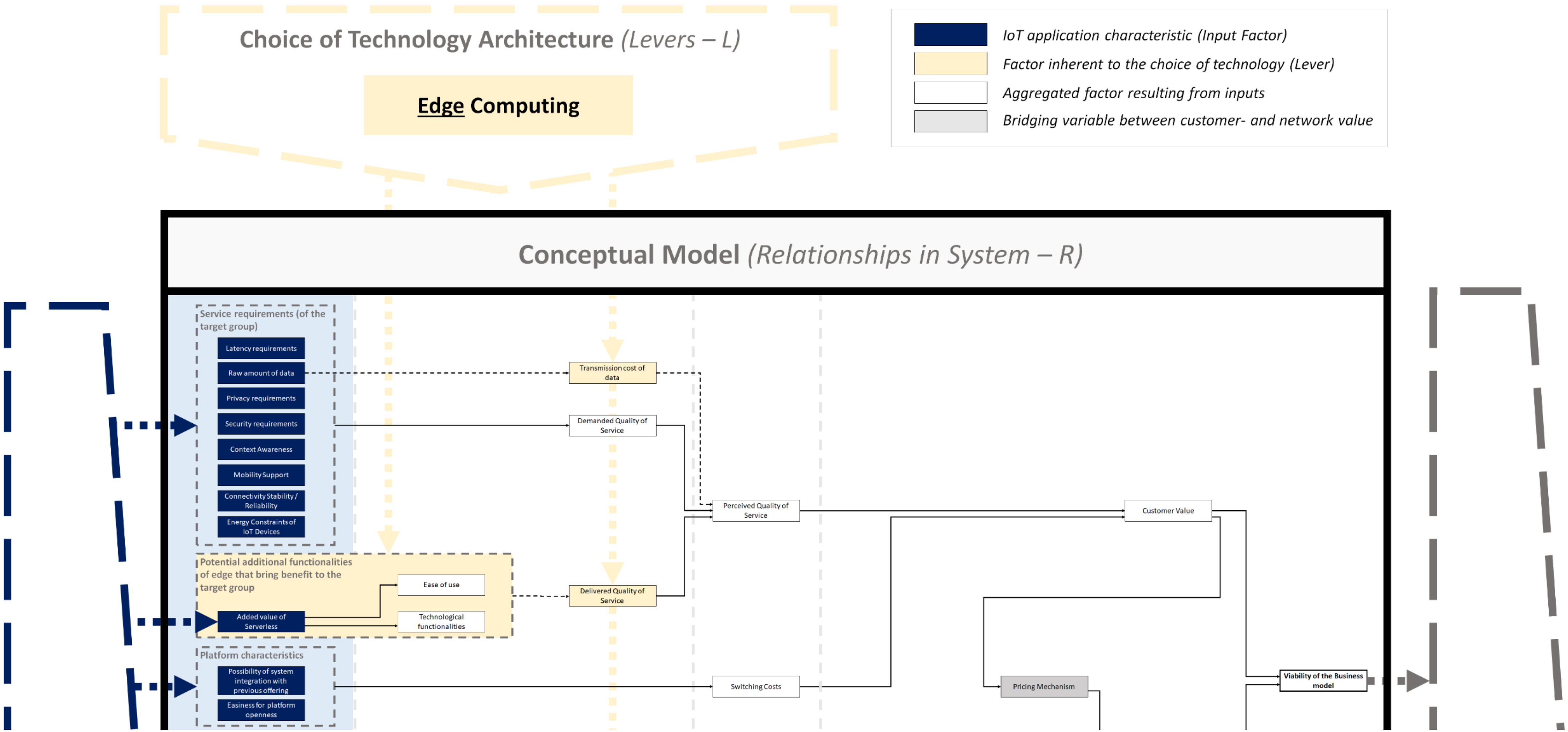
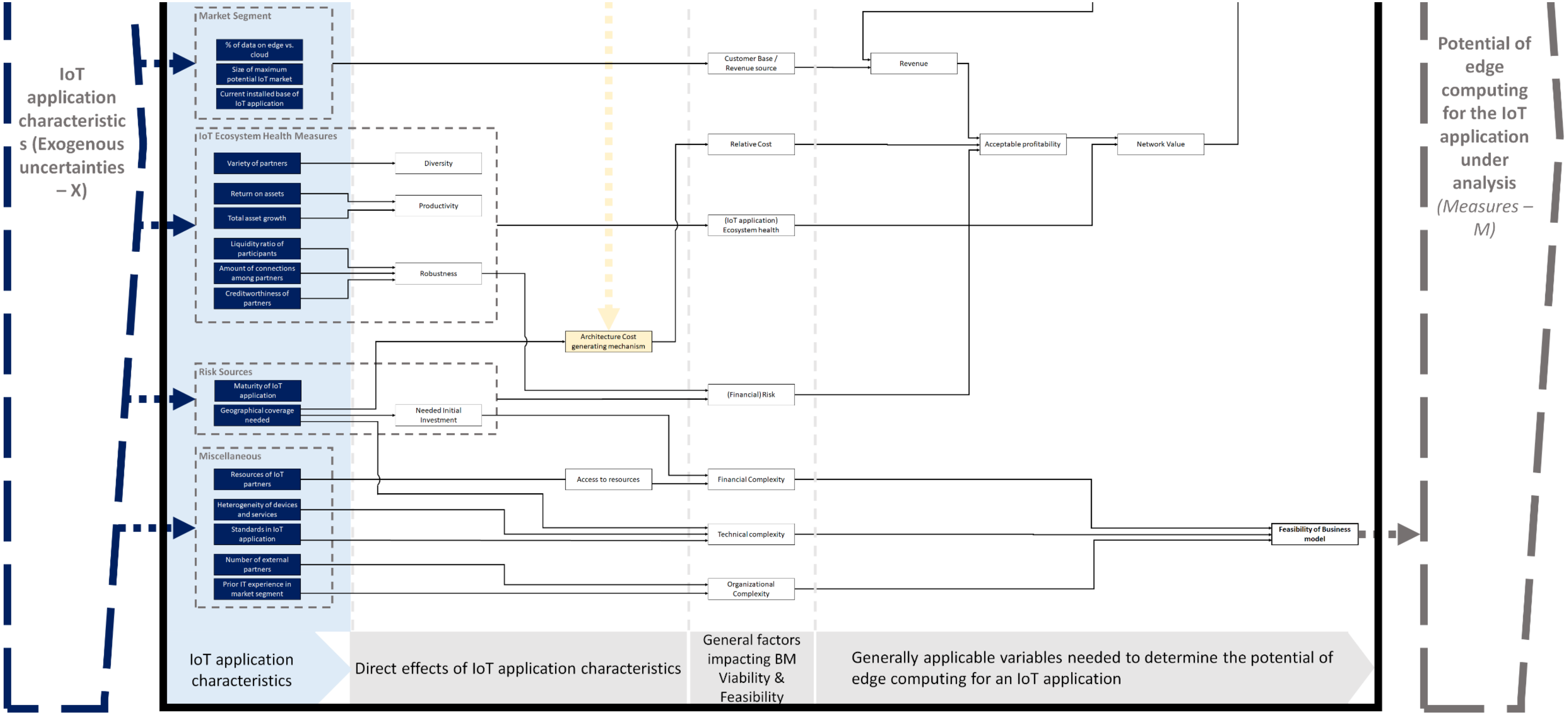


Figure 29: Graphical representation of variables that explain the financial complexity

5.2 Tool 1.0



Choice of Technology Architecture (Levers – L)
Edge Computing
IoT application characteristic (Input Factor)
Factor inherent to the choice of technology (Lever)
Aggregated factor resulting from inputs
Bridging variable between customer- and network value
Conceptual Model (Relationships in System – R)
Service requirements (of the target group)
Latency requirements
Raw amount of data
Privacy requirements
Security requirements
Context Awareness
Mobility Support
Connectivity Stability / Reliability
Energy Constraints of IoT Devices
Transmission cost of data
Demanded Quality of Service
Perceived Quality of Service
Customer Value
Potential additional functionalities of edge that bring benefit to the target group
Ease of use
Added value of Serverless
Technological functionalities
Delivered Quality of Service
Platform characteristics
Possibility of system integration with previous offering
Easiness for platform openness
Switching Costs
Pricing Mechanism
Viability of the Business model



IoT application characteristics (Exogenous uncertainties – X)
Market Segment
% of data on edge vs. cloud
Size of maximum potential IoT market
Current installed base of IoT application
IoT Ecosystem Health Measures
Variety of partners
Return on assets
Total asset growth
Liquidity ratio of participants
Amount of connections among partners
Creditworthiness of partners
Diversity
Productivity
Robustness
Risk Sources
Maturity of IoT application
Geographical coverage needed
Needed Initial Investment
Miscellaneous
Resources of IoT partners
Heterogeneity of devices and services
Standards in IoT application
Number of external partners
Prior IT experience in market segment
Architecture Cost generating mechanism
Access to resources
Customer Base / Revenue source
Relative Cost
(IoT application) Ecosystem health
(Financial) Risk
Financial Complexity
Technical complexity
Organizational Complexity
Revenue
Acceptable profitability
Network Value
Feasibility of Business model
IoT application characteristics
Direct effects of IoT application characteristics
General factors impacting BM Viability & Feasibility
Generally applicable variables needed to determine the potential of edge computing for an IoT application
Potential of edge computing for the IoT application under analysis (Measures – M)

5.3 Conclusion

The most suitable way of structuring the tool is found in the XLRM model, where the variables: IoT application characteristics (Exogenous uncertainties – X), the choice of technology architecture for edge computing (Policy lever – L), the conceptual model that explains the relations between the choice of technology and the IoT application characteristics (relationships in system – R), and the potential of edge computing for the IoT application under analysis (Measure – M), are grouped according to the XLRM structure.

It is concluded that assessing the business model viability and feasibility provides us with an answer about the business potential of edge computing for an IoT application. Business model viability is explained through the six generic variables; perceived quality of service, switching costs, customer base/revenue source, relative cost, (IoT application) ecosystem health, and (financial) risk. Business model feasibility is dependent on the three generic variables; financial complexity, technical complexity, and organizational complexity.

Based on literature review, contextualization of these nine generic variables towards the edge computing domain tells us that they are dependent on 27 exogenous uncertainties (i.e. IoT application characteristics). Main conclusions derived from this contextualization are:

<u>Business model viability</u>

- **Perceived quality of service:** is dependent on service requirements of the customer, such as; latency, raw amount of data, privacy, security, among others. Also the additional functionalities that serverless computing can contribute to edge computing influences the perceived quality of service.
- **Switching cost:** Possibility of system integration with previous offering and easiness of platform lower the switching cost for customers.
- **Customer base/revenue source**: The attractiveness of the customer base is assessed by looking at the % of data that is processed on the cloud vs. the edge (i.e. this describes the amount of data that constitutes the edge computing market), the maximum future potential of the IoT market, and the current installed base of the IoT application.
- **Relative cost**: The main driver for the relative cost of an edge infrastructure is the geographical coverage that is needed/the size of the total infrastructure.
- **(IoT application) ecosystem health**: An indication about the ecosystem health is formulated by assessing the diversity, productivity, and robustness, of the ecosystem that delivers the IoT application under analysis.
- **(Financial) risk**: Is dependent on the needed initial investment, the ecosystem robustness (i.e. how likely are customers to pay back your investment), and the maturity of the IoT application.

<u>Business model feasibility</u>

- **Financial complexity:** The main driver for this variable is the needed initial investment (i.e. higher investment increases financial complexity). Complexity is reduced if sufficient access of resources from IoT providers is possible.
- **Technical complexity:** Is mainly dependent on the heterogeneity of devices and services. Generally accepted standards in the IoT application make roll-out technically less complex.
- **Organizational complexity:** The number of external partners increases organizational complexity. Also a lack of IT experience from IoT providers makes roll-out organizationally complex.

Together, the variables identified in this chapter constitute an initial hypothesis about a tool that assesses the potential of edge computing for IoT applications.

6 Interview protocol

After having derived the first version of the tool from literature and informal talks, the next step is to validate the variables, test its comprehensiveness, and determine missing factors. Then, after refining the tool based on interviewees' input in Chapter 7, the tool is demonstrated on a case in Chapter 8. This Chapter describes the protocol which allows for rigorous validation and demonstration of the designed tool. Sections are divided into a description of the interview protocol (6.1), a description of the interviewee selection (6.2), and an explanation about the chosen method for determining the relative importance of the generic variables (6.3).

6.1 Interview protocol

Having drafted an initial model in Chapter 5, the interviews are targeted at fulfilling four objectives: First, the identified factors should be validated on their relevance and applicability. Second, the interviews should help in identifying new factors that have not been included during the first draft of the conceptual model. Third, the interviews should test the comprehensiveness of the generic factors of the tool and deliver input for ranking their relative importance. Only the generic factors will be ranked on their relative importance, as it is expected that the collection of them suffices in answering the main question. The contextual factors will not be ranked, as it cannot be expected that these are comprehensive based on the first design phase. Lastly, the interviews should allow for input on how the factors interact to the IoT chosen IoT application (see section 8.1 for a more elaborate explanation about this). Emphasis is however placed on refining the tool (based on interviewees input) as this is expected to provide the biggest contribution for in this stage of research.

In order to fulfill these four objectives, one round of semi-structured interviews was conducted. This means data for the second design iteration and for the demonstration phase are collected in one round of interviews. As the outset about what information needs to be acquired through the interview is known, a semi-structured method ensures that all relevant objectives are covered. On the other hand, this method allows to adjust questions depending on the experience and knowledge of interviewees. Based on the interviewees' input, the researcher may ask other relevant questions that are not directly stated in the interview protocol. The semi-structured interview allows for refinement of the interview process during the entire interviewing phase. Especially in the explorative part, where the interviewee is asked to indicate other relevant factors, the process should be open in order to allow the richest range of input.

A visual aid of the tool was used during the interviewing process in order to ensure rigorous discussion. As the researcher is aware that the full conceptual model overloads the interviewee with information, the tool was restructured for the interview. As can be seen in appendix A.2, the conceptual model was first divided into two parts; the research model (which is relevant for the interview), and the generic part (which is relevant to derive to the final outcome, but does not have to be interviewed). The research model is then divided into 10 boxes. The first 9 boxes represent how the contextual variables, relevant for edge computing, impact the generic factors. These 9 boxes are used in order to fulfill interview objectives 1, 2 and 3, which aim to validate the relevance of the contextual factors, identify new contextual factors that are not drafted in the initial design, and describe how these factors apply to the chosen use-case. The 10th box contains a list of the nine generic factors and is used to fulfill the third interview objective, which is to test the comprehensiveness of these factors and rank their relative importance. During the interview process, the 10 boxes are ticked-off one-by-one (from 1 to 10).

<u>The interview protocol includes six elements:</u>

1. **Explanation of the tool purpose, use and environment (throughout the whole interview):** Before asking concrete questions to the interviewee, the tool's purpose, use and environment are elaborated and the interviewee is asked if there are any unclarities regarding the tool. Furthermore, for each variable that is included in the tool, a short explanation is provided. This step is aimed at reducing inconsistencies due to misunderstandings.

2. **Validation of identified constructs (box 1-9):** This step is dedicated towards validating if all variables that have been identified in the design phase, are of relevance for determining the potential of edge computing for IoT applications. This step helps get a better understanding about how industry practitioners perceive the relevance these factors and to remove irrelevant factors.
    - Question: Do you think IoT specification variable X (contextual factor) could have impact on factor Y (generic factor) for edge computing in general?
    - Used in: Chapter 7- Second design iteration
3. **Discussion on other variables that might be of relevance (box 1-9):** This step allows new input for the tool. As this is the first model in this research direction for edge computing, it cannot be expected it is comprehensive based on the initial design phase. Therefore, this step will both give hints bout about the comprehensiveness of the designed model and allow for input of new variables. Interviewees' input in this step (combined with step 2) is used to draft a second version of the conceptual model.
    - Question: Are there missing variables in this part of the tool, and if so, which ones?
    - Used in: Chapter 7 – Second design iteration
4. **Application of the tool to IoT use-case (box 1-9):** After validating the general relevance of the factors, it's interaction with the chosen IoT application is asked. Note that this part will only be conducted with interviewees which have in-depth knowledge about the chosen IoT application. An explanation of the chosen IoT application can be found in section 8.1.
    - Question: How do you think that IoT specification variable X (contextual factor) interacts with factor Y (generic factor) of edge computing for the chosen IoT application?
    - Used in: Chapter 8 - Demonstration
5. **Relative ranking of input variables (box 10):** This step involves checking the comprehensiveness off- and ranking the generic (9) factors by means of a multi-criteria decision-making method, which is further explained in section 6.3.
    - Question method depends on the chosen multi-criteria decision-making method, see section 6.3 for the range of questions that should be asked.
    - Used in: Chapter 7 – Second design iteration
6. **A swift recap and conclusion in order to confirm the interpretations (throughout the whole interview):** In order to minimize bias due to misunderstandings of either the interviewee or the interviewer, interpretations and are recapped.

As the interview intents to cover a large range of topics and questions, the duration of the interviews was 1.5 hours. This suffices in fulfilling the four objectives while not asking an exceptionally high investment of time by the respondents. During the interviews, the main focus is to refine the tool (i.e. the first three interview objectives). Therefore, in case of time constraints, the fourth interview objective is touched upon in lesser detail. Lastly, all interviews are recorded, transcribed and attached in the thesis report (see appendix A.7) in order to ensure trackability, repeatability and add rigor to the research (Sekaran and Bougie 2010). Note that the 5^{th} element of the interview protocol (fulfilling the third interview objective) is not transcribed as this encompasses a quantitative assessment and/or yes-no answers. It is not relevant to transcribe such quantitative assessments, as it does not leave room for different interpretations.

6.2 Interviewee selection

As edge computing is a relatively new paradigm and research in its application areas is still in its infancy, there is only a limited group of people that can supply the required information. Therefore, though restricted in generalizability, judgment sampling is the most suitable sampling design. Judgment sampling refers to the process where subjects are selected based on the basis of their expertise in the subject under investigation. For an industry expert to be suitable, the prerequisite is that he should at least have conducted one concrete business project on edge computing in the IoT domain. In the judgment sampling process, the relevant target groups and corresponding experts in their respective area should first be identified. As second step, the researcher determines which subset of this group is available for interviewing. It is important that the selected interviewees reflect the diversity of the entire population (Sekaran and Bougie 2010). In order to meet these requirements, the diversity of players that are involved in the edge computing ecosystem should be interviewed. Especially the players that are directly related to providing or using the edge infrastructure should be interviewed. In Figure 30, these players are marked with a light gray color. Lastly, in order to enrich the input of new variables that are not included in the initial conceptual model (interview objective 2), people with different professional positions and positions within the respective firms should be interviewed.

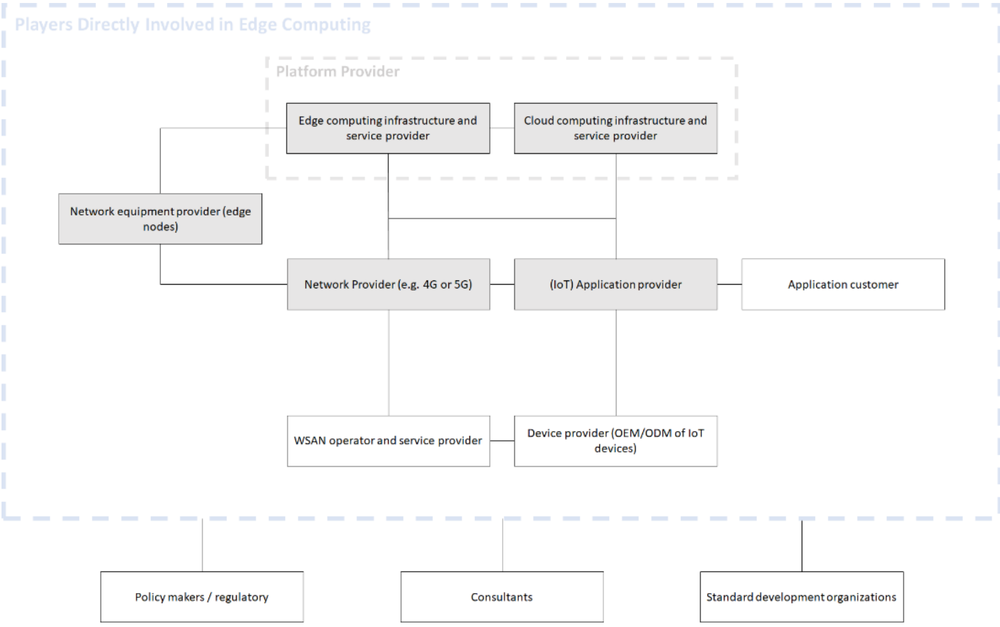


Figure 30: Company types that should be interviewed

Table 22 displays an overview of the types of companies that have been interviewed and the professional roles that interviewees had (this is derived from Table 33 in appendix A.7). Some of the interviewee's companies serve two roles in the edge ecosystem (e.g. being both network equipment provider and network provider). These companies have been counted as interviewed company type for both roles. Table 22 displays that the company types that were marked light gray in Figure 30, have all been interviewed two or more times. Based on that, we conclude that the diversity of ecosystem players is sufficiently covered. The table also displays that the interviewed experts mostly hold different positions within the company. This confirms that the second sampling criteria (i.e. diversity of respondents within the firm) is met as well.

Table 22: Interviewed company types and professional roles of respondents

Interviewed company types	Amount	Interviewed professional roles	Amount	Country	Amount
Network provider	3	Principal researcher	1	Netherlands	5
Network equipment provider	2	Director	1	Germany	3
(IoT) application provider	3	Business development manager	1	Poland	1
Consultant	3	Senior manager	2	America	1
Edge and Cloud platform provider	4	Ecosystem manager	1	India	1
		Manager	2		
		Product manager	1		
		Partner development manager	1		
		Partner technical strategist	1		

Respondents for the interviews were contacted through e-mail or LinkedIn. The contacts were recruited through the researcher's own network, EY's network, and from the first supervisor's (TU Delft) network. In the recruiting process, a 30 minutes call was conducted in order gauge the interviewees' knowledge on the related domain, introduce the interviewee in the research topic, and raise interest. All eleven interviewees meet the prerequisite that they have concrete project experience with edge computing for IoT (see Table 33 in appendix A.7). After confirmation of the interviewees' willingness to participate, the documents enumerated underneath were sent as preparation material and the interviewee was expected to take 15 minutes to get an understanding of the big picture:

- **The conceptual model (2 pages):** Page one includes the complete conceptual model as drafted in the initial design phase. Page two includes the conceptual model chopped down into the 10 respective boxes (see appendix A.2). Page 1 allows the interviewee to get a full understanding of the tool, page 2 is used to conduct the interview.
- **The interview protocol (3 pages):** Including the research's background, purpose, main question and the step-by-step interview protocol (including example questions).
- **Appendix (5 pages):** Purely additional information for the interviewee. In case of unclarities regarding the variables of the tool, definitions are provided in this document. On the other hand, if there are unclarities regarding the multi-criteria decision-making method, a general description of the method is provided in this document.

6.3 The best-worst multi-criteria decision-making method

In order to structure the process of determining the relative importance of the generic factors and thereby fulfill interview objective 4, a multi-criteria decision-making (MCDM) method is selected. For this thesis research, the best-worst multi-criteria decision-making method, or best-worst method (BWM) has been identified to deliver a distinct advantage because of two main reasons: First, BWM has been found to perform significantly better than other MCDM methods such as Analytic Hierarchy Process (AHP) or other related methods. Second, the BWM requires significantly less input, and thus requires less time to conduct, than other MCDM methods.

The BWM, has been proposed in the paper of Rezaei (2015). This MCDM model is built on the premise that decision-makers often experience difficulties in expressing the preference strength. According to Rezaei (2015), these difficulties are the main source of inconsistency for other MCDM models. Along these lines, a distinction can be made between two categories of pairwise comparisons:

- Reference comparison: Comparison a_{ij} is defined as a reference comparison if I is the best element and/or j is the worst element (Rezaei 2015. pp 51). This means that a reference comparison involves a comparison of the best element vs. the worst element, a random element vs. the best element, or a random element vs. the worst element.
- Secondary comparison: Comparison a_{ij} is defined as a secondary comparison if I nor j are the best or worst elements and $a_{ij} \geq 1$ (Rezaei 2015. pp 51). Put differently, this involves a comparison of two elements without the reference of the best- and/or worst variable. Furthermore, $a_{ij} \geq 1$ indicates that the elements are not equally ranked (i.e. one element is more important than the other).

Whereas, the execution of secondary comparisons is based on the reference comparisons, it has been found that these secondary comparisons are more difficult to execute for decision-makers. Subsequently, this leads to a less accurate model. The BWM, however starts from the philosophy that it is possible to mathematically deduce the relative importance from reference comparisons, without carrying out secondary comparisons. By doing so, the BWM has found to be performing significantly better than other MCDM methods such as AHP. Furthermore, the BWM requires fewer comparisons than other MCDMs as it only relies on reference comparisons.

In order to derive at the relative weights of the criteria under evaluation, the can BWM is executed in five steps:

1. **Determine a set of decision criteria:** This set of attributes involves the array of criteria $\{c1, c2, \dots, cn\}$ that constitutes the decision-making problem.
2. **Determine the best and the worst criteria:** From the set of decision criteria, the decision-maker specifies the most important/most desirable criteria (best) and the least important/least desirable (worst) criteria. This step does not involve any comparison.
3. **Determine the preference of the best criterion over all other criteria using a number between 1 and 9:** When the decision-maker ranks $a_{Bj}= 1$, it indicates the best criteria is a little bit more important, when the decision-maker ranks $a_{Bj}= 9$, it indicates the best criteria is extremely more important. This process results in a Best-to-Others vector which can be denoted as: $A_B= (a_{B1}, a_{B2}, \dots, a_{Bj})$.
4. **Determine the preference of all criteria over the worst criterion using a number between 1 and 9:** The same process is repeated, but then indicating the preference of other criterion on the least important/least desirable criterion. The resulting Others-to-Worst factor can be Denoted as: $A_W= (a_{W1}, a_{W2}, \dots, a_{Wj})$.
5. **Find the optimal weights ($w^*_1, w^*_2, \dots, w^*_n$):** The weights for the criteria should be optimized in such that the maximum absolute differences $|\frac{wb}{wj} - a_{Bj}|$ and $|\frac{wj}{ww} - a_{jW}|$ is minimized for all j. This equation can be solved by considering the non-negativity and sum condition for the weights as: $\min_j max\{|\frac{wb}{wj} - a_{Bj}|, |\frac{wj}{ww} - a_{jW}|\}$ AND $\sum_j Wj = 1$ AND $Wj \geq 0$, for all j

By applying these five steps of the BWM on box 10 (see appendix A.2), interview objective 4 is fulfilled.

The BWM may either be executed in a non-linear maxmin model, where the result could display multiple optimal solutions (Rezaei 2015), or in a linear maxmin model, which may be used to deduce an unique solution (Rezaei 2016). This research aims to derive to an unique weight for each of the (9) generic factors. This means that an unique solution is sought for, making the linear BWM method suitable.

Next to providing the relative importance of the tool's factors, the BWM also provides a consistency indicator ξ^{L*}. This consistency indicator intends to check if the pair-wise comparisons (of the Best-to-others and the others-to-worst factors), made by the respondents, are consistent. Inconsistent pair-wise comparisons lead to an inconsistent comparison matrix, making results unreliable. A closer value of ξ^{L*} to 0, indicates a more consistent pair-wise comparison. A comparison is fully consistent when $a_{Bj} * a_{jW} = a_{BW}$, where; a_{bj} Is the best to others vector, a_{jw} is the others-to-worst factor, and a_{bw} is the best-worst factor. Based on the consistency indicator, and the consistency index, the consistency ratio can then be calculated by: $Consistency\ ratio = \frac{\xi L*}{Consistency\ index}$. The value of the consistency index depends on the different values of a_{BW}. The consistency ratio ranges from 0 to 1, where values close to 0 display highly consistent results, and values closer to 1 display results with poor consistency. The consistency ratio is taken into account in order to indicate the reliability of the results.

6.4 Conclusion

It is concluded that semi-structured expert interviews provide the best means to gather data. With the time and resource constraints of this thesis, in order to ensure a sufficient amount of interviewees for each objective, data is gathered in one round of interviews (i.e. cross-sectional data collection). The eleven interviewees sufficiently cover different ecosystem players and managerial roles within the company, in order to display the variety within the edge computing ecosystem. Lastly, as displayed in Table 23, four interview objectives are required in order to redesign and demonstrate the framework so that it meets the design objectives drafted in Chapter 4.

Table 23: Overview of the interview protocol

Interview type	**Semi-structured expert interviews**
Interview strategy	Confirmatory and exploratory
Method	- Semi-structured questions guided by visual aid of conceptual model. - One round of interviews for second design iteration and demonstration
Amount of interviewees	11
Duration	1.5 hours
Objectives	Objective 1: Validating if all contextualized factors (identified from literature review and informal talks) are of relevance in order to determine the business model viability and feasibility. Objective 2: Gathering input on other contextual factors that are relevant but are not included in the tool yet. Objective 3: Testing generic factors on their comprehensiveness, and ranking their relative importance in determining the potential of an IoT application for edge computing. This needs to be done by means of the best-worst multi-criteria decision-making method (Rezaei 2015, 2016). Objective 4: Gathering input (from the interviewees which have an in-depth understanding of the chosen IoT application) about how the factors interact with the chosen IoT application, which is predictive maintenance .
Input	- The business potential identification tool for edge computing (Version 1.0) adjusted for the interviews (see appendix A.2) - Semi-structured questions
Output	- Confirmation of the contextual factors that were drafted in the first design phase. - New, unidentified contextual factors. - Description of the interaction of the contextual factors with the chosen IoT use-case - Confirmation of the comprehensiveness of the generic variables - Ranking of the importance of the generic variables.
Interviewees	Edge computing experts and IoT use-case specific experts involved in the edge computing ecosystem.

7 Design Phase 2 – based on input of the semi-structured expert interviews

Having drafted a hypothetical conceptual model in the first design phase (Chapter 5) and having gathered information from industry experts (appendix A.7), the next step is to integrate this new information and re-design the conceptual model. In this second iteration of the design phase, the semi-structured interviews suffice as input for re-design of the conceptual model. The four interview objectives, which were drafted in Chapter 6.1, aim to enhance the conceptual model's capabilities to meet the design objectives, as described in Chapter 4. Hence, section 7.1 describes the data analysis process, the outcome of the BWM, and the suggestions for improvement that have been identified. Section 7.2 displays the final model and provides an explanation for each variable's relevance and interactions. Lastly, section 7.3 unfolds the user guidelines of the tool, including a description of the tool's purpose, environment of use and a 10-step method by which the tool should be applied.

7.1 Data analysis

As discussed in the interview protocol (Chapter 6.1), the interviews contain a qualitative and a quantitative part. For the qualitative part (covering interview objectives 1-3), conversations have been recorded and transcribed (see appendix A.7 for transcripts). The qualitative data analysis process and outcomes are explained in section 7.1.1. The quantitative part (covering interview objective 4) unfolds in section 7.1.2.

7.1.1 Qualitative data analysis

The aim of qualitative data analysis is to make valid inferences from the large amounts of qualitative data that is available (Sekaran and Bougie 2010). According to Miles and Huberman (1994), the three general steps in qualitative data analysis are data reduction (selecting, coding and categorizing data), data display (selection of quotes, a matrix, a graph, etc.), and the drawing of conclusions. The process of qualitative data analysis is not a linear process, instead it is a iterative process where ideas and initial conclusions emerge and change during analysis (Sekaran and Bougie 2010).

The reliability of qualitative research is for a large extend about the category reliability. In turn, the category reliability depends on the extent to which the researcher is able to formulate categories that accurately select which items fall under that category (Sekaran and Bougie 2010). Whereas electronic coding is the most widely used approach to translate interview transcripts into sensible information, for this research a different coding strategy is chosen. In order to enhance the researcher's capability to accurately formulate and place codes within the context of the tool, a manual coding process is followed. Coding qualitative data manually may enhance the researcher's control and ownership over the work (Saldaña 2016). By means of stickers, key concepts of interviewees' remarks are placed on a hard-copy of the conceptual model (which has been drafted in design phase 1). This allows the researcher to move and group the stickers among the nine generic factors that influence the potential of edge computing for an IoT application.

Figure 31 displays an illustrative example of the data analysis process for the generic variable *organizational feasibility*. Interviewees' suggestions are extracted from the transcripts, and underlined parts of the quotes are generalized towards a category. These categories (i.e. light blue boxes in the figure) are the stickers that are attached on the tool's hard copy. Stickers have been renamed, merged and distributed over different generic variables multiple times. Figure 31 displays the digitized outcome of this iterative coding process for organizational feasibility. One can observe multiple remarks of interviewees under sticker. Based on three selection criteria, stickers are translated into concrete suggestions for adjustment (see section 7.1.1.1).

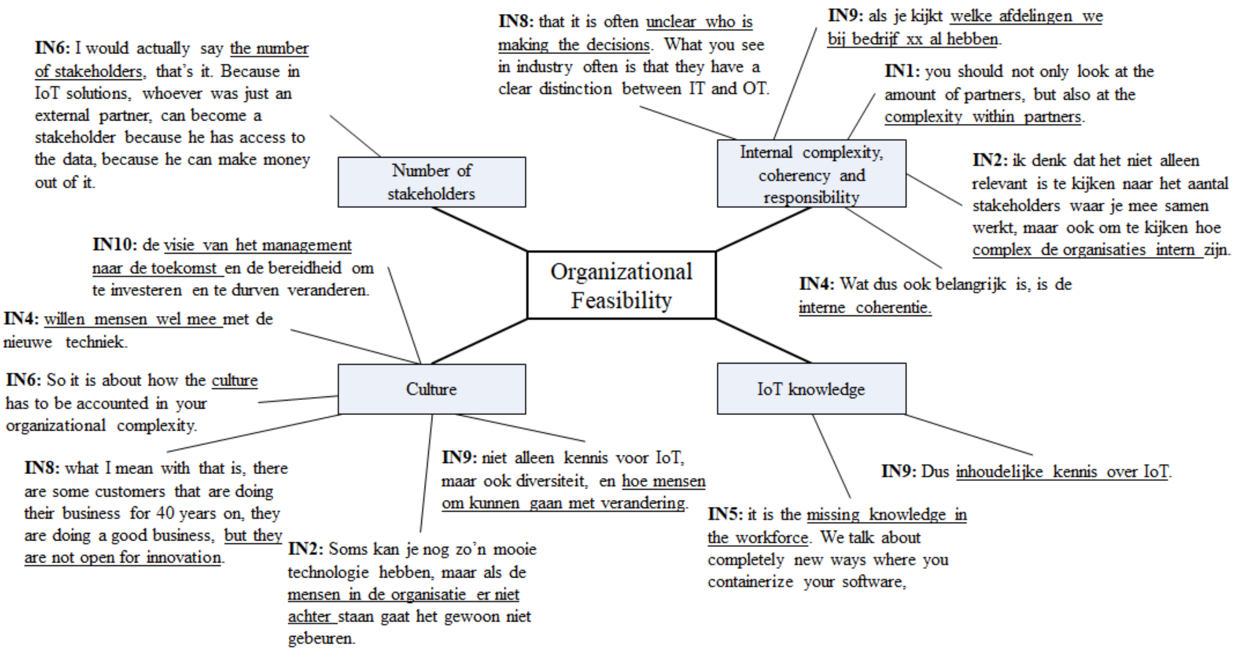


Figure 31: Illustrative example of data analysis for organizational feasibility in design phase two

This manual coding process was chosen because of the following reasons. First, the physical representation of the conceptual model helps the researcher in getting a better feeling of the data and oversight about how interviewees' remarks find their relevance in the tool. This helps in grouping the variables more accurately under the right generic factor, which enhances category validity. Second, the eleven interviewees have a diverse background. This means that their input delivers value in different respective views. Electronic coding enhances the researchers' capability to make comparisons among interviewees. However, because of the interviewees' diversity, enhanced comparison does not provide any distinct value. Lastly, usage of the conceptual tool as visual aid enhances the researcher's capability to formulate more concrete suggestions to adjust the tool.

7.1.1.1 Relevant suggestions for improvements based on interviews

As explained in the previous section, stickers with their corresponding quotes are translated into concrete suggestions for adjustment. Before accepting a proposed adjustment, the following three criteria were taken into consideration:

- **The amount of interviewees that mentioned the adjustment:** A higher amount of interviewees suggesting an adjustment provides higher reliability.
- **Contradiction of interviewees' suggestions:** If interviewees provide conflicting suggestions, the variable is analyzed more closely to get a better understanding about why their viewpoints differ. Based on this analysis, the choice to adopt or dismiss the suggestion is made.
- **Alignment of adjustment with literature:** If only one interviewee provided the suggestion, but it is aligned with what was found in literature, the adjustment may still be adopted.
- **Deductive explanation:** If neither of the earlier two criteria holds, but an interviewee provides a suggestion based on reasoning that can be deductively derived from what was already identified, the adjustment may still be adopted.

We outline an example where the first adoption criteria applies, with the sticker *culture* from the illustrative example in Figure 31. Six interviewees pointed out that that for organizational feasibility, a factor that describes the culture and people in an organization is missing. There were no interviewees that contradicted this suggestion. Hence, the suggestion is adopted. As displayed in Table 24, the quotes of the six interviewees are aggregated into one concrete suggestion. That is; to add a variable that explains the people factor, meaning the culture and vision of the organization (from C-suite level to worker level) that impacts how the innovation will be adopted.

Two cases have been identified where interviewees suggestions contradicted. In the first case, IN1 and IN4 stated that *context awareness* (as factor influencing the *perceived quality of service*) should be removed. Interviewee 1 mentioned that context awareness is a feature of an IoT application, not a direct property of the infrastructure. This argument was however dismissed because the majority agreed to the fact that context awareness is a relevant factor. Furthermore, the argument of interviewee 1 is not aligned with concrete examples from scientific literature that displays how edge nodes enhance context awareness (Dolui and Datta 2017; Perera et al. 2014; Ren et al. 2015). Hence, this suggestion was dismissed. The second case where interviewees' statements contradicted, was for the *energy constraints of IoT devices*. IN3, IN5, and IN7, suggested to remove the infrastructure requirement *energy constraints of IoT devices* as they were not sure if edge computing could reduce the energy usage on end devices compared to a cloud paradigm. This suggestion was however dismissed because of two reasons: Firstly, literature on edge computing displays concrete experiments that prove the reduction of energy usage on end devices when one shifts from a cloud infrastructure towards an edge infrastructure (Miles and Huberman 1994; Misra and Sarkar 2016; Premsankar et al. 2018; Taleb et al. 2017). Secondly, IN8 indicated to have researched this specific topic and confirmed that edge computing reduces energy consumption on end devices.

An example where the third adoption criteria applied can be found in IN1's suggestion to rephrase the variable *latency* (part of *perceived quality of service*) into *latency and jitter*. This suggestion was adopted because it provides a more comprehensive definition that is aligned with scientific literature. Whereas some papers solely describe the term latency (Ai et al. 2018; Shi and Dustdar 2016; Yu et al. 2018), the capability of edge computing to reduce jitter has been indicated as well (Bonomi et al. 2012; Satyanarayanan 2017). Hence, in order to formulate a more comprehensive definition, this suggestion was adopted (see Table 24).

The suggestion to adjust *IT experience* into *IT and IoT experience* (as part of *organizational feasibility)* provides an example where only two interviewees suggested an adjustment, but the choice was made to adopt it as the adjustment could be deductively derived from what was earlier found. The quotations that interviewees provided is displayed in the illustrative example in Figure 31. Based on the paper of Alshamaila et al. (2013), the variable *IT experience* was initially added in the first design phase. However, when deep-diving into the methodology of Alshamaila et al. (2013), it becomes apparent that they rephrased the variable prior technology experience (Heide and Weiss 1995; Lippert and Forman 2005), into IT experience. The originating definition of technology experience, however encompasses more than solely IT experience. As it can be reasonably expected that IoT experience is part of technology experience that is required to realize an edge-enabled IoT solution, this suggestion is adopted and the variable is adjusted as indicated in Table 24 .

Based on the translation process that was outlined above, Table 24 represents all adjustments that are made in the second design iteration of the tool. We can distinguish between three types of adjustments: *add* (a relevant variable is missing meaning and should be added in the tool) *adjust* (a variable is inaccurately phrased, meaning its definition or interpretation should be reformulated), *remove* (a variable is incorrectly placed in the tool and should be removed).

Table 24: Required adjustments based on expert interviews

Category	Suggestion for improvements	Action to take	Interviewee
Perceived quality of service	The concept *quality of service* should describe more. It should describe the value that is unlocked by the infrastructure.	*Adjust*	IN3
	It's important to express the value you enable by using an edge infrastructure (i.e. business value of the IoT application)	*Add*	IN4, IN5, IN8, IN9, IN10 and IN11
	The investment the customer has to do for the IoT application is missing	*Add*	IN1, IN3, IN5, IN6, IN10

	Next to latency, jitter is also an important requirement impacting response-time delay.	*Adjust*	IN1
	It's not only about data privacy, but also about data secrecy.	*Adjust*	IN1, IN2
	For interviewees it is often hard to distinguish between privacy and security. This is because privacy (and secrecy) requirements puts demands on security	*Adjust*	IN1, IN6, IN7, IN8
	Computing capability / speed and storage requirements are missing	*Add*	IN6, IN7 and IN9
	Mobility support requirements mainly put's additional requirements on connectivity (e.g. mobility of ships needs to be supported even at places with no network access).	*Adjust*	IN2, IN7
	Connectivity requirements should also include the availability of network connection in a certain location.	*Adjust*	IN3, IN6 and IN7
	Accessibility and reachability requirements are missing	*Add*	IN8
	The requirement of updates and upgrades, impacting the manageability of the infrastructure, is missing.	*Add*	IN3, IN 10 and IN11
	Speed and uncertainty of required scalability of the infrastructure is missing.	*Add*	IN8
	Serverless is to premature and cannot be seen as a driver for edge (yet). Many other interviewees indicated they are not familiar with the topic.	*Remove*	IN1, IN2, IN6, IN8 and IN9
Switching cost	Not only the system integration is relevant, but also the process integration	*Adjust*	IN4
	API's are an important aspect, which should be separately mentioned as part of openness	*Add*	IN3, IN4 IN9
	Interoperability should be mentioned as bridging variable between openness and switching cost.	*Add*	IN1
	Complexity and lead-time of migration is missing.	*Add*	IN7 and IN9
	The opportunity cost- and risk of integration (e.g. downtime because of integration), which impact switching cost for customers, is missing	*Add*	IN5 and IN9
	Possibility of trail-and-error at low opportunity cost, in turn decreasing switching cost, is missing.	*Add*	IN5, IN8, IN10
	A part of switching cost can be directly related to migration cost, this variable is missing.	*Add*	IN6 and IN9
Customer base / revenue source	Interviewees indicated to have difficulties understanding what is the installed base, therefore it should be defined more clearly	*Adjust*	IN1, IN5, IN7 and IN8
	Edge providers may generate new revenue by utilizing maintenance contracts and other additional services.	*Add*	IN2, IN5 and IN8

	Time to consume is missing (i.e. how long will it take before I generate revenue).	*Add*	IN4, N11
	Next to % of data on edge vs. cloud, edge computing may potentially enable an additional amount of data that can be processed on the cloud	*Adjust*	IN2
	The possibility, value and leverage of platform ownership in an IoT segment should be included	*Add*	IN7
Relative cost	It's not (only) about geographical coverage but mainly about the scale of implementation (which also includes geographical coverage)	*Adjust*	IN1, IN3, IN5, IN8 and IN9
	Still, geographical location (not coverage) is also a factor that may drive relative cost	*Add*	IN1, IN2, IN5 and IN7
	Protection of edge nodes from its environment (i.e. especially in case of hostile environments) is missing	*Add*	IN6
	Absence / presence of current hardware can impact the relative cost that have to be made.	*Add*	IN1, IN2, IN8 and IN9
	The relative cost should not only include roll-out, but also cost of ownership, operation and maintenance	*Adjust*	IN1, IN6 and IN7
IoT application's ecosystem health	The metrics for ecosystem health, on the left side of the box, are to specific and cause confusion	*Remove*	IN1, IN4, IN5, IN8 an IN9
	The knowledge and experience that players in the IoT ecosystem can bring to the table (i.e. non-financial resources) may also impact the network value	*Add*	IN4 and IN8
(Financial) Risk	Sometimes it is possible to roll out iteratively. Iterative roll-out mitigates the risk involved with high-initial investment.	*Add*	IN9 and IN11
	Legal risk and exposure (in case of system failure) may also impact the (financial) risk.	*Add*	IN1 and IN6
	There are different financial arrangements (e.g. co-ownership or full ownership of client) which may impact the financial risk.	*Add*	IN1, IN2, IN3, IN4, IN5 and IN8
Financial complexity	The financial different financial arrangements that are possible (look at factor from financial risk) could potentially unlock new financial resources	*Add*	IN1, IN2, IN3, IN4, IN5 and IN8
	The chosen infrastructure, plus the number of movements between edge nodes and between the edge and cloud, may impact the difficulty of billing during runtime	*Add*	IN4, IN9
	Financial complexity is not the right verb. It is more about financial feasibility, meaning can we actually get the financing around? Instead of; how complex is it to get the financing around? (do the same for technical complexity and organizational complexity)	*Adjust*	IN7 and IN8 and IN9
Technical complexity	It's not only about heterogeneity of devices and services, but also about their corresponding modularity and the heterogeneity of libraries, standards and modularity of the application.	*Adjust*	IN1, IN4 IN8 and IN9

	Interviewees had difficulties separating between *heterogeneity of devices and services* and the *standards in IoT application*. Therefore these variables should be formulated more clearly.	*Adjust*	IN2 and IN7
	The maturity of the chosen infrastructure's elements, needed to fulfill the requirements, may also make roll-out more complex.	*Add*	IN8
Organizational complexity	Amount of external partners is formulated inadequately. It should be formulated into number of stakeholders to make it more clear	*Adjust*	IN6
	Internal complexity, coherency and responsibility clarity is missing.	*Add*	IN1, IN2, IN4, IN8 and IN9
	The people factor, meaning the culture and vision of the organization (from C-suite level to worker level), impacting how the innovation will be adopted, is missing.	*Add*	IN2, IN4 IN6, IN8, IN9 and IN10
	Not only IT experience is relevant, but also stakeholders' IoT experience is important (this is a separate discipline than IT)	*Adjust*	IN5 and IN9

7.1.2 Weighting the generic variables

This section weights the variables based on output of the BWM. From the eleven respondents, one did not feel comfortable ranking the variables. In IN7's opinion, the nine generic factors are interwoven, making it hard to indicate their distinct relative importance. The other ten interviewees have provided their input which is displayed in Table 25.

Before weighting the generic variables, each interviewee was asked if the nine generic factors are sufficient in order to answer if there is potential for edge computing in an IoT application under analysis. All interviewees indicated that, if the feedback they provided on the tool would be included in those factors, the nine generic factors would be sufficient to answer the main question. It is concluded that the nine generic factors are sufficiently comprehensive in order to extract meaningful results out of the BWM. It should however be noted that the BWM was applied on the tool as designed in phase 1. As the tool is adjusted in the second design phase (i.e. contextual factors are adjusted, removed and added), the weights might not be completely accurate. This implication results from the choice of cross-sectional data collection. As the generic factors stay similar, the BWM still provides interesting insights about the relative importance of factors. Therefore, the weights as derived from tool's design 1, will be applied on the tool from design 2. The implications that come with this are taken into consideration while drafting conclusions.

Based on the relative importance of the nine factors that individual respondents have indicated (see appendix A.3), the standard deviation is calculated. A higher standard deviation indicates larger inconsistencies in data. Then, based on the average and the standard deviation of each factor, the coefficient of variation / relative standard deviation ($Coefficient\ of\ variation = \frac{Standard\ deviation}{Average}$) was calculated. The coefficient of variation suffices as standardized measure of dispersion, which is often indicated as percentage, and can be used to effectuate a better understanding of the standard deviation within the context of the data (i.e. the mean of the data) . The prerequisite of using the coefficient of variation, is that the measurements have a real zero (i.e. it is on a ratio scale) (Salkind 2010). As the relative weights resulting from the BWM can range from 0 to 1, this prerequisite is met. Furthermore, the coefficient of variation helps us in analyzing for which generic factors there is more consensus than others.

The coefficient of variation for the factors perceived value of the infrastructure (35.25%), Customer base / revenue source (33.39%) and relative cost of infrastructure (38.40%) are relatively low, indicating interviewees indicated these factor's importance relatively consentient. From this we derive with acceptable consistency, that the perceived value of the infrastructure is the most important factor (weighing 0.243). The customer base is the second most important factor to consider when analyzing the potential of edge computing for an IoT application (weight is 0.145). The relative infrastructure cost ranks among the less important variables (weighting 0.068). Furthermore, the variables (Financial) risk (C.V. = 55.19% & weight = 0.107), organizational feasibility (C.V. = 62.27% & weight = 0.091) and switching cost (C.V. = 65.77% & weight = 0.069) exhibit a moderately high coefficient of variation, meaning interviewees displayed less consensus on these variables. Lastly, the factors technical feasibility (C.V. = 69.66% & weight = 0.0752), IoT application's ecosystem health (C.V. 70.50% & weight = 0.112) and financial feasibility (C.V. 74.66% and weight 0.058) displayed to have a high coefficient of variation, meaning there are large inconsistencies in interviewees' opinion on the relevance of these factors. The problem of big variations could be solved by adding more data points (i.e. a larger group or respondents), which allows for better convergence of results, leading to more general consensus on the average weights.

Based on the consistency ratio (KSI) displayed in Table 25: Results of Best-Worst MethodTable 25, it can be observed that the pair-wise comparisons (of the Best-to-others and the others-to-worst factors), made by the respondents, are approaching zero. This tells us that the respondent's pair-wise comparisons are relatively consistent, making them sufficiently reliable.

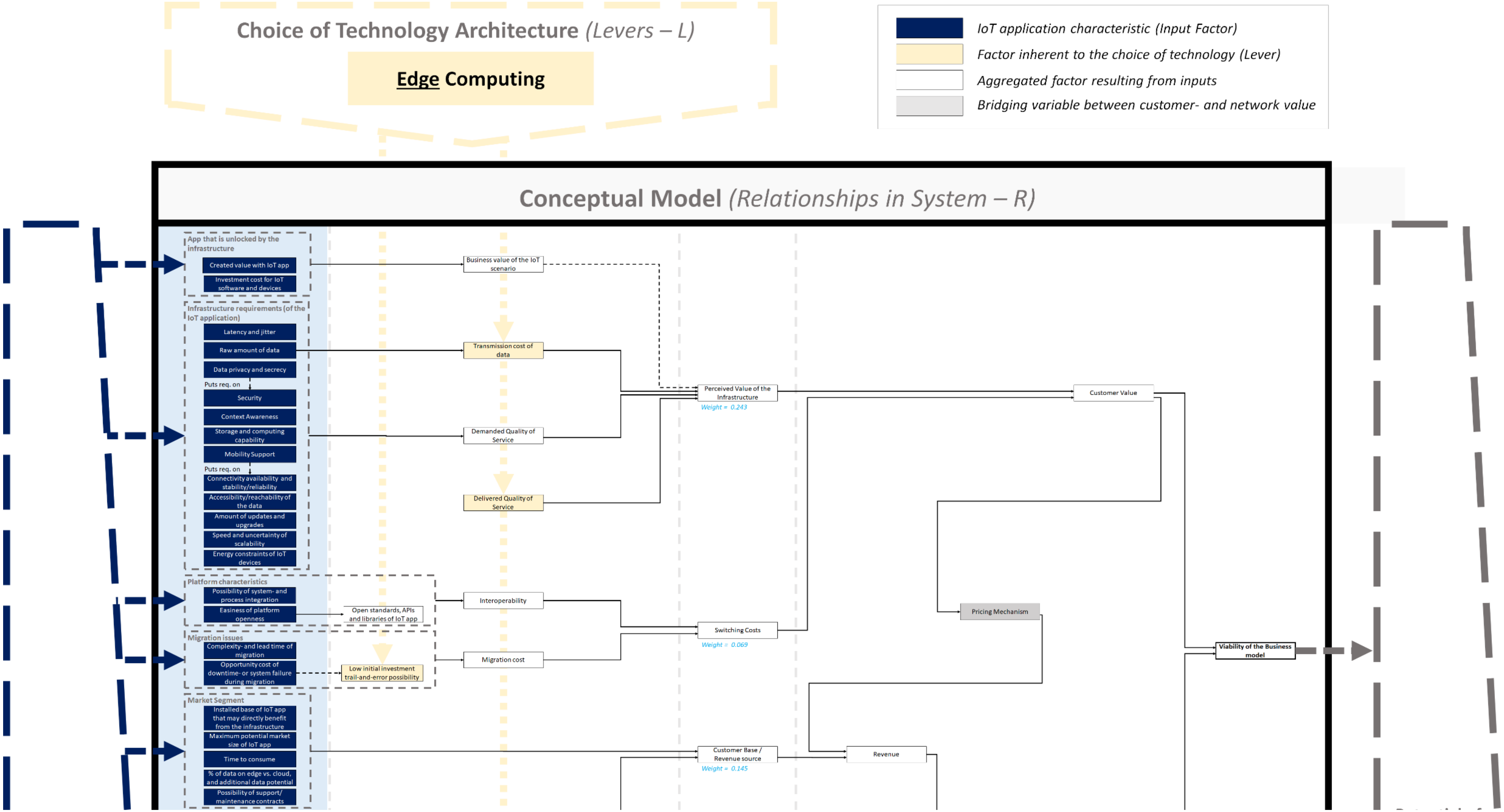
Table 25: Results of Best-Worst Method

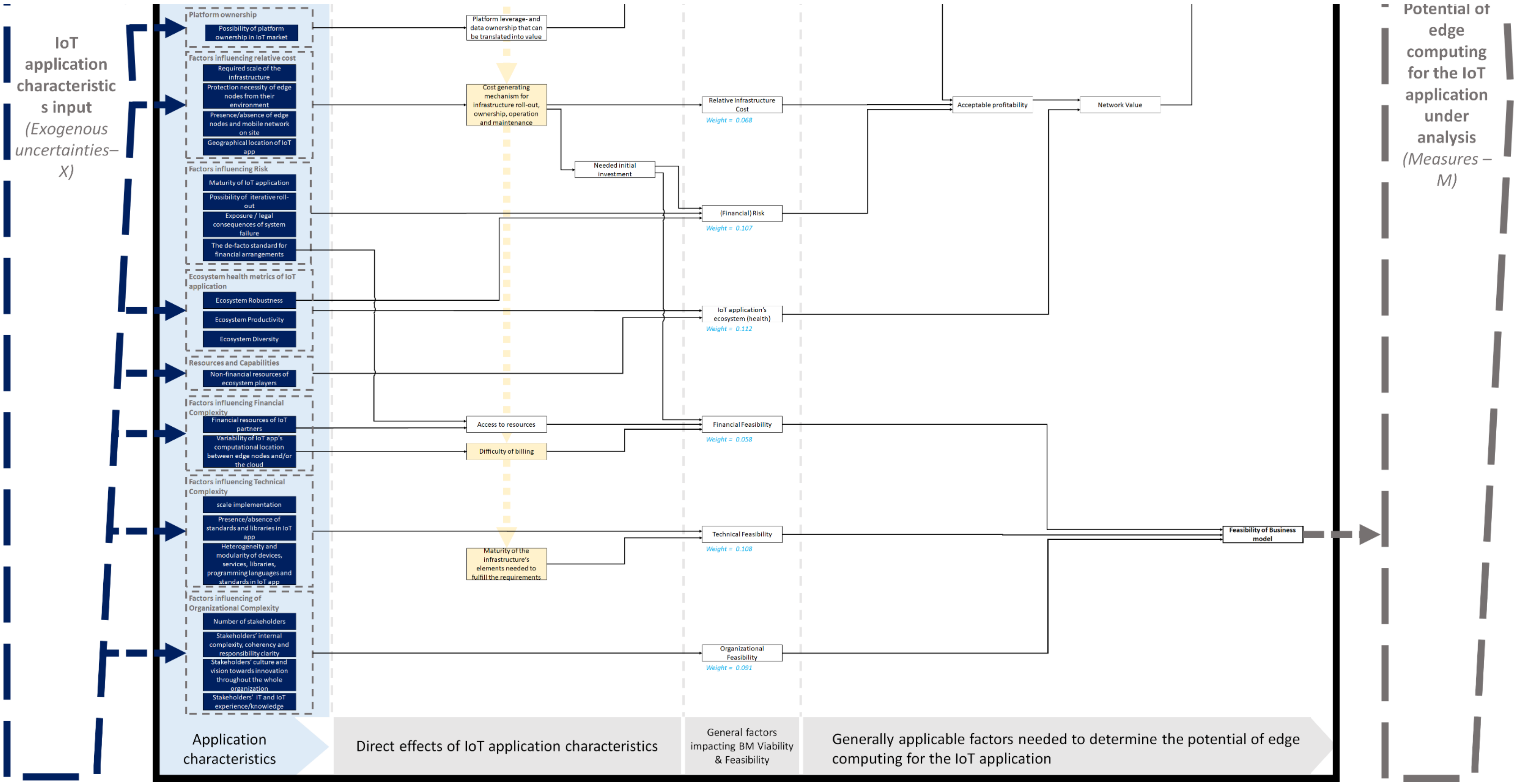
	A.W.	**M.W.**	**S.D.**	**C.V.**
Perceived value of the infrastructure	0,243	0,266	0,0857	35,25%
Switching cost	0,069	0,056	0,0453	65,77%
Customer base / revenue source	0,145	0,137	0,0491	33,96%
Relative infrastructure cost	0,068	0,062	0,0261	38,40%
IoT application's ecosystem health	0,112	0,094	0,0786	70,50%
(Financial) risk	0,107	0,088	0,0592	55,19%
Financial feasibility	0,058	0,050	0,0431	74,66%
Technical feasibility	0,108	0,089	0,0752	69,66%
Organizational feasibility	0,091	0,081	0,0566	62,27%
Consistency ratio	*0,079*	*0,074*	*N.A.*	*N.A.*

A.W. = Average Weight
M.W. = Median Weight
S.D. = Standard Deviation
C.V. = Coefficient of variance

Based on these results, it is concluded that the *perceived value of the infrastructure* and the *customer* base are the most important and second most important variables. When assessing the potential of edge computing for an IoT application, the outcomes of these variables count more heavily. The *switching cost, relative infrastructure cost,* and *financial feasibility* are the least important variables. Hence, the outcomes of these variables should be weighted less in the identification of the potential of edge computing for an IoT application under analysis. Lastly, the *IoT application's ecosystem health, financial risk, technical feasibility, and organizational feasibility,* are of moderate importance. The average weights as displayed in Table 25 are added in final tool.

7.2 Final tool





IoT application characteristics input
(Exogenous uncertainties– X)
Platform ownership
Possibility of platform ownership in IoT market
Factors influencing relative cost
Required scale of the infrastructure
Protection necessity of edge nodes from their environment
Presence/absence of edge nodes and mobile network on site
Geographical location of IoT app
Factors influencing Risk
Maturity of IoT application
Possibility of iterative roll-out
Exposure / legal consequences of system failure
The de-facto standard for financial arrangements
Ecosystem health metrics of IoT application
Ecosystem Robustness
Ecosystem Productivity
Ecosystem Diversity
Resources and Capabilities
Non-financial resources of ecosystem players
Factors influencing Financial Complexity
Financial resources of IoT partners
Variability of IoT app's computational location between edge nodes and/or the cloud
Factors influencing Technical Complexity
scale implementation
Presence/absence of standards and libraries in IoT app
Heterogeneity and modularity of devices, services, libraries, programming languages and standards in IoT app
Factors influencing of Organizational Complexity
Number of stakeholders
Stakeholders' internal complexity, coherency and responsibility clarity
Stakeholders' culture and vision towards innovation throughout the whole organization
Stakeholders' IT and IoT experience/knowledge
Platform leverage- and data ownership that can be translated into value
Cost generating mechanism for infrastructure roll-out, ownership, operation and maintenance
Needed initial investment
Access to resources
Difficulty of billing
Maturity of the infrastructure's elements needed to fulfill the requirements
Relative Infrastructure Cost
Weight = 0.068
(Financial) Risk
Weight = 0.107
IoT application's ecosystem (health)
Weight = 0.112
Financial Feasibility
Weight = 0.058
Technical Feasibility
Weight = 0.108
Organizational Feasibility
Weight = 0.091
Acceptable profitability
Network Value
Feasibility of Business model
Potential of edge computing for the IoT application under analysis
(Measures – M)
Application characteristics
Direct effects of IoT application characteristics
General factors impacting BM Viability & Feasibility
Generally applicable factors needed to determine the potential of edge computing for the IoT application

7.2.1 Explanation per variable

Based on the definitions as drafted in the first design phase (see Chapter 5) and the valuable insights interviewees provided, an explanation for each variable in the final model (section 7.2) is elucidated in appendix A.4. These explanations should help the industry practitioners in understanding how the variable is defined and how it interacts with other variables. This is especially relevant when applying the framework, where industry practitioners need to have an understanding about variables, before they can indicate how it applies to an IoT application scenario.

7.3 User guidelines

7.3.1 Tool's purpose and environment of use

The purpose of the tool is to enable informed decision making for selecting IoT application areas for which edge computing contains substantial potential. The 45 contextual input variables of the tool should be used to formulate to a qualitative estimation about the nine generic factors. These generic variables in turn explain the business model viability and business model feasibility, which provides us with an indication about the business potential of edge computing for an IoT application. The other purpose of the tool is to facilitate potential customers in their estimation about the value that edge computing may contribute to their focal IoT application. With these two purposes the tool has the intention to contribute to breaking the current deadlock situation where neither infrastructure providers, nor IoT providers are incentivized to invest in an edge computing ecosystem.

Having drafted the tool, two primary and two secondary scenarios in which it may be applied are identified. The first primary scenario enfolds when a potential edge computing provider wants to analyze whether a specific IoT application area has high potential for an edge offering. The tool can then be used in order to inform the potential edge provider about why a target market may contain substantial potential. Based on that information, the potential provider can take an informed decision whether to target the respective IoT market. The second primary scenario comes from the other side of the spectrum, where potential edge computing customers want to analyze if edge computing is a suitable solution for their IoT application area. For the customer it is important to get an understanding about the value they gain from an edge infrastructure. For them, it is also relevant to analyze if there is substantial value for potential edge providers. This is because edge providers need to be willing to roll-out an edge infrastructure that customers may demand (i.e. there needs to be sufficient customer and network value).

One of the secondary scenarios unfolds when service providers or customers have already made the choice to implement an edge computing infrastructure in their market, but development and/or utilization is staggering. In hindsight, these stakeholders might use the tool to analyze which aspects are the reverse salient staggering successful roll-out. They can use this information to either dedicate efforts to solve the identified problem or, if the problem cannot be solved, abandon the idea. The last (secondary) scenario envelops when customers want to analyze which aspects they should focus on before rolling out an edge infrastructure. Customers could be wondering if they are organizationally, financially and technically speaking ready for roll-out. The tool (feasibility part) can then help in structuring the thoughts about factors that should be taken into account for successful roll-out. Subsequently, customers may use the tool's output in order to prepare the organization for future roll-out.

Having defined the scenarios in which companies in general may use the tool, this section explains the positioning of the tool inside the company. The tool constitutes a high-level strategic analysis of the problem. As individuals at higher levels of the organization are generally expected to have greater influence on strategic decisions, due to their centrality and strategic level in the firm (Carpenter, Geletkanycz, and Sanders 2004), the tool's output targets the upper echelon of organizations. This means that upper echelon management should use the tool's output in order to make informed decisions on strategic level (i.e. selecting specific IoT application areas to target). Inside the four scenarios which were illustrated in the previous paragraph, there are three generic uses of the tool's output. First, an upper echelon manager may use the tool's output in order to formulate logical arguments and discuss management decisions with other upper echelon managers. Second, an upper echelon managers may use the tool's output to display the rationale of a strategic decision and thereby facilitate a better understanding and support within their team. Third, a general employee whom has strong believe in a strategic choice, can use the tool's output to formulate arguments in order to convince an upper echelon manager in his vision. It is expected that upper echelon managers have sufficient knowledge to apply the tool, as they generally have a broader overview of the problem (i.e. they are in a position that requires high level overview of the business). This is required, as the tool takes into account the diverse service, technology, organization and finance domains. Also, this tool requires a high-level strategic analysis, meaning that in-depth technical skills are not required.

7.3.2 Ten constructive steps to apply the tool

Now, the totality of variables that influence the business potential of edge computing for IoT applications has been identified and been aggregated into a conceptual model. This section translates the conceptual model into a tool, by providing a step-wise guide to apply it. In the expert interviews, the hypothesis that the manifold of variables in the full conceptual model overloads users with information, and thereby confuses them, has been confirmed. Therefore, it is hard for industry practitioners to understand and apply the full conceptual model that was drafted in section 7.2. In order to solve this problem, a step-by-step guide including ten constructive steps, has been drafted. These ten steps are based on the positive feedback interviewees provided about the separation of the conceptual model into 10 distinct boxes. More specifically, the interviews have indicated that separating the nine generic factors (perceived value of the infrastructure, switching costs, customer base/revenue source, relative infrastructure cost, (financial) risk, IoT application's ecosystem (health), financial complexity, technical complexity and organizational complexity) into nine distinct boxes, enhanced the interviewees' understanding of the tool. This insight has inspired and thereby formed the bases for the method by which the tool should be applied. This means that, industry practitioners whom want to apply the tool, should follow the ten constructive steps that have been displayed in appendix A.5. Whereas the 10-step method is in its essence the conceptual model cut-up into numerous pieces, the interviews have displayed that providing information step-by-step enhances practitioners' understanding (i.e. they are not overloaded with manifold variables).

In the ten-step method that is displayed in appendix A.5, within the first nine steps, practitioners should use the contextual factors (i.e. dark blue and light yellow) on the left side of the box as arguments to give an elaborate explanation about how the input variables (which are specifications of the IoT application under analysis) interact with the generic factor. Based on these input variables, arguments can thus be formulated that argue for positive or negative influence on the generic factor. By means of this process, practitioners get a sense about the extent to which the generic factors is sufficiently covered. If a practitioner would for example start at step 1, he/she would use the variables about the application that is unlocked by the infrastructure and the infrastructure requirements, in order to indicate to what extent customers perceive substantial value for an edge computing infrastructure. By taking into consideration each of the contextual factors (i.e. are they of importance, absent, present, staggering development, driving development, etc.) an elaborate argument can be formulated. By doing this for each of the nine generic factors, a sufficient argument that can be used to derive to the final answer, is formulated. Therefore, after conducting the same process for the first nine steps, in the tenth step, the full model plus output from the first nine steps, is used to formulate a final answer about the potential of an IoT application for edge computing. Chapter 8 displays how this works by demonstrating the tool on one IoT application.

7.4 Conclusion

Now, after the second iteration of the design phase, the second sub question; h*ow can the identified concepts be combined into a tool that indicates the potential of edge computing for distinct IoT applications?* Is answered. It is concluded that the majority of the variables that were combined in the tool in the first design iteration are relevant. All interviewees indicated that each individual generic variable is relevant and that together they provide a comprehensive set of variables that are needed to indicate the potential of edge computing for an IoT application. However, the tool needs refinement in order to ensure accurate reflection of reality. Main conclusions that are derived from refinement include:

Business model viability: Instead of perceived quality of service, perceived value of the infrastructure more accurately explains how customer value is created with an edge infrastructure.

- **Perceived value of the infrastructure:** Serverless computing is in it's infancy. Therefore, this concept does not (yet) play a role in determining the perceived value of the infrastructure. Furthermore, the infrastructure requirements; accessibility of data, amount of updates and upgrades, and speed and uncertainty of scalability, are of relevance.
- **Switching cost:** The complexity- and lead time of migration, and opportunity cost of downtime- or system failure during migration, are relevant additionally to the variables identified in the first design iteration.
- **Customer base/revenue source:** Next to the variables identified in the first design iteration, the time to consume and the possibility of support/maintenance contracts are important for assessing the customer base/revenue source.
- **Relative infrastructure cost:** Additionally to the required scale of the infrastructure, the variables; protection necessity of edge nodes from their environment, presence/absence of edge nodes and mobile network on site, and geographical location of IoT app, are relevant for determining the relative cost. Furthermore, one should not only look at the cost of roll-out, but also at the cost of ownership, operation, and maintenance of the infrastructure.
- **IoT application's ecosystem (health):** The variables that explain the ecosystem robustness, productivity, and diversity, are to specific and cause confusion. Non-financial resources of ecosystem players additionally plays a role in the network value that results from an IoT application's ecosystem.
- **(Financial) risk:** There are different standards for financial arrangements in order to roll-out an edge infrastructure. A possibility of iterative roll-out can mitigate the risk involved with high investments. Lastly, the exposure/legal consequences of system failure form a financial risk while the infrastructure is in operation.

Business model feasibility: Financial, technical, and organizational feasibility more accurately reflect the intended measure (instead of complexity).

- **Financial feasibility:** The variability of an IoT application's computational location between edge nodes and/or the cloud makes billing significantly more difficult (impacting financial feasibility).
- **Technical feasibility:** All identified variables are relevant and cover the most important aspects. Distinction between heterogeneity of standards and presence/absence of standards was not clear.
- **Organizational feasibility:** Next to the number of stakeholders, their internal complexity is relevant. Also stakeholder's culture and vision towards innovation is relevant. Lastly, next to stakeholder's IT experience, their IoT experience is relevant.

Based on the best-worst method, we conclude that; perceived value of the infrastructure and the customer base/revenue source count are the most important variables in order to assess the business potential. The switching cost, relative infrastructure cost, and financial feasibility, make up the least important set of variables. Lastly, the IoT application's ecosystem health, financial risk, technical feasibility, and organizational feasibility, are of moderate importance.

Finally, the total combination of the identified concepts into one tool, that indicates the business potential of edge computing for distinct IoT application, is displayed in section 7.2

8 Demonstration

This Chapter enfolds the demonstration of the tool on an IoT application by means of the ten constructive steps which have been explained in section 7.3.2. The demonstration intents to help readers understand how the tool should be applied in practice. This phase is also used as input for the evaluation (Chapter 9) that measures to what extent the tool meets the design objectives and thereby solves the problem that has been identified in Chapter 4.

According to Peffers et al. (2007), one can execute the demonstration phase by means of; experimentation, case study, simulation proof, or another appropriate activity. In the demonstration phase of this thesis research, the conceptual model is applied on an IoT application, thus constituting a case-study. This was identified to be the most suitable demonstration approach as it displays how the tool should be applied and what practical utility it delivers. First, the case selection criteria are elaborated upon in section 8.1. Then, section 8.2 provides a description of the chosen case, and an elaboration why this case meets the selection criterial. Section 8.3 describes how data has been gathered, and section 8.4 explains how the qualitative data is analyzed and codified. With the data that has been analyzed, the tool is then applied in section 8.5.

8.1 Case selection criteria

Section 3.1.1.3 displayed that there is an extensive range of applications which can be used to demonstrate the designed model. In order to allow for rigorous demonstration, the selection of the case should however be guided by the earlier identified problem (Chapter 1) and defined objectives of a solution (Chapter 4). More specifically, an encompassing case should be able to illustrate to what extend the solution is desirable (related to the established objectives in Chapter 4) and how the tool answers the problems hitherto not addressed. Following from that, three selection criteria have been drafted:

- In order to demonstrate the added value of the tool, there should be ambiguity about the potential of edge computing for the selected use-case.
- The IoT application should be more than just a proof of concept, meaning concrete examples are around. This allows for a more concrete display of the value-creating elements that influence adopter's decision to adopt an edge infrastructure or not.
- Lastly, as this research explores a novel field, it can be expected that little information is available about an IoT application's interaction with the tool's business model variables. Therefore, the majority of data is gathered through primary sources (i.e. interviews). As information for the tool's refinement and demonstration is gathered in one round of interviews (see the interview protocol in Chapter 6), a sub-group of the respondents should have sufficient knowledge about the chosen use-case. This could be difficult, because there are only small groups of people with in-depth knowledge about edge computing for individual IoT applications. Hence, the availability of respondents plays a role in the case selection.

8.2 A case description of predictive maintenance in Industry 4.0

Since its beginning in the late 18th century, the industrial manufacturing domain has evolved over several revolutions. The first industrial revolution (1760-1840) involved the construction of railroads and the introduction of the steam engine, in turn enhancing the capabilities of mechanical production. Then, in the early 19th century, the second industrial revolution enabled mass production by fostering the invention of the assembly line and the use of electric machinery. The third industrial revolution made its entry in the 1960s, focusing on an increasingly digitized manufacturing process. This encompasses development of mainframe computing, semiconductors, personal computing and the Internet. Now, we are in the midst of the fourth industrial revolution, employing the idea of IoT by means of cyber-physical systems in industrial automation, allowing for real-time data collection and analysis. This latest revolution enables a more efficient, better targeted and smarter production process than was ever possible before (Schwab 2017).

In the industry 4.0 domain, predictive analytics can be used to systematically process data, translate this into information which explains uncertainties and thereby allow for better informed decisions (Lee, Kao, and Yang 2014). More specifically, companies no longer rely on periodic inspections (i.e. conventional maintenance and inspection), but use the loads of data that are produced by their cyber-physical systems, in combination with predictive analytics, in order to effectuate the concept of 'predictive maintenance'. By implementing this concept correctly, manufacturers can significantly increase equipment lifetime, increase Operating Life Cycles (OCLs) and decrease unintended downtime (Mckone and Weiss 2009). More specifically, by measuring and managing the prognostic health of devices, potential device failures can be estimated. A typical 4-step process for developing a prognostic health measurement system for devices has been drafted by Swanson (2001). In the first step, maintenance records are used in order to determine which components are critical in order to identify machinery reliability, safety, and potential down-time. Put differently, a reliability centered maintenance analysis is conducted in order to determine which components most accurately measure the health of a device. This analysis has as output a prioritization of the measures that should be monitored by the predictive maintenance application. In the second step, additional sensors are placed in order to measure the highly prioritized components which have been identified in step 1. Then, with the output of these sensors, in the third step, the detection algorithm is developed by training the algorithm (i.e. with a supervised or unsupervised machine learning algorithm). The output of this algorithm is used in order to state a prognosis about the instrument which defines what the physical health of the instrument is and whether it should be replaced or not, in turn effectuating the predictive maintenance application (Swanson 2001). The general idea of predictive maintenance in industry 4.0 could be a potential use-case for edge computing. First of all, the high-cost of data collection and transmission can be reduced by collecting, filtering and pre-processing data at the edge of the network, before sending it to the centralized cloud datacenter (Yamato, Fukumoto, and Kumazaki 2017). Furthermore, by using edge analytics, the high bandwidth utilization requirements that are stressed by the massive amounts of data generated by predictive maintenance can be relieved (Rehman et al. 2018). Especially, when predictive maintenance is deployed in a scenario where active solutions for rearrangements or redesigns, in order to optimize machine-use, are facilitated, the large collection of sensor data may be more efficiently handled by edge nodes than the cloud (Matt 2018). Additionally, new privacy and security protection mechanisms may be established. The decentralized edge paradigm cloud however bring new, unidentified challenges to the table, such as legal compliance rules and technical complexity among others (Rehman et al. 2018).

The predictive maintenance case, as described above, matches the selection criteria because of the following reasons:

- Whereas scientific literature suggests that edge computing may provide some benefits to predictive maintenance in industry 4.0, no clear-cut assessment about its potential has been made. This hints that ambiguity resides in the value of edge computing for predictive maintenance.
- Predictive maintenance is an idea that has been around for a long time. There are numerous industrial factories where predictive maintenance has been implemented (Mobley 2002). This implies that it is more than just a prove-of-concept, meaning real-life examples are around.
- Because of the researcher's network in industrial manufacturing, experts with an ample understanding about both edge computing and predictive maintenance are sufficiently available.

8.3 Data gathering

As explained in the interview protocol (Chapter 6), this research constitutes one round of interviews. Only the subset of the 11 interviewees that have substantial knowledge about the chosen case, are asked about the interaction of the tool's factors with the predictive maintenance. An interviewee is suitable for this subset if he has directly been involved in at least one predictive maintenance project for industry 4.0. Hence, all interviewees were asked about their experience with predictive maintenance before starting the interview. Interviewees 1, 2, 3, 5, 6, 7, and 8, have been identified to possess substantial knowledge about industrial manufacturing and the related predictive IoT application. Therefore, these seven interviewees make-up the subset that provides information for demonstration of the tool. For more specific information about the background of these interviewees, Table 33 in appendix A.7 can be consulted.

The cross-sectional data collection method translates into one round of interviews that suffices for both refinement and demonstration of the tool. For the demonstration this means that interviewees have been asked about the interaction of the variables based on the tool of the first design phase. However in the second design phase, multiple variables have however been removed, refined, and added. For the variables that were added in in the second design phase, interviewees could thus not be asked to provide information. This is the implication that results from the choice of cross-sectional data collection. Hence, full demonstration of the tool as designed in the second phase was not possible. In order to partially mitigate this limitation and thereby deliver a more elaborate demonstration, additional literature source (i.e. scientific papers, trend analysis, market reports) were consulted. The qualitative interviews are analyzed by coding the transcripts (see section 8.4).

8.4 Coding and data analysis

All interviews have been transcribed. These transcriptions have then been electronically codified in atlas.ti in order to make sense of the qualitative data. Atlas.ti is a software tool for qualitative and mixed method data analysis. The coding process was conducted by pre-determining labels in order to categorize the data. Predetermination of these labels was fully guided by the tool that was designed in the second design iteration. This process of determining labels, structures the demonstration, as it provides direct insight about interviewees remarks per variable's interaction with predictive maintenance. Furthermore, this coding process is aligned with the 10 constructive steps to implement the tool (explained in section 7.3), which requires one to provide an explanation per individual variable. Through this labeling process, nine global themes were defined, representing the nine generic factors that have been drafted in the tool. Underlying organizational themes represent the IoT application characteristics (i.e. the 45 contextual input variables) that explain the generic variables. Three separate organizational themes were added, as their underlying quotes could not be grouped underneath the organizational themes that were directly extracted from the tool.

Figure 32 displays an illustration of the global theme *technical feasibility*, which is one of the nine generic variables of the tool. The three contextual variables; *scale of implementation*, *presence/absence of standards and libraries in IoT app*, and *heterogeneity and modularity of devices, services, libraries, programming languages, and standards in IoT app*, then represent the underlying organizational themes. From this figure, one can observe that all remarks interviewees provided about the interaction of the tool's variables with predictive maintenance, are grouped under the respective organizational theme. Also remarks about the aggregate industry of industrial manufacturing, which are relevant for an organizational theme, have been codified. The totality of these remarks per organizational theme are used to formulate a description of the variable's interaction in the demonstration. Section 8.5.9 displays the inferences that were derived from Figure 32. The full set of coding networks, for all nine global themes, has been included in appendix A.6. Section 8.5 contains all inferences that were derived from these coding networks per global theme.

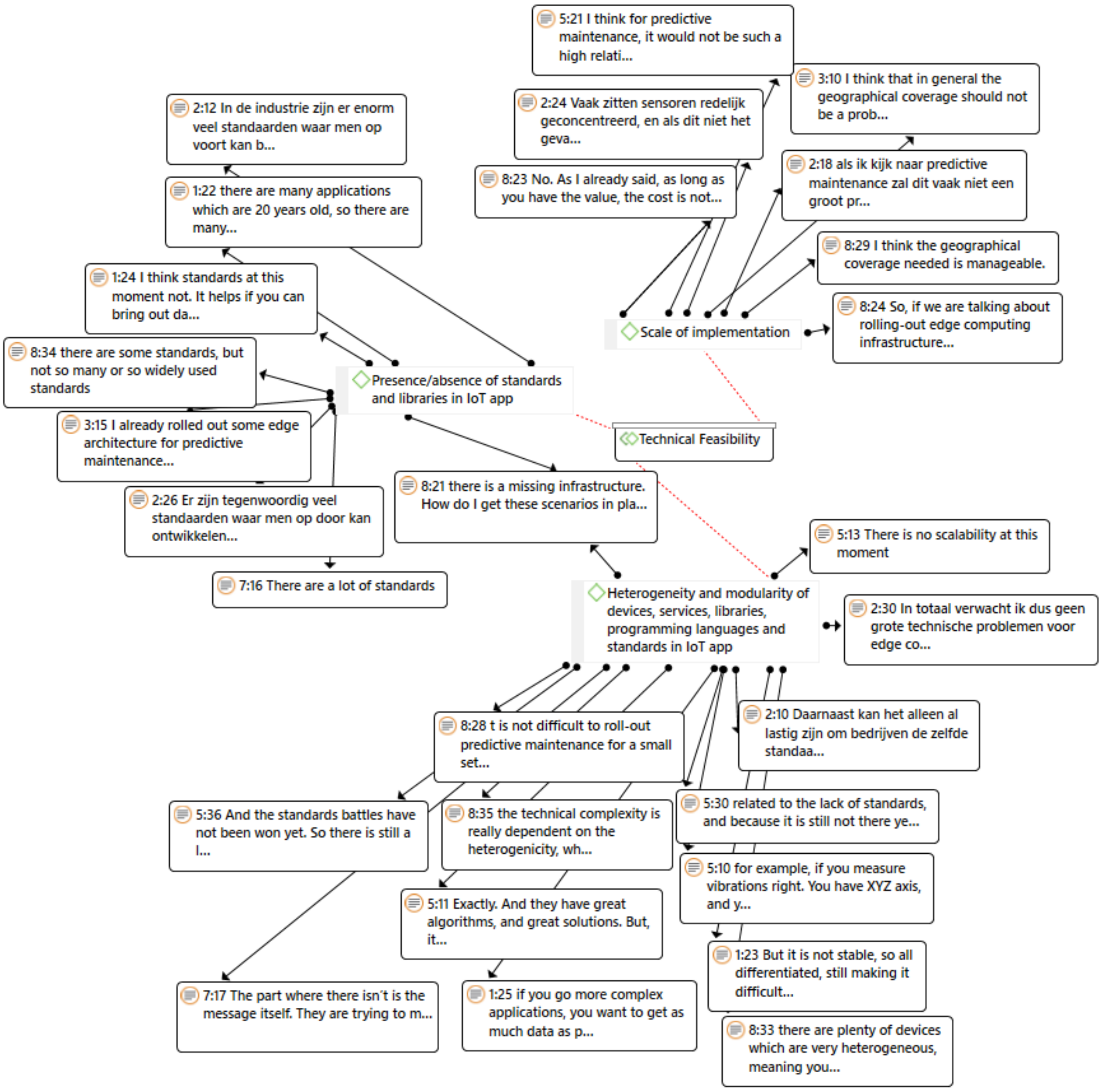


Figure 32: illustrative example of a coding network in the demonstration phase: technical feasibility

8.5 Applying the tool

Based on the coding networks of appendix A.6, this section unfolds the 10-step application of the tool on predictive maintenance for industry 4.0.

8.5.1 Determining the perceived value of the infrastructure for the customer

8.5.1.1 Added value of predictive maintenance

Created value with IoT app: On the premise that predictive maintenance is rolled-out in large use-cases, the cost savings could be huge. Subsequently, industrial manufacturers do not mind paying a lot for the infrastructure that effectuates the predictive maintenance scenario, as long as the cost don't exceed the benefit that is delivered by the IoT application (interviewee 8). However, with predictive maintenance there is a scalability problem. Subsequently, there is no scalable benefit. This scalability problem then implies that some cost can be saved by the application, but the total benefit is not substantial (interviewee 5 and 8). This is also indicated by O'Donovan et al. (2015), whom state that the lack of openness results in poor reuse of data and integration processes, prohibiting scalable solutions.

Investment cost for IoT software and devices: When rolling-out a predictive maintenance scenario, apart from investment costs for a computation platform (i.e. edge computing or cloud computing), the user incurs cost for deploying the scenario itself. For predictive maintenance, the sensors themselves are rather cheap (Interviewee 1, 3, 5 and 6). Apart from that, there is already a huge amount of sensors that are installed which may be utilized in order to effectuate a predictive maintenance scenario (interviewee 1). However, the software development of predictive maintenance is the main cost driver. Development is still expensive as, in order to establish an effective algorithm, expensive data scientists need to be hired (interviewee 5). Furthermore, current predictive maintenance scenarios are mainly tailored to small and specific use-case and there is only a limited amount of large scale solutions. Subsequently, because scalability is difficult, the relative investment cost for a predictive maintenance scenario are rather high (interviewee 5 and 8).

8.5.1.2 Infrastructure requirements

Latency and jitter: Overall, response time delay as a result of latency- and/or jitter problems, should not impact the overall functioning of an predictive maintenance application. Interviewee 3 and interviewee 6 indicated that there are some cases of predictive maintenance where latency and jitter requirements could be important. However, as indicated by the other five interviewees, generally speaking latency and jitter does not constitute a major driver for customers to choose for an edge platform. Especially, with the idea that "predictive maintenance is done to predict the future" (interviewee 2 and 7), minor response time delays should not impact the overall functioning.

Raw amount of data: As indicated by six out of seven interviewees, the raw amount of data that needs to be process is a major reason why customers would choose for an edge computing infrastructure. The raw amount of data can be a serious bottleneck to handle with other infrastructures. Therefore, data intensive predictive maintenance systems are likely to enjoy the benefits of pre-processing data in close proximity to the user devices. Several interviewees have indicated that this is the main infrastructure requirement that will drive adoption of edge computing by predictive maintenance application. Interviewee 8 indicated that he has not experienced any major problems with the raw amount of data so far. This could however be related to his experience that predictive maintenance is not scalable so far (i.e. large complex systems are not around yet). However, in order to utilize the true potential of predictive maintenance, a large scale is required. This would then significantly increase the amount of data that has to be transmitted, and therefore it is likely that the raw amount of data will become a serious problem.

Data privacy and secrecy: Five out of six interviewees have indicated that privacy and secrecy are an important edge characteristic for predictive maintenance (one interviewee did not specifically answer). Whereas it can be argued that there are no individuals involved in predictive maintenance, hence there can't be any privacy requirements (interviewee 1), the secrecy aspect may especially be relevant. Several players in the industrial manufacturing industry are reluctant to adopt cloud technologies because of sensitive data (interviewee 8). The secrecy aspect is then relevant because data may contain information about how you set-up your factory and how you produce products (interviewee 7). Therefore, privacy and secrecy is generally speaking important for predictive maintenance, in turn partly driving requirements for security.

Security: For players in industrial manufacturing that are considering whether to adopt an edge infrastructure or not, security is a major consideration (as indicated by seven out of seven interviewees). Security is partly important in order to protect the sensitive data (interviewee 7), but also in order to prohibit any malicious activities from happening, in turn leading to default indications of equipment that needs to be maintained (interviewee 3).

Context awareness: Three interviewees have indicated context awareness is important, but the other three have indicated context awareness is not important (one interviewee did not specifically respond). This input does not provide us with an indication whether context awareness is a requirement that would drive predictive maintenance towards adoption of an edge infrastructure. According to the papers of Schmidt et al. (2017) and Schmidt and Wang (2018), contextual information is key for predictive maintenance as this provides the algorithm with additional conditions that affect health (e.g. environment, use intensity, etc.). Subsequently, by feeding contextualized data into the machine learning algorithms that effectuate predictive maintenance scenarios, more accurate predictions can be established. More accurate predictions in turn result in higher cost saving. Therefore it can be assumed that context awareness is a factor driving the decision of users towards an edge infrastructure.

Storage and computing capability: Usually, individual predictive maintenance techniques do not require large amounts of computation and storage capabilities (Mobley 2002). Subsequently, whereas the amount of sensor data can become so large that processing on the edge is more efficient (interviewee 1, 2, 3, 5, 6 and 7), the computation and storage requirements to run predictive maintenance algorithms are not exorbitantly high. Therefore, it is viable to do pre-processing tasks on edge nodes. (Jantunen et al. 2017).

Mobility support: In factory automation (i.e. industry 4.0) devices are often located at a specific place and thus not moving around (interviewee 2). subsequently, six out of seven interviewees have indicated that mobility support is not an important characteristic of edge computing for predictive maintenance applications.

Connectivity availability and stability / reliability: The connectivity has to be reliable enough in order to effectuate proper analysis of the data, but short loss of connection should not impact the overall functioning of predictive maintenance (interviewee 1, 2, 3, 5, 7). There are some cases where connectivity is key (as indicated by interviewee 6 and 8). However, generally speaking, constant availability and stability of connectivity is not a major factor that impacts customers' decision to use an edge infrastructure.

Accessibility / reachability of the data: In order to develop accurate predictions, the use of an cloud-based infrastructure could enhance the amount of data that is fed into the algorithm. Therefore, in order to develop the algorithms themselves, It might be beneficial to use an cloud-based platform in order to analyze data of sensors across plants and thereby enhancing data exchange among IT tools (Mourtzis et al. 2016; Schmidt and Wang 2018). These requirements could thus constitute an argument against the adoption of edge computing as data access on a global scale is beneficial to the IoT application. However, next to model development, in order to utilize real-time monitoring and execution of the algorithms the data exchange among IT tools might not be required.

Amount of updates and upgrades: As this was a new variable in the tool, interviewees have not been asked about this. Furthermore, no information regarding this variable is available on the Internet, meaning there is a blank in this variable.

Speed and uncertainty of scalability: When consulting literature it becomes apparent that; while digitization of factories accelerate, the amount of devices that will constitute a smart manufacturing facility is hard to predict. Subsequently, it is highly desirable that the infrastructure exhibits dynamic scalable solutions. This is especially relevant in the light that the manufacturing industry is increasingly intensive in nature, where unpredictable and unforeseen developments are to be expected (Krause et al. 2010; O'Donovan et al. 2015).

Energy constraints of IoT devices: The input of interview participants does not provide a clear direction about the importance of the energy constraints of IoT devices with predictive maintenance in industry 4.0.. However, when looking at the argumentation of these respective interviewees, it becomes apparent that the benefits energy constraints could deliver could be huge when there is a lack of power supply (Interviewee 1 and 7). However, when looking at industrial manufacturing, it can be expected that power supply is readily available. This makes energy constraints rather a secondary benefit, instead of a main benefit that is sought for (interviewee 2, 8).

Table 26: Indication of infrastructure requirements of predictive maintenance with regards to an edge infrastructure

	IN1	IN2	IN3	IN5	IN6	IN7	IN8	Total R	Total N
Latency and jitter	N	N	R	N	R	N	N	2	5
Raw amount of data	R	R	R	R	R	R	N	6	1
Privacy and secrecy	R	R	N	-	R	R	R	5	1
Security	R	R	R	R	R	R	R	7	0
Context awareness	N	R	N	-	R	R	N	3	3
Storage and computing capability	-	-	-	-	R	-	-	1	0
Mobility support	N	N	N	N	R	N	N	1	6
Connectivity availability and stability / reliability	N	N	N	N	R	N	R	5	2
Accessibility / reachability of the data	-	-	-	-	-	-	-	0	0
Amount of updates and upgrades	-	-	-	-	-	-	-	0	0
Speed and uncertainty of scalability	-	-	-	-	-	-	-	0	0
Energy constraints of IoT devices	R	N	N	N	R	R	N	3	4

R = Relevant for choosing edge
N = Not relevant for choosing edge
- = No input.

8.5.2 Determining the switching cost for the customer

Possibility of system- and process integration: seven out of seven interviewees have indicated that system integration, in general, should cause no major problems. The main argument behind this, explains that predictive maintenance can partially run as a stand-alone system, not requiring any integration with other processes or systems a client currently has running.

Easiness of platform openness: In the process automation industry, many players are unwilling to open-up their ideas to others (interviewee 2). This is confirmed by O'Donovan et al. (2015) who state there are problems in manufacturing facilities' nature where data is often proprietary and inaccessible. Subsequently, data integration is a complicated and time consuming task. Hence, it is hard to effectuate open standards, APIs and libraries for predictive maintenance, making the interoperability of different tools challenging (Chiu, Cheng, and Huang 2017; O'Donovan et al. 2015).

Complexity and lead time of migration: As this was a new variable in the tool, interviewees have not been asked about this. Furthermore, no information regarding this variable is available on the Internet, meaning there is a blank in this variable.

Opportunity cost of downtime- or system failure during migration: In factory automation it is often the case that machines have been running for many years, without any mistakes or problems. Manufacturing companies then are reluctant to innovate, as it could result in system down-time, potentially causing millions of loss (interviewee 5). However, if the use-case is large enough, and significant benefit can be gained, industry players don't have any problems spending millions in order to effectuate this (interviewee 8).

8.5.3 Determining the customer base and how it will suffice as revenue source

Installed base of IoT app that may directly benefit from the infrastructure: The sensors that could be integrated into a cyber-physical system, in turn realizing the idea of IoT and thereby potentially effectuating a predictive maintenance scenario, have been around for a long time. Furthermore, there is a massive installed base of automation technology that could benefit from the IoT technology. However, in order for this to happen, predictive maintenance algorithms should first be developed for the dedicated system (interviewee 1, 7 and 8). Furthermore, in the trend study conducted by Milojevic and Nassah (2018), 55% of the interviewed participants indicated to be at least running pilots with predictive maintenance. These two indicators provide us with a hunch that there is interest of companies in the IoT applications, and a major installed base of sensors that may directly benefit from an edge infrastructure. Subsequently, there may be an attractive customer base.

Maximum potential market size of IoT app: There is enormous potential for predictive maintenance, it could be a game changer, the potential market is manifold of what is currently captured (interviewee 2, 5 and 7). This anticipated potential is confirmed by the large expected Compound Annual Growth Rate (CAGR) of 27% between 2016 and 2022 (Half-Cooked Research Reports 2019; MarketWatch 2019).

Time to consume: As indicated by interviewee 2, 3, 5, 7 and 8, predictive maintenance is still in it's infancy. Correspondingly, there are still major issues to be resolved before predictive maintenance will be a widely adopted practice (Jalan 2018). Whereas no concrete time to consume can be indicated, the infancy of predictive maintenance and the major issues that need to be resolved increase the expected adoption time.

% of data on edge vs. cloud, and additional data potential: Especially with processes that generate massive amounts of data, one wants to pre-process data on the edge before sending it to the cloud. This is related to the bandwidth requirements companies are currently coping with (interviewee 2). Subsequently, by relieving these limits by means of an edge computing infrastructure, an increased amount of data may be processed (i.e. of sensors which were previously not processed) (interviewee 3). Neither interviewees, nor a consult on literature review could provide an indication about the % distribution of data processing on the cloud vs. the edge.

Possibility of support / maintenance contracts: In the industrial manufacturing industries, customers expect something long living. Subsequently, they expect long-time support of the products and services they buy (interviewee 8). Predictive maintenance will especially offer possibility for new business models for OEMs (interviewee 5).

Possibility of platform ownership in IoT market: As this was a new variable in the tool, interviewees have not been asked about this. Furthermore, no information regarding this variable is available on the Internet, meaning there is a blank in this variable.

8.5.4 Determining the relative infrastructure cost (of edge vs. cloud)

Required scale of the infrastructure: Generally speaking, rolling-out an edge infrastructure for predictive maintenance in industry 4.0 does not require any prohibitively large scale implementations. Subsequently, hardware costs for the edge infrastructure are not expected to drive up major costs (interviewee 3 and 5)

Protection necessity of edge nodes from their environment: In industrial environments, it could be possible that the edge nodes needs to be protected for temperature, sunlight, water etc. (interviewee 6). However, as industrial plants (i.e. manufacturing facilities) currently constitute the locations under analysis, it can be expected that edge nodes can be located in safe environments, thus not requiring any exorbitantly high cost for protection.

Presence / absence of edge nodes and mobile network on site: There are some famous, highly cited cases, where initial investment was very low. This was mainly because all equipment (i.e. sensors and mobile network) were already there. Subsequently, they only had to implement the cloud platform (interviewee 1).

Geographical location of IoT app: As this was a new variable in the tool, interviewees have not been asked about this. Furthermore, no information regarding this variable is available on the Internet, meaning there is a blank in this variable.

8.5.5 Determining the (financial) risk for the service provider

Initial investment: Interviewee 2 and 3 stated that generally speaking, the initial investment of an edge computing infrastructure for predictive maintenance should not be the problem.

Ecosystem robustness: The ecosystem of players that will adopt a predictive maintenance solution is robust. The connections among industry players are relatively stable as they have been working together for longer amounts of times, and the companies themselves have been around for decades. Also, these companies are not likely to go bankrupt, even if they have some financially difficult times (interviewee 2, 3, 5 and 7)

Maturity of IoT application: Whereas there are some examples of predictive maintenance solutions available, it is still in it's infancy. Many customers are still in the proof of concept phase meaning they have some stand-alone system on which they test with a predictive maintenance solution. Whereas development of predictive maintenance is quite far, the utilization and large scale roll-out, which would effectuate the real benefit of predictive maintenance, is still premature. Companies are talking a lot about predictive maintenance, but real efforts are lagging behind (interviewee 2, 3, 5, 7 and 8).

Possibility of iterative roll-out: As all interviewees have indicated, predictive maintenance can run on a stand-alone system, not impacting the overall functioning of a factory. This implies that predictive maintenance solutions may be gradually added as the software and infrastructure matures. This may partially suffice as mitigation for risk.

Exposure / legal consequences of system failure: Generally speaking, in case of system malfunction, a device default cannot be accurately predicted. This could lead to unnecessary system down-time or to device failure (as the default has not been predicted). There are some cases where machines might be working side-by-side with humans, in this case safety is key (interviewee 5). Generally speaking this should however not be the case, therefore the exposure and legal consequences can be expected to be relatively low.

The de-facto standard for financial arrangements: In the industrial manufacturing domain, customers (i.e. either the ones who will roll-out the predictive maintenance system or the ones who will use the system) are owners of the edge infrastructure. This mainly results from the fact that a dedicated edge infrastructure will be built in the manufacturing plant (interviewee 1, 2, 3, 5 and 8).

8.5.6 Determining the value generated by the IoT application's ecosystem (health)

Ecosystem robustness: The ecosystem of players that will adopt a predictive maintenance solution is robust. The connections among industry players are relatively stable, as they have been working together for longer amounts of times, and the companies themselves have been around for decades. Also, these companies are not likely to go bankrupt, even if they have some financially difficult times (interviewee 1, 2, 3, 5 and 7)

Ecosystem productivity: Current manufacturing companies are making money in general, but they are not enjoying major profits (interviewee 2 and 7).

Ecosystem diversity: Whereas the customers that would adopt a predictive maintenance solution are not diverse (interviewee 7), the total ecosystem that has to work together in order to deliver a predictive maintenance solution, is rather diverse (interviewee 2).

Non-financial resources of ecosystem players: As this was a new variable in the tool, interviewees have not been asked about this. Furthermore, no information regarding this variable is available on the Internet, meaning there is a blank in this variable.

8.5.7 Determining if the desired edge infrastructure is financially feasible

Needed initial investment: Interviewee 2 and 3 stated that generally speaking, the initial investment of an edge computing infrastructure for predictive maintenance should not be the problem.

Financial resources of IoT partners: 83% of the participants in the trend study of (Milojevic and Nassah 2018) expected to invest in predictive maintenance in the next two years. No concrete analysis or indication about financial resources of companies involved in industrial manufacturing has been obtained (through interviews and online research). However, a large portion of the fortune 500 companies is heavily involved in manufacturing processes (Fortune 500 2019), providing us with an indication that the environment has sufficient financial resources. This is aligned with interviewee 8's remark, that companies do not mind investing millions into a solution, as long as the returns offset the cost, thus indicating that financial resources itself is not the problem.

Variability of IoT app's computational location between edge nodes- and/or cloud: As this was a new variable in the tool, interviewees have not been asked about this. Furthermore, no information regarding this variable is available on the Internet, meaning there is a blank in this variable.

8.5.8 Determining if the desired edge infrastructure is technically feasible

Scale of implementation: In the majority of predictive maintenance applications for industry 4.0, sensors are relatively concentrated inside a factory. Furthermore, the overall scale of implementation should not be a big problem, as it is usually limited to the factory or industry area, thus not requiring national roll-out (interviewee 2, 3, 5 and 8).

Presence / absence of standards and libraries in IoT app: In the industry domain, there are many applications which have been around for years, being built on standards that have been around for even longer. Subsequently, there are a lot of standards around (interviewee 1, 2, 7 and 8).

Heterogeneity and modularity of devices, services, libraries, programming languages and standards in IoT app: Whereas the standards are present, there are not so many widely accepted standards. This generates serious problems for the scalability of predictive maintenance. Especially in the messaging protocols, libraries and programming environments, there are not common standards yet. This implies that edge roll-out for predictive maintenance is rather easy on small scale, but large scale solutions, covering entire factories, or even factory parks is technically very complex (interviewee 2, 5, and 8). Furthermore, O'Donovan et al. (2015) indicate that the openness of standards is restricted, in turn also complexifying the delivery of scalable solutions. Open standards should be developed in order to promote scalability and data accessibility. Additionally, a challenge resides in both the heterogeneity and modularity of machinery and component types in multi-vendor production systems, complexifying large-scale roll-out even further (Chiu et al. 2017; Krause et al. 2010; Weyer et al. 2015)

8.5.9 Determining if the desired edge infrastructure is organizationally feasible

Number of stakeholders: Generally speaking, the number of stakeholders that have to work together in order to deliver a predictive maintenance solution is not too big (interviewee 3, 5 and 8)

Stakeholders' internal complexity, coherency and responsibility clarity: Inside manufacturing companies' organization, there is a clear distinction between IT and OT departments. However, when rolling out an edge computing infrastructure for predictive maintenance, both IT (the edge infrastructure) and the OT (increase of operational efficiency by means of predictive maintenance) are required. This then results in internal ambiguity about who is in charge for the project. Many industry players have difficulties figuring out who can make the final decisions (interviewee 8).

Stakeholders' culture and vision towards innovation throughout the whole organization: There are some players, which are definitely making profit, but are doing the exact same thing over 40 years. These players are not as open for innovation, and it is very hard to change this perspective (interviewee 8). Whereas getting the whole organization behind the plan is crucial in most applications, the impact it will have on predictive maintenance is less. Generally speaking predictive maintenance does not have a massive impact on the organization itself (interviewee 2). Furthermore, there is a mismatch between the IT and OT visions of companies willing to adopt an edge computing infrastructure (i.e. manufacturing companies), which have high regard for safety, security and efficiency, and the providers of potential edge computing solutions, which have different key values (interviewee 8). The book of Mobley (2002) states that a culture shift inside organizations is required in order convince the whole organization that a shift towards predictive maintenance is required. This can however be difficult

Stakeholders' IT and IoT experience / knowledge: Whereas many industry players have sufficient knowledge about OT and IT (interviewee 2 and 8), their respective workforce is missing IoT, cloud and edge experience and knowledge. For example, the work force has no experience about the new ways for containerizing your software in order to make it suitable for edge or cloud solutions (interviewee 5). For predictive maintenance, one of the major factors currently blocking adoption is the missing knowledge and experience of manufacturing companies about this domain (Jalan 2018).

8.6 Conclusion: Using the whole model and answers of steps 1-9, to derive to the final answer

The major value of predictive maintenances for customers lays in the cost savings it can effectuate. This benefit is increased by scaling-up predictive maintenance towards a factory wide solution. An edge computing infrastructure provides benefits to predictive maintenance in industry 4.0 due to four infrastructure requirements. First and foremost, an edge computing infrastructure mitigates the serious bottleneck of massive data streams that cannot be sent to the cloud. This is especially relevant when scaling-up the predictive maintenance solution towards factory wide implantation with thousands of data points. Therefore, raw amount of data is the most important requirement of predictive maintenance that drives customers' decision towards an edge computing infrastructure. Secondly, an edge computing infrastructure enhances the overall security that industrial manufacturer require. Thirdly, the desired data secrecy of industrial manufacturers can be facilitated by the edge. Lastly, an edge computing infrastructure extents the aggregation of context aware data, making predictive maintenance algorithms more accurate.

However, many players in the manufacturing industry are unwilling to open-up their standards, APIs and libraries. Whereas this does not cause major issues for system integration with customers' current systems, because predictive maintenance can often run on a stand-alone system, it does cause problems for large-scale implementation. For factory-wide implementation, a heterogeneous set of devices and services need to be integrated. Whereas there are sufficient standards present, these standards are not open and therefore there is not a commonly used set of standards. This complexifies the integration of these heterogeneous components into one system. This implies that, the biggest benefit edge computing may deliver for predictive maintenance, which is facilitation of huge amounts of raw data, cannot be effectuated as large-scale implementation is not feasible. Furthermore, the technical infeasibility of large scale implementation diminishes the cost savings and corresponding business value the IoT application may generate for customers. Therefore, the perceived value of the infrastructure, which is the most important determinant for estimating the potential of edge computing for an IoT application, is currently blocked and the generated customer value is only a fraction of what it could potentially be.

On the other side of the token, looking at the customer base/revenue source (which is the second most important aspect), a major potential market awaits, one that is manifold of the current predictive maintenance market. Whereas the time to consume is hard to predict and consumption is expected to mainly be generated in the future, the current installed base of sensors that may directly benefit from the solution is enormous. This implies that, a major potential market segment awaits. Additionally, the relative infrastructure cost of edge computing for predictive maintenance is not expected to be abundantly high, as the required infrastructure scale is mainly limited to factory-wide and no major protection of edge nodes from their environment is required.

Looking at the (financial) risk that service providers take, the infancy of the IoT application (predictive maintenance) immediately catches eye. However, this major risk is partly mitigated by the de-facto standard of financial arrangements where customers own the dedicated edge infrastructure. Furthermore, the possibility of iterative roll-out reduces the risk. Therefore, it is concluded that, the (financial) risk for service providers is manageable. Lastly, it has been indicated that the IoT ecosystem is relatively *healthy* (based on robustness and productivity) benefiting the ones dependent on it. Therefore, based on the customer base, the relative cost, the (financial) risk and the IoT application's ecosystem (health), it is concluded that there is substantial value for the network of companies that would provide the respective edge solutions.

Lastly, looking at the business model feasibility, as discussed before, large-scale implementation is currently technically not feasible. This technical infeasibility especially results from the heterogeneity of devices, libraries, programming languages and standards in the predictive maintenance domain. On the other hand, financial feasibility does not provide major issues as industrial manufacturing companies have substantial resources and the de-facto standard for financial arrangements pushes them for dedicated system ownership. Looking at the organizational feasibility however, major problems arise. Especially the stakeholders' culture and vision towards innovation as well as stakeholders' experience and knowledge about the predictive maintenance and edge computing domains is lacking behind. These implications impact the organizational feasibility, in turn complexifying edge roll-out.

Based on the insights described in this section, it is concluded that substantial value can be gained by the network of companies that would provide the solution. However, because of the technical infeasibility of large-scale roll-out, major customer value cannot be obtained. Additionally, organizations in the industrial manufacturing domain are organizationally not ready for major shifts towards the IoT domain. On the other side of the token, if these issues are resolved, major potential gains await for both the customer, which are IoT application providers, (i.e. cost saving) as well as potential providers (i.e. extra revenue sources). Hence, it is recommended that providers start to make small investments in order to develop common standards and to make customers organizationally ready for implementation. Until these goals are reached, it is advised to search for another potential IoT application that may create value in the short-run.

9 Evaluation

Evaluation can take many forms, such as; comparing the objectives of a solution with the artifact, objective quantitative performance assessment, conducting satisfaction surveys, and simulations among others. Conceptually, an evaluation could range from logical arguments to empirical evidence and mathematical proof (Peffers et al. 2007). In this thesis' evaluation phase, a measurement about the extent to which the artifact supports a solution to the identified problems and thereby provides utility is conducted. This evaluation is executed by comparing how well the designed tool and its demonstration fulfill the design objectives that have been drafted in Chapter 4. The choice for this evaluation strategy can be explained in twofold: First, evaluating the tool based on the design objectives that have been drafted in Chapter 4 allows for a reduced bias in the evaluation process of assessing how well it solves the problem hitherto not addressed. Second, because of time- and resource constraints an additional interview round to evaluate the tool was not feasible. Implications that are identified in this evaluation phase are used to moderate conclusions and formulate recommendations for further research.

9.1 Evaluating the extent to which the designed tool meets the design objectives

Objective 1: Business model variables should be contextualized towards the edge computing domain.

It is argued that the design objective that aimed at the contextualization of business model variables towards the edge domain has been fulfilled. The nine generic variables; perceived value of the infrastructure, switching cost, customer base/revenue source, relative infrastructure cost, (financial) risk, IoT application's ecosystem (health), financial feasibility, technical feasibility, and organizational feasibility, have been contextualized towards the edge computing domain. This was done by means of two design iterations, that include data extracted from literature review, informal talks, and semi-structured expert interviews. This indicates that multiple data sources have been used, increasing the validity of the contextualized variables. It should however be noted that the new variables that have been added in the second design phase, have not been validated. This implication results from this thesis' cross-sectional (i.e. one-shot) data collection method, imposing a one-time data gathering moment. Therefore, a distinction should be made between variables that have been identified in the first design phase and found their support during expert interviews, and the variables that have been identified in the second design phase and have thus not been validated. In order to minimize the possibility of adding variables that are not relevant, variables only were added under the condition that they are substantially supported, meaning that they; found support with a substantial amount of interviewees, were sufficiently aligned with literature, and/or could be deductively derived. Table 27 displays the contextual variables that have been included since the first design phase (and have thus been validated), and the variables that were added in the second design phase (which should be validated in future research). We conclude that the contextualization of business model variables is delivered by 27 contextualized variables that have been validated (left side of Table 27) and 26 contextualized variables that should be validated in a new round of interviews (right side of Table 27).

Table 27: List of variables that have been drafted in the 1st design phase vs. in the 2nd design phase

Contextual variables that have been drafted in the first design phase and validated in the second design phase	Contextual variables that have been identified in the second design phase, and should be validated
Perceived value of the infrastructure	
1. Latency and jitter	1. Created value with IoT app
2. Raw amount of data	2. Investment cost for IoT software and devices
3. Data privacy and secrecy	3. Business value of the IoT application
4. Security	4. Storage and computing capability
5. Context awareness	5. Accessibility/reachability of the data
6. Mobility support	6. Amount of updates and upgrades

7. Connectivity availability and stability/reliability 8. Energy constraints of IoT devices	7. Speed and uncertainty of scalability
Switching cost	
9. Possibility of system- and process integration 10. Easiness of platform openness	8. Open standards, APIs and libraries of IoT app Complexity- and lead time of migration 9. Opportunity cost of downtime- or system failure during migration 10. Low initial investment trail-and-error possibility
Customer base / revenue source	
11. Installed base of IoT app that may directly benefit from the infrastructure 12. Maximum potential market size of IoT app 13. % of data on edge vs. cloud, and additional data potential	11. Time to consume 12. Possibility of support/maintenance contracts 13. Possibility of platform ownership in IoT market 14. platform leverage- and data ownership that can be translated into value
Relative infrastructure cost	
14. Required scale of the infrastructure	15. Protection necessity of edge nodes from their environment 16. Presence/absence of edge nodes and mobile network on site 17. Geographical location of IoT app
(Financial) Risk	
15. Needed initial investment 16. Maturity of IoT application	18. Possibility of iterative roll-out 19. Exposure/legal consequences of system failure 20. The de-facto standard for financial arrangements
IoT application's ecosystem (health)	
17. Ecosystem robustness 18. Ecosystem productivity 19. Ecosystem diversity	21. Non-financial resources of ecosystem players
Financial feasibility	
20. Needed initial investment 21. Financial resources of IoT partners 22. Access to resources	22. Variability of IoT app's computational location between edge nodes and/or the cloud 23. Difficulty of billing
Technical feasibility	
23. Scale of implementation 24. Presence/absence of standards and libraries in IoT app 25. Heterogeneity and modularity of devices, services, libraries, programming languages and standards in IoT app	24. Maturity of the infrastructure's elements needed to fulfill the requirements

Organizational feasibility	
26. Number of stakeholders 27. Stakeholders' IT and IoT experience/knowledge	25. Stakeholders' internal complexity, coherency and responsibility clarity 26. Stakeholders' culture and vision towards innovation throughout the whole organization

Objective 2: The tool's output should be an indication about the business potential of edge computing for the IoT application under analysis.

In the demonstration phase, the case *predictive maintenance in industry 4.0* was analyzed. In the ten-step process by which the tool should be applied, the final (tenth) step provides an indication about the business potential of edge computing for predictive maintenance. Whereas it does not provide us with a dichotomous answer, it does provide an elaborate explanation about its potential. The demonstration phase displayed that the tool possesses substantial explanatory power to unfold that considerable value can be gained for the network of companies that would provide an edge computing solution for predictive maintenance. Furthermore, because large-scale implementation of predictive maintenance is technically not feasible at this moment, substantial customer value cannot be effectuated. Additionally, organizations in industrial manufacturing are organizationally not ready for major shifts towards the IoT domain of predictive maintenance. Finally, the tool has indicated that, if these issues are resolved, there is a major potential for edge computing for both the customer and the potential providers. The tool's output in the demonstration phase then stipulates that potential of edge computing for predictive maintenance in industry 4.0 lays in the future instead of the now. Hence, the demonstration has displayed that the tool contains the capacity to provide an indication about the potential of edge computing for an IoT application under analysis. We conclude that this design objective has been met.

Objective 3: Edge service providers and IoT service providers should be able to use the tool.

In order to adequately apply the tool, both a customer-centric as well as provider-centric view is required. First, the customer value that is created should be identified (customer-centric view). This should be done by asking potential adopters about their IoT application and corresponding requirements. One would get a biased assessment if edge service providers would be the ones providing estimations about the customer value of edge customers. Therefore, it is of importance that customers (i.e. IoT application providers) provide input for these viable. On the other side, the value that is created for the network of companies providing an edge infrastructure (i.e. network value) should be determined (provider-centric view). This means that, the contextual variables that are related to the provider's value should be filled in by edge providers themselves, as customers cannot be expected to provide representative information about the value creation mechanism of edge computing for edge providers. On the feasibility aspect, both a customer-centric and provider-centric view are required in order to adequately formulate the problems that may make roll-out financially, technically or organizationally complex. The tool thus requires the input of both edge service providers and IoT service providers. Interviewees have also indicated that it may be required to interview all parties in the ecosystem in order to acquire unbiased information. Based on these indications, it is not recommended for edge providers or IoT providers to apply the tool in isolation. They should rather collaborate in order to gain maximum utility from the tool. On the positive side, the tool may facilitate and drive the communication and relations between customers and providers. On the negative side, this implies that maximum utility of the tool cannot be effectuated if it is applied by a sole edge provider nor by a sole IoT provider, making application a resource intensive process. However, the collaborative process that is required in order to apply the tool provides us with an ample indication that the tool can be used by edge providers and IoT service providers. Therefore, it is concluded that this design objective has been fulfilled. In order to allow the tool to be applied in an isolated environment, thus not requiring collaboration, future steps could be taken in order to make the contextual factors quantitatively measurable, reducing the bias resulting from the subjectivity of qualitative assessment.

Objective 4: By using the tool, edge providers and IoT providers should be able to formulate arguments that elaborate upon the business potential of edge computing for distinct IoT applications.

In the tool's 10-step application, an explanation for each contextual input variable (i.e. IoT application's characteristics) should be provided. This means that, for proper application of the tool, one is required to elaborate why and how a certain factor applies. In the final step of the application, a conclusion formulated based on the description of the contextual factors that have been explained in the first nine steps. The description per variable, as well as the conclusion that follows from it, constitutes a qualitative assessment. Hence, it requires the ones applying the tool to provide explicit argumentation for the factors' interaction. This means that the tool's fourth design objective, aimed to enabling edge providers and IoT providers to formulate arguments, has been fulfilled.

Looking at the demonstration phase, this is confirmed. By following the 10-step process of applying the tool, arguments have been provided in order to describe the potential of predictive maintenance in industry 4.0. Based on interviewees' input, the interaction of each variable was explained. Then, based on these explanations, plus the relative weights that indicate the relative importance among the nine generic factors, an elaborate conclusion about the potential of edge computing for predictive maintenance in industry 4.0 was formulated. The qualitative assessment required us to provide logical arguments about the business potential of edge computing for predictive maintenance in industry 4.0. The tool's outcome suggested that there is currently no substantial potential because of a lack in customer value that can be generated, as well as the organizational complexities that arise in the industry. Further argumentation then suggests that a bright future may await for edge computing for predictive maintenance in industry 4.0 if main challenges are addressed. More specifically, the reverse salient regarding technical and organizational feasibility need to be solved Based on this elaborate output of the demonstration phase, it is concluded that the qualitative assessment of the tool requires one to provide an logical arguments.

Objective 5: Use of the tool should clarify how edge computing creates value for potential adopters (i.e. IoT application providers).

By including the variable *Customer value*, which was extracted from the STOF model, emphasis is placed on how an edge infrastructure may create value for potential adopters. The customer value is in turn explained by the perceived value of the infrastructure and the switching cost that customers incur when switching towards the respective edge paradigm. The perceived value of the infrastructure is explained in twofold. First, the business value of the IoT application under analysis, that is effectuated by using an edge infrastructure, explains a part of the perceived infrastructure value. Second, the match between the demanded quality of service (dependent on the infrastructure requirements of the IoT application) and the delivered quality of service, explains the second part of the perceived infrastructure value. Then, based on the switching cost that a customer may incur (related to the interoperability and the migration cost), part of the customer value may be depleted. The contextualization of these generic variables towards the edge computing domain provides an elaborate clarification about how edge computing may create value for its users.

The latter has been displayed in the demonstration phase. The main indicator that sufficed as argument for a lack of current potential for edge computing in predictive maintenance applications, was the lack of customer value that resulted from a scalability problem of the solution. Whereas edge computing may provide a couple of contributions to predictive maintenance, its biggest value (for this application) lays in the ability to aggregate and process enormous amounts of data that could not be processed with other infrastructures. However, because of the heterogeneous devices and standards, large scale implementation of predictive maintenance is not feasible. Subsequently, the biggest contributor of edge computing for predictive maintenance cannot be delivered. Furthermore, as large-scale implementation of predictive maintenance solutions is not feasible, the business value of the IoT application itself is only a fraction of its potential as well. This explanation indicates that tool has clarified how edge computing may deliver value to the customer and what reverse salient is currently blocking it. Therefore, it is concluded that the design objective aimed at clarifying how edge computing creates value for potential adopters, has been fulfilled.

Objective 6: In order to guide the process of informed decision making, an explicit description about how increase/decrease and presence/absence of the exogenous characteristics of an IoT application impact the business model viability and feasibility of edge computing should be elaborated in the tool.

Based on the literature reviews, informal talks, and input provided by the eleven interviewees, in the second design phase of the tool, an explanation of each contextual variables' (60) interaction with it the corresponding generic variables (9) has been described. These descriptions unfold how the increase/decrease and presence/absence of the respective variable which is inherent to an IoT application, impacts the corresponding generic variable.

Looking at the demonstration phase, an explanation about how each of the 45 contextual input variables applies to predictive maintenance in industry 4.0 has been exemplified. Therefore, the way in which the tool is applied, and should be applied, encompasses the indication about how increase/decrease and presence/absence of the 45 IoT application characteristics impacts the nine generic factors, which in turn impact the business model feasibility and viability of edge computing. Hence, this design objective has been fulfilled. Whereas a description about the interaction of variables (i.e. increase/decrease or presence/absence) has been unfolded, no quantifiable measurement was established. This implies that the tool constitutes a subjectivity bias that is contingent to the qualitative assessment of each variable. Further research could be done in order to quantify the tool and thereby partially mitigate the subjectivity bias.

Objective 7: In order to enable accurate identification of the business potential, the relative importance of factors that influence the business model viability and feasibility of edge computing should be distinguished.

During the interviews, the best-worst multi-criteria decision-making method has allowed us to rank the 9 generic factors on their relative importance. The choice to solely rank these generic factors (and thus not the contextual factors) was made because of a threefold reasons. First, ranking the generic factors should provide substantial utility in the process of distinguishing between primary- and secondary determinants for the potential of edge computing for IoT applications. Second, as research about business models of edge computing is scant, this is the first research that has contextualized generic business model variables towards the edge domain. Hence, the researcher could not guarantee that the factors that were drafted in the first design phase are comprehensive. This would then have implications, as the Best-Worst-Method requires a comprehensive set of variables in order to get meaningful results. The assumption that the initial set of variables is not comprehensive has been confirmed in the second design phase, where 15 contextual variables have been adjusted and 27 contextual variables have been added based on the expert interviews. Lastly, because of time and resource constraints (i.e. 6 month timeframe of thesis research and 1.5 hour interviews), it was not feasible to rank the relative importance of all contextual factors in the interviews while fulfilling the other (3) interview objectives.

Then, the cross-sectional data gathering method of this thesis research resulted in one round of interviews that was conducted. Resulting from that, the tool's contextual variables had to be validated on their relevance and comprehensiveness in the same interview round that the generic variables were ranked on their relative importance. This has implications as a substantial amount of variables have been adjusted, added and removed. Furthermore, the naming of (some of the) generic variables has been refined in order to make them more adequate. Whereas the ranking that has been established should still provide us with some utility, the reliability of the exact weights cannot be guaranteed. Additionally, the limited amount of interviewees (10) that provided input for the BWM resulted in a considerably high coefficient of variance for some variables. This impacts the reliability of these variables' weights, meaning we are left with increased uncertainty. Because of these two implications, it is advisable to distinguish between variables of high importance, moderate importance and low importance instead of referring to the exact weights. Furthermore, a second round of interviews should be conducted in order to obtain the new weights of the respective model designed in phase 2.

Looking at the demonstration phase, it was observed that the ranking of relative importance played a significant role in adequate identification the potential of edge computing for predictive maintenance in industry 4.0. In this demonstration, the most important generic factor (perceived value of the infrastructure) formed a major problem. As the perceived value of the infrastructure that was lacking behind, it is argued that edge computing for predictive maintenance for industry 4.0 does provide major potential at this moment. However, based on the second most important variable, it was indicated that in the future (if major issues are resolved) there awaits a major potential market which can provide value for both the customer and the provider. This implies that the importance of the factors has guided our argumentation for the potential of edge computing for the respective IoT application. Without the relative weights, we might have ended-up with a different conclusion, as only two of the nine generic variables deliver problems for the potential of edge computing for predictive maintenance.

It has not been demonstrated how a factor which constitutes a low weight would affect the overall indication of the potential of edge computing for an IoT application. The guidance that is provided on this spectrum of the weights has not been gauged, meaning it may be advisable to demonstrate the tool to other cases in order to see how the ranking may guide the argumentation process in those cases.

9.2 Evaluating upon the demonstration process

In Table 32, Appendix A.6, one can observe that different variables have been elaborated upon to a different extend by the interviewees (i.e by the amount of quotes per global theme and per organizational theme).

Data for the demonstration has been gathered in interviews based on the old tool (i.e. design phase 1), thus not including additional/revised variables that have been added in the second design phase. This implication is imposed by the cross-sectional data collection method, meaning data was collected at one point in time. Interviewees thus provided suggestions for the new model, as well as input for the (old) model's interaction with the chosen use-case. Therefore, for some factors no input or limited input has been provided by interviewees.

Furthermore, looking at the number of quotes that have been codified per variable, it is observed that interviewees provided varying amounts of input per variable. For example; whereas for the needed initial investment of predictive maintenance in industry 4.0 only two quotes have been extracted, for the maturity of the IoT application thirteen quotes have been identified. These contextual variables both explain the generic factor *(financial) risk* and have both been included since the first design phase. Still, large deviation exists in the amount of input interviewees provided. This could be the result of two things. First, interviews were conducted in the limited time span of 1.5 hours with the main focus of refining the tool and secondary focus on demonstrating the tool on predictive maintenance. As a result, in some interviews, a limited amount of time was available for discussion of the tool's interaction with predictive maintenance. This decreased the level of detail in which some variables are demonstrated. Second, the variation among the amount of input interviewees provided for the tool's variables could be the result of a lack of understanding about the variable. Interviewees may feel more comfortable providing explanations about variables for which they have a substantial understanding. This could be the result of two things; first, the lack of clarity in the explanation about the variable for which interviewees may feel hesitant to seek clarification (Sekaran and Bougie 2010). Second, interviewees may have the tendency to answer topics for which they contain substantial background knowledge, meaning they neglect answering variables for which they are not completely sure about the interaction with the IoT application.

The varying degree of elaboration among variables has implications for demonstration of the tool, because each factor should be considered during demonstration. In order to formulate a more comprehensive demonstration of the tool, literature was consulted. Both scientific and grey literature (e.g. trend analysis, market reports, etc.) were used in order to supplement the interview data. For some variables, information was not available (i.e. data has not been gathered through interviews and was available on the Internet). Therefore, these variables were left blank. We conclude that a full demonstration was not possible. However, the framework was sufficiently demonstrated in order to display how it should be applied and how it meets de design objectives. Hence, the demonstration is satisfactory for this thesis research.

In order to resolve the main implications of the demonstration process as executed in this research, it is advisable to do another iteration of the demonstration phase. This should be done based on the new tool, including variables that were identified in the second design phase as well. This new iteration of the demonstration phase should be executed by means of interviews that have the sole objective to gather information for the demonstration. A structured process should be executed in order to ensure that interviewees provide information for each of the 45 input variables (if they do not feel comfortable answering this should be noted down as well). This can then be used in order to fully demonstrate the case and in order to analyze why there are inconsistencies of interviewees' input among the variables.

9.3 Limitations

Because of certain choices in the research process, a couple of limitations arise. This section evaluates upon the main limitations that follow from these research choices.

Three limitations result from the cross-sectional data collection method of this thesis. In one round of interviews data was collected in order to; validate the contextual variables, add new contextual variables, rank generic variables on their relative importance, and demonstrate the tool on a case. Within the time and resource constraints of this study, cross-sectional data collection was the only option that allowed for a substantial number of respondents to provide input for each of these parts. The first of limitation is that variables that were identified in the second design iteration (based on input of the interviews), could not be validated. The implications that follow from this were minimized by solely adding variables to the tool if they met specific criteria. More specifically, variables were only included if; a substantial number of interviewees supported the suggestion, the earlier found literature supported their relevance, or they could be deductively deduced from what was earlier found. Whereas these selection criteria minimize the possibility of including irrelevant variables, they have not been empirically validated.

Another limitation resulting from the cross-sectional data collection method is a potential inadequacy of the relative weights that have been attached to the nine generic variables. Whereas the nine variables have been tested on their comprehensiveness (i.e. all interviewees indicated these nine variables sufficiently explain the potential of edge computing for an IoT application), some of their definitions have been refined. Also the contextual variables that explain these generic variables have been adjusted. This implies that the exact weights that were deduced by means of the Best-Worst-Method cannot be guaranteed. However, as the general reasoning behind the generic variables still applies, we believe that these weights still provide a sufficiently valid indication about relative ranking. In order to filter for potential inaccuracy of the relative weights, variables can be grouped into three groups. The perceived value of the infrastructure and the customer base/revenue source are categorized in the group of high importance. The (financial) risk, IoT application's ecosystem (health), technical feasibility, and organizational feasibility, are of moderate importance. Lastly, the switching cost, relative infrastructure cost, and financial feasibility, are of low importance.

The third limitation that results from the cross-sectional data collection method unfolds in the demonstration phase of this research. Interviewees were asked to provide input about the contextualized variables of the tool that was designed in the first iteration. This implies that newly identified variables (identified in the second design iteration) were not included in the interview protocol. For these variables, data could thus not be gathered during the interviews. The implication that results from this is partially mitigated by supplementing interview data with information from literature. However, as the application of edge computing in predictive maintenance for industry 4.0. constitutes a novel problem, limited data was available. For some parts grey literature was used and for other parts no information could be gathered at all. Also the amount of quotes that interviewees formulated for the variables that were included since the first design phase, varied significantly. This could either result from time constraints of the interview, or from unclarities about certain variables. Following from these two observations, we conclude that full demonstration has not been done. As a result, the recommendation about the potential of edge computing for predictive maintenance in industry 4.0 could contain an error margin. Interviewees have however been asked about main problems that arise for predictive maintenance with respect to the nine variables. Therefore, we believe that the most prominent variables that influence edge computing's potential for this respective field have been identified in the demonstration. It is concluded that the demonstration's output is still sufficiently valid in order to formulate an accurate conclusion about the potential of edge computing for predictive maintenance in industry 4.0.

Another limitation results from this thesis' ambitious aim to cover a broad field of literature in the novel research field of edge computing. With the researcher's limited experience in academia, an understanding about the relevant concepts had to be built from scratch. This means that, because of time and resource constraints, this research constitutes a high-level analysis of the relevant literature. Hence, for some concepts, a more in-depth analysis might reveal new insights. This explicit choice is aligned with the high-level strategic analysis that is required in order to assess business potential. Also, it can be expected that the most prominent aspects have been included (i.e. the tool has been validated by 11 field experts). It can however not be guaranteed that the tool includes a comprehensive set of factors. Comprehensiveness was not the aim of this thesis, nor required to provide an ample indication about the potential of edge computing for an IoT application domain. Instead, deriving the most important set of variables is sufficient.

The concept of edge computing is interwoven with the concepts of blockchain, Artificial Intelligence (AI) and 5G. First of all, 5G and edge computing may complement each other and thereby provide a reinforcing effect (Taleb et al. 2017). Second, AI may grant capabilities to individual edge nodes e.g. in terms of enhanced communication schedules (Li et al. 2017). On the other hand, AI (pre) processing may become one of edge computing's major customers. Third, blockchain solutions may be used to orchestrate edge computing's hierarchical- and distributed control systems (Stanciu 2017). However, because of time and resource constraints, the choice was made to exclude these concepts from the research scope. We believe that the topics of 5G, Blockchain, and AI, require separate attention. This research was the first step towards a better understanding of business models behind edge computing. Therefore, the explicit choice to exclude these concepts was required in order to define a feasible scope.

Lastly, the pricing mechanism that may be used to divide the customer surplus and provider surplus has not been studied in detail. Whereas it became apparent that if the customer value is increased, a higher price may be asked in order to increase the provider value. The exact mechanism by which this effect can be explained has not been studied. This means that we do not know how customer value affects price. This topic has been left out of scope because it is an indirect effect of customer value, which has been extensively described in this study. Therefore, we believe that it is not crucial to understand the pricing mechanism in order to do a high-level evaluation of the business potential of edge computing.

9.4 Conclusion

In the previous section, arguments were provided for how the designed tool meets the design objectives as drafted in Chapter 4. From that, it is concluded that the designed tool meets all seven design objectives. Now, sub question three; *To what extent does the designed tool facilitate informed decision making for selecting IoT applications in which edge computing delivers a viable and feasible business case?* can be answered. This sub-question is answered by indicating how the tool's seven solutions meet the design objectives and thereby facilitate informed decision making.

S1. The tool provides a set of 45 contextual input variables that explain 9 generic variables. These variables enhance our understanding about business models for edge computing. This facilitates informed decision making, as it provides a concrete list of variables that should be analyzed.

S2. Whereas the output of the tool does not provide a dichotomous answer, it's output is a formulated indication about business potential of edge computing with respect to the IoT application. This guides informed decision making, as the qualitative answer is sufficiently elaborate in order to decide whether to enter an IoT application area or not.

S3. In order to minimize subjectivity bias resulting from the qualitative input of the tool, both a customer-centric and provider-centric view is required in order to adequately apply the tool. Hence, the tool is targeted at edge providers and IoT providers as they should collaboratively apply the tool in order to get optimal results.

S4. The qualitative assessment that is required for the tool's 10-step implementation, has as result that the conclusion which follows (in the 10^{th} step), represents a logical argumentation describing how the generic variables impact the business model potential. This elaborate answer about the business potential of edge computing guides informed decision making, by providing explicit arguments instead of solely an indication.

S5. By incorporating the business model variable *customer value*, the tool includes an assessment of the business value edge computing brings for potential adopters. Hence, the by applying the tool, potential adopters can understand the business value edge computing may- or may not contribute to their IoT application area.

S6. The tool provides a description about how each variable's increase/decrease and presence/ absence impacts the respective generic variable (see appendix A.4). This provides guidelines for informed decision making as it helps in translating one's knowledge about edge computing and the focal IoT application, into an assessment of the business potential.

S7. In the demonstration, the tool's distinction among the relative importance of generic variables displayed to provide guidance. This solution especially provides guidance in the prioritization of findings that are derived from the qualitative assessment of the tool's generic variables. Hence, design objective seven is fulfilled.

Finally, in the demonstration phase, the conclusion was that there is currently no substantial potential for edge computing in predictive maintenance in industry 4.0. Based on this, companies are recommended to refrain from making big investments in this market (i.e. with regards to edge computing). With this answer, the ambiguity that resided around the potential of edge computing in the IoT application area is resolved. Hence, based on this demonstration, it is concluded that the tool provides clear-cut guidance in the assessment of the business potential of edge computing for IoT application areas and thereby facilitates informed decision making.

10 Conclusion

Having executed all steps of the DSRM, the conclusion of this thesis research can be presented. In order to do so, the section 10.1.1 elaborates how the main question has been answered. Furthermore, section 10.1.2 explains how main findings can be generalized. Section 10.1.3 and 10.1.3.2 unfold this study's scientific and managerial contributions. Based on the implications of this research, section 10.2 provides recommendations for future research areas. Lastly, paragraph 10.3 discusses how this thesis research is aligned with the Management of Technology (MoT) program.

10.1 Main findings

In order to formulate the main findings of this research, first the main question is answered in section 10.1.1. The findings are generalized to a broader field in section 10.1.2. Hereafter, an argumentation for this research's scientific- (section 10.1.3) and managerial contribution (section 10.1.3.2) is provided.

10.1.1 Answering the main question

The aim of this research was to design a business model viability and feasibility tool, that is contextualized towards the edge computing domain and can be used to identify the potential of edge computing for IoT application areas. Based on that identification, the tool should allow for informed decisions to target IoT application areas that hold substantial potential for both customers and providers. In turn, this aimed to reduce the uncertainty revolving around business models of edge computing for distinct IoT applications and thereby contribute to breaking the current deadlock where neither infrastructure providers nor IoT providers are incentivized to invest in an edge ecosystem. In order to fulfill this objective, the main question was drafted as: *How can technical-, business- and organizational factors be included in a tool, that can be used to identify the business model viability and feasibility of edge computing in distinct IoT application areas?*

Main technical, business and organizational factors are elucidated in the tool through nine generic variables that explain the business model viability and feasibility. Ranking the relative importance of these generic variables for edge computing enhances the process of analyzing and providing arguments to derive from individual answers about the variables, towards a final conclusion of the business potential. Lastly, the process of contextualizing these nine generic variables towards the edge computing domain constitutes a major part of designing a tool that is able to identify the business potential of edge computing in distinct IoT application areas. Figure 33 displays a simplified version of the designed tool that results from answering the main question. Next sections elaborate upon the three parts that were outlined in this paragraph.

The business model variables of the STOF model and the structure of the XLRM framework provide suitable guidelines for design of the generic part of the tool. we argue that nine generic variables are relevant for analyzing the business model viability and feasibility of edge computing. The relevant business model viability variables are; perceived value of the infrastructure, switching costs, customer base/revenue source, relative infrastructure cost, (financial) risk, IoT application's ecosystem health. The relevant business model feasibility variables are; financial feasibility, technical feasibility, and organizational feasibility. Based on the expert interviews, we conclude that each individual variable is relevant and that these generic variables together provide a comprehensive set of factors that are needed to identify the potential of edge computing for an IoT application.

Ranking the relative importance of the nine generic variables provides additional utility to the ones using the tool, as it provides tangible guidelines to combine the results of assessing the individual variables into one final conclusion. Along those lines, in the process of identifying the business potential of edge computing for an IoT application, the outcomes of the variables; perceived value of the infrastructure and the customer base/revenue source count more heavily as these variables were identified to be the most important. The switching cost, relative infrastructure cost, and financial feasibility, make-up the least important set of variables, meaning their outcome should be weighted less in the process of analyzing the business potential. Lastly, the IoT application's ecosystem health, financial risk, technical feasibility, and organizational feasibility, are of moderate importance.

The contextualization of the nine generic variables towards the edge computing domain is relevant in order to draft a tool that is able to identify the business potential of edge computing for IoT applications. Main conclusions that are derived from the contextualization of the generic variables include:
Business model viability variables:

1. **Perceived value of the infrastructure (customer perspective):** For a potential adopter it is important to gain substantial value from the usage of an edge computing infrastructure. The value that is gained is explained through the adopter's infrastructure requirements and the value of an IoT application that is unlocked with the edge infrastructure.
2. **Switching costs (customer perspective):** When a potential user decides to switch from situation A to B (towards an edge infrastructure), it incurs switching cost. This research has found that for edge computing, the switching costs are dependent on the interoperability of old and new systems, and the migration cost for switching towards the edge paradigm.
3. **Customer base/revenue source (provider perspective):** For service providers, it is important that there is a substantial customer base as they aim to build upon their competencies, standards, and platforms, in order to drive down the marginal cost and reproduce similar infrastructures for multiple customers. This research found that it is relevant to look at the current installed base of an IoT application that directly benefits from the architecture and thereby generate short term revenue, but also at the future potential customer base of the IoT application. Furthermore, additional revenue sources that edge computing may generate are relevant for edge providers in order to assess the potential of edge computing for an IoT application.
4. **Relative infrastructure cost (provider perspective):** The major driver for the relative infrastructure cost is the required scale of the infrastructure. Hence, for IoT applications that require a massive scale of implementation, edge computing has a high relative cost. Also the geographical location and the protection necessity of edge nodes from their environment could drive-up the cost. One factor that drives down the relative costs is the number of edge nodes that are already present on the site.
5. **(Financial) risk (provider perspective):** The financial risk an edge provider takes when rolling-out an edge infrastructure is explained through the needed initial investment, the maturity of the IoT application, and the legal consequences of system failure. Part of the risk can be mitigated by iteratively rolling-out the edge infrastructure and thereby decreasing the initial investment, or by setting up a co-investment and co-ownership as financial arrangement which decreases the initial investment for an edge provider.
6. **IoT application's ecosystem health (provider perspective):** Distinct IoT applications are delivered within different ecosystems. A healthy ecosystem provides value to the members that depend on it. Hence, for potential edge providers, it is relevant to look at the ecosystem health (i.e. robustness, productivity, and diversity) as well as the non-financial resources that players in the IoT ecosystem bring to the table.

Business model feasibility variables:

7. **Financial feasibility (provider perspective):** In order to effectuate an edge infrastructure, there should be a financially achievable solution. The height of the initial investment significantly impacts the financial feasibility. However, access to external resources from IoT providers reduces this complexity. Furthermore, the difficulty of billing edge computing users, which results from the computational location variability of an IoT application, makes financial utilization increasingly complex.
8. **Technical feasibility (provider perspective):** The technical feasibility plays a prominent role in the determination whether there is an achievable solution to roll-out the edge infrastructure. The scale of implementation significantly complexifies an edge roll-out as it involves exponentially increasing overhead, management and orchestration issues. The presence of standards partially reduces this complexity by enhancing collaboration and interoperability between systems and devices. However, an IoT application's heterogeneity or modularity of devices, services, libraries, programming

languages, and standards, could make implementation complicated because of the large range of interfaces, incompatible runtimes, management of standards, etc. that have to be managed.

9. **Organizational feasibility (provider perspective):** Lastly, the organizational complexity determines if an organizationally achievable solution can be established. Projects that require the involvement of a large number of stakeholders are significantly more complex, as visions and interests among them need to be aligned. Also, the internal complexity, coherency, and responsibility clarity of companies themselves are important as this could potentially complexify the decision-making process. Furthermore, stakeholders' culture and vision towards innovation throughout the whole organization impact the adoption process. Lastly, a lack of stakeholders' knowledge of IT and IoT significantly increase the roll-out of an edge infrastructure.

Demonstration of the tool on the case of predictive maintenance in industry 4.0, showed that there is currently, as long as major challenges are not over won, no substantial value for edge computing in this respective field. Hence, based on this demonstration outcome, it is concluded that the tool contains the capability to reduce uncertainty about the potential of edge computing for IoT applications.

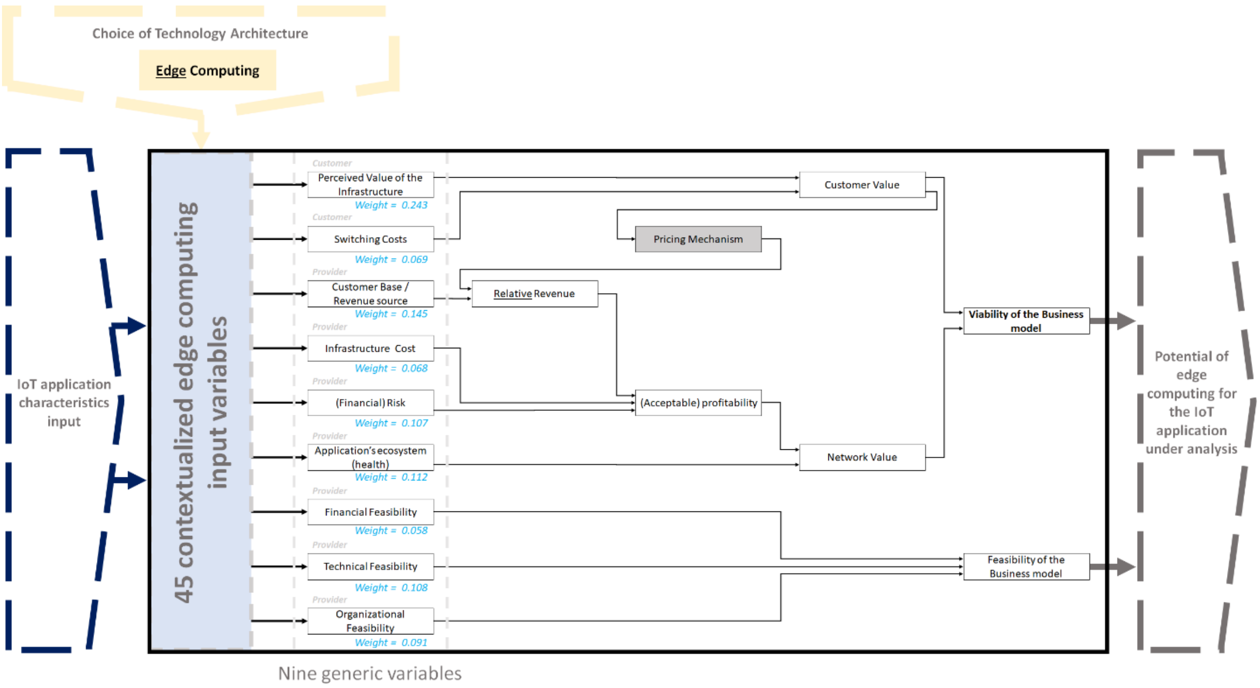


Figure 33: Simplified version of the tool for identifying the business potential of edge computing for IoT applications

10.1.2 Generalizing main findings

Whereas the tool was designed with the main aim to equip industry practitioners with a way to identify the business potential of edge computing for distinct IoT applications and thereby facilitate informed decision making, main findings can be generalized towards a broader field. Main findings can be generalized on two distinct fields. First, the nine generic variables of the tool are applicable to a broader field of study than solely edge computing. Second, the contextualized edge computing variables provide value apart from the business model tool. More specifically, the variables provide us with a better understanding about business model variables for edge computing in general.

In order to display how the generic variables can be generalized, we refer to the working definition for edge computing: An approach, which is aimed at solving the inherent problems of cloud computing regarding IoT, shifting the computing power away from the centralized data centers and envisioning a decentralized computing infrastructure, offering the same utility computing service, but with close proximity to the user and data source, which can be organized in a Cloudlet-, Fog computing- or

Mobile Edge Computing IT solution. From this definition it is inferred that edge computing is a mobile service, delivered through a computing infrastructure, that aims to enable another service offering (IoT). This implies that, the generic part of the tool can be used for a broader purpose. More specifically, the nine generic variables may apply to any mobile service delivered through an infrastructure. This follows from the choice of the STOF business model ontology as guiding philosophy for drafting the generic part of the tool. The STOF model guides designers in the process of answering fundamental questions regarding the viability and feasibility of mobile service innovations. This implies that, the variables that were extracted from the STOF model are expected to apply to the broader field of mobile service innovations. Hence, the nine generic factors can be used to assess the business model potential of a mobile service, effectuated through an infrastructure, that provides value to another application. However, in order to use these generic factors, a contextualization per variable should be done.

Figure 34 displays the part of the tool that can be generalized towards the broader field of mobile service innovations. Examples of mobile services for which the generic tool can be contextualized are: Cloud computing, 5G, and optical wireless networks, among others.

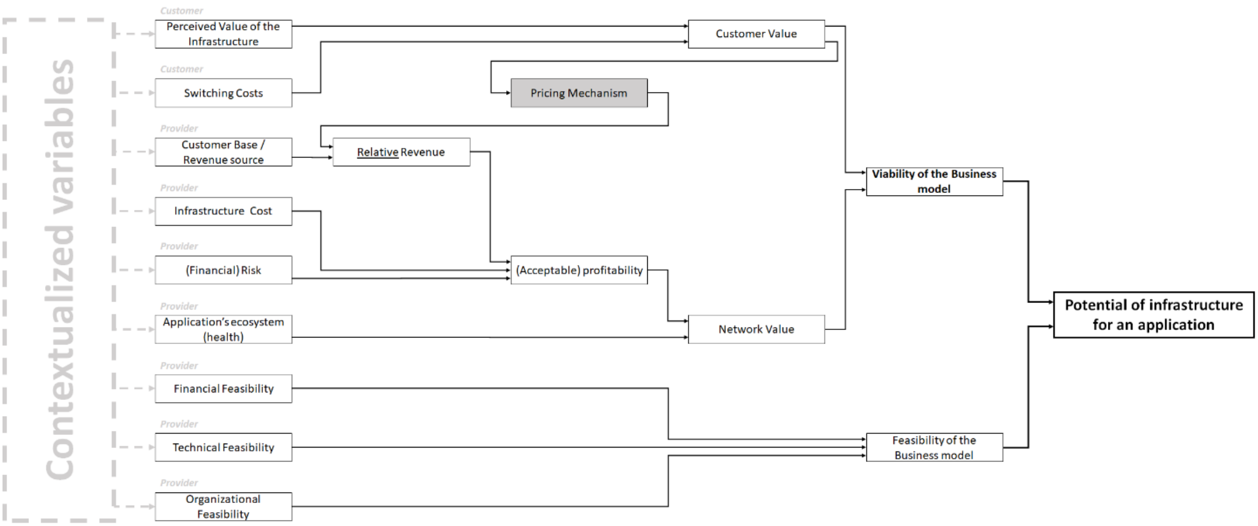


Figure 34: Generalized tool for identifying the business potential of a mobile service innovation, effectuated through an infrastructure, that unlocks another service offering.

The contextualized factors for edge computing do not only provide us with a tool that helps in identifying the potential of edge computing for distinct IoT applications, but it also provides a better understanding of the edge computing paradigm in general. First, the contextual factors provide us with a better understanding about how edge computing may provide value for customers. The customer value that edge computing generates is explained in twofold. First, the value that is unlocked by utilizing an edge computing infrastructure in order to effectuate a desired application, plays a major role in the perceived value of edge computing. For example, in the case of predictive maintenance in industry 4.0., the cost savings that could be effectuated by predictive maintenance, pay a prominent role in the assessment of the potential of edge computing for that application. The second way in which the value edge computing delivers to customers is explained, is through the infrastructure requirements that customers have. A customer may-, or may not decide to choose for an edge computing platform based on following 12 requirements: Latency and Jitter, Raw amount of data, privacy and secrecy, security, context awareness, storage and computing capability, mobility support, connectivity availability and stability/reliability, accessibility/reachability of the data, amount of updates and upgrades, speed and uncertainty of scalability, and energy constraints of IoT devices.

At a higher level of abstraction, the tool provides us with a better understanding about nine respective fields of edge computing. First, as explained in the previous paragraph, we have a better understanding about how an edge computing infrastructure creates value for customers. Second, we have a better understanding about factors that may drive-up the cost of switching towards an edge infrastructure for customers. Third, the tool provides us with a better understanding about how the customer base of potential IoT market segments for edge computing should be estimated. Fourth, the tool outlines factors that play a major role in driving-up the cost of owning, operating, maintaining and rolling-out an edge computing infrastructure. Fifth, we now have a better understanding about factors that impact the (financial) risk of service providers that aim to roll-out an edge infrastructure. Sixth, the tool provides us with a better understanding about how an IoT application's ecosystem is of importance for edge providers' decision to target an IoT market segment or not. Seventh, eighth, and ninth, we now have a better understanding about factors that impact the financial-, technical- and organizational feasibility of rolling-out an edge computing infrastructure. These nine respective fields may be used separately in order to solve different problems. However, in order to solve the problem of identifying the potential of edge computing for distinct IoT applications, the nine variables should be used collaboratively.

10.1.3 Scientific contribution

10.1.3.1 Contribution to business model literature of edge computing

The first scientific contribution of this thesis research is found in the contextualization of generic business model variables towards the edge computing domain. As has been identified in the problem identification, literature on the technical and organizational factors of edge computing is scant. This leads to a lack of understanding about edge computing business models in general. This research has contributed to that knowledge gap by contextualizing nine generic business model variables towards the edge computing domain. More specifically, this thesis research provides us with a better understanding about nine respective fields within the edge computing domain, which are; perceived value of the infrastructure, switching cost, customer base/revenue source, relative infrastructure cost, (financial) risk, IoT application's ecosystem (health), financial feasibility, technical feasibility and organizational feasibility.

As displayed in Table 28, this research's scientific contribution to the business model literature on edge computing, unfolds in 45 exogenous input variables that are relevant for assessing the potential of edge computing within distinct IoT applications. 24 of these 45 contextualized input variables have been described in literature before. However, they were scattered over numerous scientific articles (i.e. no article enumerated this list of variables that are relevant for edge computing). Hence, the contribution to these variables, lays in their aggregation into one business modelling tool. 14 of these 24 variables were adjusted. For these variables an additional contribution is delivered in the refinement of their definitions and/or interactions within the edge computing domain. On the right side of Table 28, the 21 variables that were added based on interviewees' input are listed. To the best of the researcher's knowledge, no literature has directly described the interaction of these variables with edge computing. This means that, this thesis research discovered 21 new business model variables that are relevant for edge computing. Whereas it can be argued that these variables themselves are not new, their relation to edge computing has not been described in scientific literature before. Therefore, this is considered a valuable contribution to the business model literature on edge computing.

Table 28: Variables that constitute the scientific contribution for contextualization of business model variables towards the edge computing domain

Contextual input variables for which scientific contribution lays in their aggregation into one business modelling tool. ** Variable has not been adjusted in second design iteration*	**Contextual input variables for which no literature was found to describe their relevance for edge computing, meaning this is the first research that describes their relevance.**
Perceived value of the infrastructure	
1. Latency and jitter	1. Created value with IoT app
2. Raw amount of data*	2. Investment cost for IoT software and devices
3. Data privacy and secrecy	3. Storage and computing capability
4. Security	4. Accessibility/reachability of the data
5. Context awareness*	5. Amount of updates and upgrades

6. Mobility support 7. Connectivity availability and stability/reliability 8. Energy constraints of IoT devices*	6. Speed and uncertainty of scalability
Switching Cost	
9. Possibility of system- and process integration 10. Easiness of platform openness*	7. Complexity- and lead time of migration 8. Opportunity cost of downtime- or system failure during migration
Customer base/revenue source	
11. Installed base of IoT app that may directly benefit from the infrastructure 12. Maximum potential market size of IoT app* 13. % of data on edge vs. cloud, and additional data potential	9. Time to consume 10. Possibility of support/maintenance contracts 11. Possibility of platform ownership in IoT market
Relative infrastructure cost	
14. Required scale of the infrastructure	12. Protection necessity of edge nodes from their environment 13. Presence/absence of edge nodes and mobile network on site 14. Geographical location of IoT app
(Financial) risk	
15. Maturity of IoT application*	15. Possibility of iterative roll out 16. Exposure/legal consequences of system failure 17. The de-facto standard for financial arrangements
IoT application's ecosystem (health)	
16. Ecosystem robustness* 17. Ecosystem productivity* 18. Ecosystem diversity*	18. Non-financial resources of ecosystem players
Financial feasibility	
19. Financial resources of IoT partners*	19. Variability of IoT app's computational location between edge nodes and/or the cloud
Technical feasibility	
20. Scale of implementation 21. Presence/absence of standards and libraries in IoT app 22. Heterogeneity and modularity of devices, services, libraries, programming languages, and standards, in IoT app	
Organizational feasibility	
23. Number of stakeholders 24. Stakeholders' IT and IoT experience/knowledge	20. Stakeholders' internal complexity, coherency, and responsibility clarity 21. Stakeholders' culture and vision towards innovation throughout the whole organization

10.1.3.2 Contribution to the process of business model development

The scope is shifting from theoretical business model ontologies, towards more practical approaches of business model tooling. This is crucial, as business model thinking should contribute to practical solutions. Currently, the scientific field of business model tooling is mainly focused at business model design, testing, and implementation. Also, the majority of business model tooling approaches focus on financial evaluation, thus neglecting non-financial aspects. This research contributes to the under-studied scientific field of business model tooling for informed decision making in initial stages of the business model development process.

We argue that before designing, testing, and implementing, business models (i.e. what the majority of tools is focused on), an initial assessment about the business potential is beneficial. This is because business model design, testing, and implementation, constitute a time and resource consuming process. This study delivers a business modelling tool that can be used to identify the business potential of edge computing for distinct IoT applications, based on business model viability and feasibility. As displayed in Figure 35, the tool that is used to identify the business model potential, is utilized prior to the business model design phase. The input of the tool is a mobile service, in a specific application area, without explicit ideas about the business model logic behind it. The output of the tool is a qualitative indication about the potential business model viability and feasibility in an application area(also without a design of the business model). Only if there is substantial business model potential, the business model design phase is entered. This process increases the efficiency of business model development, as it allows for an initial quick assessment before starting the resource intensive business model design phase.

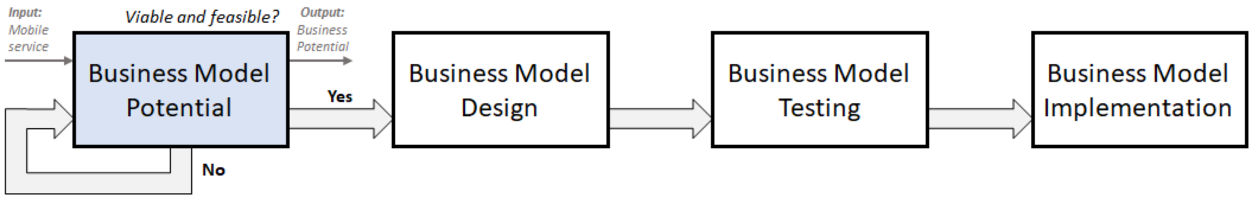


Figure 35: Contribution to the process of business model development

Whereas the tool was specifically designed for the edge computing domain, from section 10.1.2 we conclude that the nine generic variables; perceived value of the infrastructure, switching costs, customer base/revenue source, relative infrastructure cost, (financial) risk, IoT application's ecosystem (health), financial feasibility, technical feasibility, and organizational feasibility, can be generalized towards the broader field of mobile service innovations. Hence, the generic part of the tool can be used as guide to assess the business potential for mobile service innovations in distinct application areas. However, in order to use these generic variables, they should be contextualized to the new unit of analysis. Two examples of mobile services for which the generic tool can be contextualized are: Cloud computing and 5G.

The designed tool adds to existing tools that can be used to assess the business potential. First, it differentiates from business model tools that are focused on financial evaluation, by including non-financial variables (i.e. the technical and organizational domain). Secondly, it adds to the business tool drafted in the book of Bouwman et al. (2008), which allows for identification of the business potential based on business model viability. Thirdly, the designed tool is more comprehensive than the value proposition canvas Osterwalder et al. (2014), which can be used to identify the business potential based on the value that is created to customers. We argue that identification of customer value is not sufficient to assess the potential. Instead, for a viable business model, there should be sufficient value for both the customer and the network of companies that deliver the service. Solely identifying a viable business model is also not sufficient to provide an ample indication about the business potential. Instead, there should be both a viable and feasible solution. This is especially relevant in highly complex environments (e.g. edge computing) where roll-out can be technically, organizationally, or financially, difficult. Neglecting feasibility may lead to a very attractive business case as output (i.e. a viable business model), but without an achievable solution, it is impossible to effectuate the desired business case.

10.1.4 Managerial contribution

On the managerial side, the lack of understanding about edge computing business models led to an uncertainty about the actual business value of edge computing for distinct IoT applications, resulting in deadlock situation where neither edge providers nor IoT providers are incentivized to engage in an edge computing ecosystem. The designed tool contributes to solving implications that resulted from this problem area on behalf of both the adopter (i.e. IoT providers) and the provider (i.e. edge providers).

Potential adopters can use the tool in order to identify and argue if edge computing provides a suitable solution for their IoT application area. These adopters should also use the tool to analyze if an edge computing infrastructure provides sufficient value for edge service providers. This is crucial, as edge service providers need to gain substantially in order to incentivize them to facilitate roll-out of the desired infrastructure. The tool thus helps potential adopters in their process of evaluating the innovation (i.e. edge computing) and identifying which advantages and disadvantages it may bring to them specifically. In that sense, by using the tool, potential adopters have an enhanced amount of innovation-evaluation information to their access. As can be deduced from Rogers (2003) innovation diffusion theory, the increase in accessible innovation-evaluation information, reduces uncertainty. Reduced uncertainty in turn contributes to increased adoption rates, as potential customers have better mains to assess the value of an innovation to their business. Hence, we argue that the tool contributes to reducing the uncertainty about the edge computing innovation and thereby has the potential to enhance adoption rates. These increased adoption rates are crucial for incentivizing potential edge computing providers to invest in an edge computing ecosystem. This is because increased adoption enlarges their customer-base and thereby drives revenue. Another way in which the tool provides value for potential adopters, is in a scenario where they already decided to effectuate an edge infrastructure, but development and/or utilization is staggering. The tool can then be used in hindsight, in order to analyze which aspects are the reverse salient staggering successful roll-out. This information is then used to make a decision to dedicate efforts towards solving the identified problem, or if the problem cannot be resolved in the short-run, abandon the idea. By doing so, the tool contributes to the process of problem identification for failed roll-outs of an edge infrastructure. Lastly, potential adopters may plan to deliver an IoT application in the future (i.e. a future IoT application). If edge computing is expected to deliver substantial value to this application area, the tool helps in identifying to what extent the potential adopter is organizationally, financially, and technically, ready for roll-out (i.e. the feasibility aspect of the tool). Identified complexities can then be resolved prior to the future roll-out, in order to smoothen the implementation process.

For potential providers, the biggest unknown was related to the analysis of the business potential edge computing has for distinct IoT application areas. Because of this unknown, these providers were not able to make informed decisions to target IoT markets that hold substantial business potential. Also, this unknown resulted in a classical bootstrapping problem, where potential providers were reluctant to invest in an edge computing ecosystem. With the designed tool, potential edge computing providers can now analyze this business potential. As the tool is requires a qualitative assessments for each variable, it pushes the ones applying it to provide logical arguments. Subsequently, through the 10-step process of applying the tool, the designed artifact facilitates the formulation of informed decisions by means of logical arguments. We argue that this output provides contributions for potential edge computing providers in two ways. First, the identification of business potential enables potential edge providers to make choices provide substantial business value. Hence, informed decisions that result from the tool allow potential providers to solely target markets that contain considerable potential. Second, the logical arguments that substantiate the tool's conclusion, provide proof for the business model viability and feasibility. These arguments can then be used to convince edge providers to invest in an edge computing ecosystem. Hence, the tool's output contributes to breaking the current deadlock situation.

10.1.4.1 Contribution to edge computing for predictive maintenance in industry 4.0.

Next to the managerial contribution in the general domain of edge computing, the demonstration phase provides us with an indication about the potential of edge computing for predictive maintenance in industry 4.0. More specifically, the tool indicates that currently, there is no substantial potential for predictive maintenance in industry 4.0. This results from the technical infeasibility of large-scale roll-out of predictive maintenance in industry 4.0, because of the large heterogeneity of devices and standards. As a result, edge computing's largest contribution to the idea of predictive maintenance, which is; enabling decentralized computational offloading for the enormous amount of data streams (i.e. mitigating bandwidth requirements and reducing transmission cost), is not touched upon. Furthermore, large scale roll-out is a prerequisite in order to gain maximum value out of predictive maintenance in terms of cost saving. As this is not possible, edge computing does not unlock substantial customer value and the business model cannot be deemed to be viable. However, if major challenges are overcome, a major potential market awaits, one that is manifold of the current market and one that may provide substantial value to the customer as well. For potential edge providers, the tool identifies that predictive maintenance in industry 4.0. provides an attractive potential application area. To conclude, we advise edge providers to make small initial investments for edge computing in predictive maintenance in order to solve the current problems. Until those problems are resolved, we advise not to target on major roll-out in this IoT application area. Instead, providers should look for other IoT applications in order to generate short-term revenue. This output of the tool contributes to the field in two ways. First, it identifies that major investments in this respective IoT application area are not recommended as there is currently no substantial customer value. The ambiguity that revolved around the potential that edge computing delivers to predictive maintenance has thereby been solved. Second, two problem areas that hinder the potential are identified. Hence, the tool contributes to the field of predictive maintenance in industry 4.0 by pointing out specific areas that should be focused on.

10.2 Recommendations

10.2.1 Applying the tool on other IoT application areas

It is recommended to apply the tool to other IoT application areas in order to uncover their potential. This research demonstrated the tool on one IoT application area. The tool's output suggested that this application area currently does not hold substantial potential. However, as identified in section 3.1.1.3, there is a myriad of potential IoT application areas for edge computing. Applying the tool on other IoT application areas should thus be done in order to discover an area that holds substantial value. We recommend only to enter an IoT application area if the tool's output suggests that there is substantial potential. Several companies are recommended to take initiative to apply the tool:

- **Potential edge providers (e.g. Microsoft, Google, Amazon, Siemens):** It is recommended that these types of companies use the tool in order to make informed decisions to enter IoT markets that hold substantial potential.
- **Network providers (e.g. Huawei, KPN, Liberty Global, Vodafone):** Edge providers are potential customers for network providers. Hence, we recommend network providers to use the tool in order to support potential edge providers in targeting viable and feasible IoT application areas.
- **Consultants (e.g. EY, Deloitte, PwC, KPMG):** The non-biased view of external consultants is relevant for applying the tool. These companies are recommended to use the tool in order to provide a non-biased assessments about the potential of edge computing in IoT application areas. With that, they can advise potential edge providers, network providers, and IoT service providers, about interesting IoT application areas that should be targeted.
- **IoT service providers (e.g. Waymo, Oculus, IBM):** We recommend these companies to use the tool in order to gauge if edge computing provides value for their service offering. It is also recommended for these types of companies to use the tool in order to estimate to what extent they are technically, organizationally, and financially, ready for roll-out.

10.2.2 Improving the tool

In order to solve the limitations of this research, this section provides a number of recommendations for further improvement of the tool. First of all, it is recommended to do a second round of expert interviews in order to validate the tool as drafted in design phase 2. This should help in validating the empirical relevance of the adjusted- and newly identified variables. Secondly, it is recommended to do another evaluation of the tool by means of a new interview round, where interviewees are asked about the clearness, usability and utility of the tool. Whereas the tool has been evaluated upon the design objectives as drafted in Chapter 4, the tool has not been evaluated by input of other respondents. Therefore, evaluating the tool by means of expert interviews provides enhanced insights about the tool's utility as experienced by industry practitioners. Third, it is recommended to research how the relevant domains of blockchain, AI and, 5G, impact the potential of edge computing for an IoT applications. These interrelated domains are large research topics and should therefore be separately researched. Fourth, it is relevant to deep-dive into the pricing mechanism, in order to see how an increase in customer value translates into an increase in price. Researching the pricing mechanism is relevant in order to determine adequate pricing of an edge computing service and in order to make a quantitative assessment of the expected returns for potential edge providers. Fifth, it is recommended to reweight the relative importance of the generic variables. This is especially relevant in order to enhance the reliability of the weights and thereby provide us with a better estimate. Sixth, it is recommended to simplify the tool. Whereas the manifold of variables that were identified in this research are relevant in order to answer the complex main question, it results in a tool that is relatively complicated. For scientific purposes it is argued that the identified variables are all relevant. However, for managerial purposes, simplification (i.e. reducing the amount of variables) can bring additional utility as it simplifies use of the tool. Lastly, it is recommend to uncover in what way the qualitative arguments that are part of applying the tool, can be substantiated with quantitative proof. By doing so, the subjectivity bias that is indulged by the qualitative assessment per variables is reduced.

10.2.3 Contextualizing the generic part of the tool towards other mobile services

For mobile services that are dealing with problems similar to those identified in this research (i.e. lack of understanding about business models, problems to identify high potential application areas, and/or problems convincing providers and adopters to engage with the innovation), we recommend to contextualize the generic part of this tool towards their focal mobile service. Examples of such mobile services are: Cloud computing, 5G, and optical wireless networks, among others. Doing so, contributes on two behalves. First, it contributes by analyzing the business potential for potential application areas of those specific mobile services and thereby enhances informed decision making. Second, it contributes by demonstrating the philosophy that; identification of business model potential, prior to business model design, increases the efficiency in the business model development process.

10.3 Reflection on edge computing

Having finished the thesis project, this section reflects back on edge computing in general. Is edge computing here to stay? If so, in what way will it interact with the current cloud computing paradigm? And, how should companies roll-out such infrastructures? These complex questions can currently not be empirically validated. However, after deep-diving into the business model variables that influence the potential of edge computing for IoT applications, a personal view to these questions can be formulated.

To the first of these questions, there are serious reasons to believe that edge computing is here to stay. Whereas initial ideas on edge computing emerged in the late 1990s and the first initial edge computing concept already arose in 2012, we are finally at a tipping-point where edge will become reality. Especially with the rise of the IoT, which is rapidly approaching the plateau of productivity, the benefits that edge computing delivers become increasingly important. In the previous decade, where cloud computing became the de-facto standard, edge computing's benefits did not deliver substantial value for computational offloading. In the light of IoT, this however changes. On the technical side, solving the inherent complexities of overhead, orchestration, and network function virtualization (among others), of such decentralized infrastructures, finally becomes feasible. Hence, we now have an infrastructure that delivers substantial value and is becoming feasible. We believe that the idea of IoT is here to stay. Furthermore, we believe that the decentralized off-loading capacity which edge computing delivers, is a prerequisite for many IoT applications in order to function properly. This is especially because of their proven infrastructure requirements of; low latency and jitter, band-width requirements, data privacy and secrecy, security, context awareness, mobility support, connectivity, and energy usage. Therefore, we believe that edge computing is here to stay. The fact that major tech companies such as; Google, Microsoft, Amazon, and IBM, are heavily investing in their edge computing capabilities, implies that these companies share this view.

The general idea of edge computing is not expected to render cloud computing obsolete. Instead, edge computing will proof to be a valuable extension to cloud computing. Cloud computing's distinct benefit of almost infinite computing power, low cost due to economies of scale, and possibility of cross-regional data aggregation, are still valuable to many IoT applications. These benefits cannot be delivered by an decentralized edge computing infrastructure. Therefore, it is expected that cloud computing will be complemented with an edge layer. This integration will prove to be valuable as it enables customers to leverage the benefits of both infrastructures. Hence, a three-layered infrastructure with; IoT devices (layer 1), edge nodes (layer 2), and a cloud data center (layer 3), is the most likely solution. streamlined integration of these three layers is however still difficult due to complexities with virtual resource management (i.e. configuring the underlaying infrastructure layers) and task-partitioning (for off-loading). As much effort is dedicated to solving these complexities, it is expected that these issues will be resolved in the near future. Especially with innovations such as serverless computing (which is still a premature concept), configuring the computational pipe-line will be simplified. We believe that, when this is technically feasible, uniform edge-cloud platforms become the new de-facto standard. Companies like Google and Microsoft are already promoting the concept of an uniform edge-cloud platform (e.g. Azure edge as add-on to Azure cloud).

The question that relates to the strategic roll-out of edge computing infrastructures is even more complicated to answer. Initially, it is advisable to target IoT application areas with a small to moderate scale. Currently, large-scale roll-out of edge computing is complex. This is due to the enormous amounts of heterogeneous devices that have to be integrated, but also because of the abundantly high investment that is required. As edge computing is still in it's infancy, high investments come with an even higher risk. Therefore, we recommend companies to start with pilots in IoT application areas that are small to moderate in scale. Companies can strategically target such applications (according to their location) in order to iteratively built-up an established network of edge nodes throughout the country. In future stages, the network of established edge nodes can then be used to support large-scale applications. This provides two advantages. First, it mitigates the high risk involved with high initial investment, as an iterative process of developing an edge network is followed. Second, companies can wait until solutions that solve the technical complexities involved with management, orchestration, and integration of heterogeneous devices, are realized.

10.4 Link between Management of Technology program and this thesis research

The Management of Technology (MoT) program is built on the premise that industries are increasingly in need of professionals that are familiar in both technology and management practices. Therefore, the program aims to educate engineers in the area of management and thereby manifests the believe that managers should be knowledgeable in their respective management context (Gosling and Mintzberg 2006). The multidisciplinary dimensions of this thesis research (i.e. including technical, organizational and financial aspects), and technical understanding of the underlying problem (i.e. edge computing), perfectly exemplifies the type of research Management of Technology alumni should exhibit. Especially the high-level strategic analysis about IoT application selection for edge computing, which required both a technical and strategic understanding of the problem, displays how strategic decisions in high-tech context cannot be solely made with either technical or managerial skills. Subsequently, this master thesis has provided an example that confirms the premise that high-tech industries are increasingly in need of MoT students to solve the problems they inherently have to cope with. This master thesis research has specifically been inspired- and facilitated by the courses Digital Business and Research Methods for Business.

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A Appendices

A.1 How the CSFs and CDIs of the STOF model can or cannot be translated

A.1.1 CSFs and CDIs for customer value

In order to create customer value, Bouwman et al. (2008) stipulated that four CSFs should be addressed, each with their distinct CDIs.

- **[Service domain] Clearly defined target group:** This CSF describes the extent to which a service provider is able to target a realistic and attractive market segment. In turn, the added value of a service differs per market segment and thus, the target group and value proposition are interrelated.
- **[Service domain] Compelling Value Proposition:** The benefits that are delivered to the user of a service, by its provider. Instead of focusing on the technical possibilities of a technology, the value proposition refers to the value creating elements.
- **[Technology domain] Acceptable Quality of Service:** This relates to the technical functionalities the enabling infrastructure delivers. Distinct technological infrastructures deliver a different quality of service.
- **[Service domain] Unobtrusive Customer Retention:** Whereas obtrusive customer retention mechanisms can be used in order to retain customers, it can hamper the ease-of-use and thereby decrease the customer value.

Table 29: Translation of the STOF CDIs, to customer value determinants resulting from the choice of technology or choice of IoT application

CDF	CDI	Effect on Comparable Customer Value of Edge
Clearly Defined Target Group [Service domain]	Targeting	**Can be translated:** Each target group specifies a distinct customer segment, having a different set of service requirements. Each customer segment experiences the technology value differently. For the tool that identifies the business model potential, different target groups, or in this case IoT applications with their corresponding characteristics, perceive different value elements. This leads to a different perceived value of the service.
	Accessibility for Customers	**Cannot be translated:** The choice of medium, which is used to access the service and realizes the accessibility for customers, provides the same access options for both infrastructures (e.g. 4G, 5G, cable, WiFi, etc.). Therefore this is a design issue, and not a customer value determinant influenced by the input characteristics of an IoT application.
Compelling Value Proposition [Service domain]	Value Elements	**Can be translated:** There are tensions between the possibilities offered by the technology and the demands of the customer. The value creating elements refer to elements that directly add value for the customer, regardless of the choice of technology. The value elements can be translated into service requirements that create value and thus impact the demanded quality of service.
	Pricing	**Cannot be translated:** Whereas pricing directly influences the customer value, it is also directly related to the profitability of the service (influencing the network value). Therefore, in the tool, pricing is seen as a medium to distribute the customer surplus that is created with the choice of

		infrastructure. This should assure that the chosen technology infrastructure delivers added customer value as well as added network value.
	Branding	**Cannot be translated:** The branding variable is mainly related to how the brand of the service can be established (which is in this case edge computing). However, the brand of the edge computing service, offered by a certain firm, is not necessarily dependent on the IoT application. A brand will be established in general, meaning there is little use in distinguishing for branding value between multiple IoT applications which can be targeted.
Acceptable Quality of Service [Technology domain]	Security	**Can be translated:** The security relates to the implemented technical architecture. Whereas on one side, the security is a technical feature of the architecture, on the other side, security can be seen as a requirement/value-creating element for the user. This means that security is both a property of the technological infrastructure and a requirement of the IoT application.
	Quality of Service	**Can be translated:** The choice of technological architecture delivers its distinct technical functionalities. In turn these functionalities have a profound impact on the delivered Quality of Service.
	System Integration	**Can be translated:** The system integration relates to the extent the new service is integrated/compatible with the previous infrastructure. When deciding to implement a new infrastructure (in this case edge) it is usually possible to integrate the service with the old architecture (in this case cloud). This can potentially provide an additional benefit for the new infrastructure over the old infrastructure.
Unobtrusive Customer Retention [Service domain]	User Profile Management	**Cannot be translated:** User profile management describes different design choices that can be made in order to manage user profile. Whereas these choices have impact on the customer value, for the tool that will identify the business model potential, this CDI is not relevant, as it constitutes a design choice that is not necessarily inherent to an IoT application. Therefore this can be seen as a design variable, and not a network value determinant inherently influenced by the choice of technology or IoT application.
	Customer Retention	**Cannot be translated:** For customer retention, different design choices can be made in order to retain customers. Whereas these choices have impact on the customer value, for the tool that will identify the business model potential, this CDI is not relevant, as it constitutes a design choice that is not necessarily inherent to an IoT application. Therefore this can be seen as a design variable, and not a network value determinant inherently influenced by the choice of technology or IoT application.

A.1.2 CSFs and CDIs network value

In order to create network value, Bouwman et al. (2008) stipulated that four CSFs should be addressed, each with their distinct CDIs.

- [Finance Domain] Acceptable Risk: Describes the level of uncertainty regarding technology choices and market circumstances.
- [Finance Domain] Acceptable Profitability: Relates to the positive financial result the network of company can make, according to the desired risk/return profile. The profit is acceptable if it performs better in the relative sense (e.g. compared to other firms, ecosystems, technology options).
- [Organization Domain] Sustainable Network Strategy: Relates to the strategy in order to secure access to resources and capabilities.
- [Organization Domain] Acceptable Division of Roles: The distribution of roles within and among firms that participate in the value network.

Table 30: The relevance of the STOF CDIs, to the network value value determinants resulting from the choice of technology or choice of IoT application

CDF	CDI	Effect on Relative Network Value of Edge
Acceptable Risk	Division of Investments and Risks	**Can be translated:** With the introduction of a new service, there always is an uncertainty and related risk about the return of investment (ROI). Furthermore, the higher the risk, the higher the required expected ROI to off-set this risk, and make for an interesting investment (DeMarzo 2013). Looking at the edge computing domain, bigger roll-out of the infrastructure (i.e. for applications that require a larger geographical coverage) comes with increased investment costs. Increased investments in turn increase the risk-level. The higher risk level then leads a higher requirement on the ROI to make for an interesting investment, in turn lowering the network value.
	Value Contributions and Benefits	**Cannot be translated:** This CDI relates to the fair and viable revenue sharing arrangement between network partners according to the value they deliver. Whereas the network of customers is different for each IoT application, the network of partners working together to realize the edge computing architecture will stay similar. Therefore, the way fair and viable revenue sharing is realized is a design variable, not being influenced by the technology input or IoT use-case input.
Acceptable Profitability	Value Contributions and Benefits	*Description in column above*
	Pricing	**Can be translated:** Pricing has direct influence on the relative revenue, affecting the profitability of the service, and in turn increasing or decreasing the network value. On the other side of the token, the price level has direct influence on the relative perceived customer value. Correspondingly, pricing is a variable that bridges between the customer- and network value. A higher price decreases the customer value, but may increase the network value. Shifting the scope to the tool that will identify the business model potential, pricing can be used to re-allocate some of the

		generated customer surplus towards producer surplus. More specifically, for each application, a different level of customer surplus is generated by implementing an edge computing architecture (note; for some IoT applications, edge computing might also destroy customer surplus compared to e.g. cloud computing). Then, in order to assure a viable business model that generates both customer- and network value, pricing can re-allocate some of the generated customer surplus towards additional network surplus. In this way, the pricing mechanism can be utilized in order to balance the customer- and network value.
	Division of Costs and Revenues	**Cannot be translated:** This CDI is somewhat similar to the CDI *Value Contributions and Benefits*, but explicitly describes how costs and revenues are divided. Similarly, whereas the network of customers is different for each IoT application, network of partners working together to realize the edge computing architecture will stay similar. Therefore, the way costs and revenues are divided, is a design variable, not being influenced by the choice of infrastructure or IoT application characteristics.
	Acceptable Customer Base	**Can be translated:** In the STOF model, the design variables; customer retention, accessibility for customers, and network openness, partially influence the customer base. The concept of acceptable customer base can however also be looked at in the general sense, as the customer base. In this sense, the customer base/amount of customers/revenue source, together with the price, directly translates into a generated revenue. The revenue then is related to the profitability of the service, which impacts the network value.
	Customer Retention	**Cannot be translated:** For customer retention, different design choices that can be made in order to retain customers. Whereas these choices have impact on the network value, the business to-be designed tool's input variables; choice of infrastructure and IoT application characteristics, are not related to this CDI. Therefore this can be seen as a design variable, and not a network value determinant inherently influenced by the choice of technology or IoT application's characteristics.
	User Profile Management	**Cannot be translated:** User profile management describes different design choices that can be made in order to manage user profile. Whereas these choices have impact on the customer value, the business to-be designed tool's input variables; choice of infrastructure and IoT application characteristics, are not related to this CDI. Therefore this can be seen as a design variable, and not a network value determinant inherently influenced by the choice of technology or IoT application's characteristics.
	Accessibility for Customers	**Cannot be translated:** The choice of medium, which is used to access the service, provides the same access options for both infrastructures. Therefore it is a design issue, and not a network value determinant inherently influenced by the choice of infrastructure or IoT application's characteristics.
	Network Openness	**Cannot be translated:** The network openness relates to the degree new actors can join the value network and provide services to customers. Whereas this is an important design variable that can create or destroy network value, it is not relevant for the tool that will identify the business model potential. Whereas the network of customers is different for each IoT application,

		the network of partners realizing the edge computing infrastructure will stay similar for different applications. Furthermore, network openness can create value, depending on de alignment with the situation (i.e. dependent on market, service type, market competition), but does not directly create or diminish value depending on the chosen infrastructure or IoT application. Therefore, network openness is rather a design variable than a determinant for the comparison tool.
Sustainable Network Strategy	Network Governance	**Cannot be translated:** In most value networks, there is one dominant actor which developed the service offering, or has access to the majority of customers, which manages the value network. These central (keystone) players usually selects collaboration partners and monitors if everyone complies to the rules. Relevant design choices in this area are customer ownership and control over resources and capabilities. Translating this to the edge computing domain it becomes apparent that, the network of partners realizing the edge computing infrastructure will stay similar for different IoT applications. Furthermore, whereas Network Governance is an CDI which can deliver value if designed correctly, it does not directly create or diminish value depending on the chosen infrastructure or IoT application. Therefore, Network governance is rather a design variable, than a determinant for the comparison tool.
	Network Complexity	**Can be translated:** The number of relations an edge computing provider has to realize in order to realize an edge computing infrastructure can differ per IoT application. Whereas for some applications the provider might only have to work together with one or a couple of partners, in other applications roll-out might constitute a complicated web of stakeholder management. Therefore, the network complexity can be translated into the number of partners needed to realize the offering.
Acceptable Division or Roles	Network Complexity	**Can be translated:** *Description is in column above*
	Partner Selection	**Cannot be translated:** Partner selection refers to the description about how partners are selected in order to gain access to critical resources and capabilities which are needed to realize the focal service offering. One can distinguish between partners delivering irreplaceable resources and partners providing supporting resources. This CDI encompasses issues about the decision to include or exclude certain partners. Whereas the network of partners rolling-out the IoT application might differ per application, the network of partners available for selection for rolling out the edge-infrastructure will remain similar for each application. Therefore, Partner Selection is rather a design variable, than a determinant impacting the network value based on the choice of infrastructure or IoT application.

A.2 Preparing the conceptual model V1.0 for interviews

The conceptual model, as drafted in the first design phase (Chapter 5), is cut into two main pieces. The left part constitutes the research model which contains the factors that are directly expected to have influence on the potential of an IoT application for edge computing. The right side contains the generic model, which has been drafted from the STOF model. Whereas the generic model is needed in order to derive to a final answer about the potential of an IoT application for edge computing, there is no novelty in these factors. Therefore, it is not relevant to validate the relevant and/or interaction of these factors. Subsequently, only the left part (research model) is interviewed.

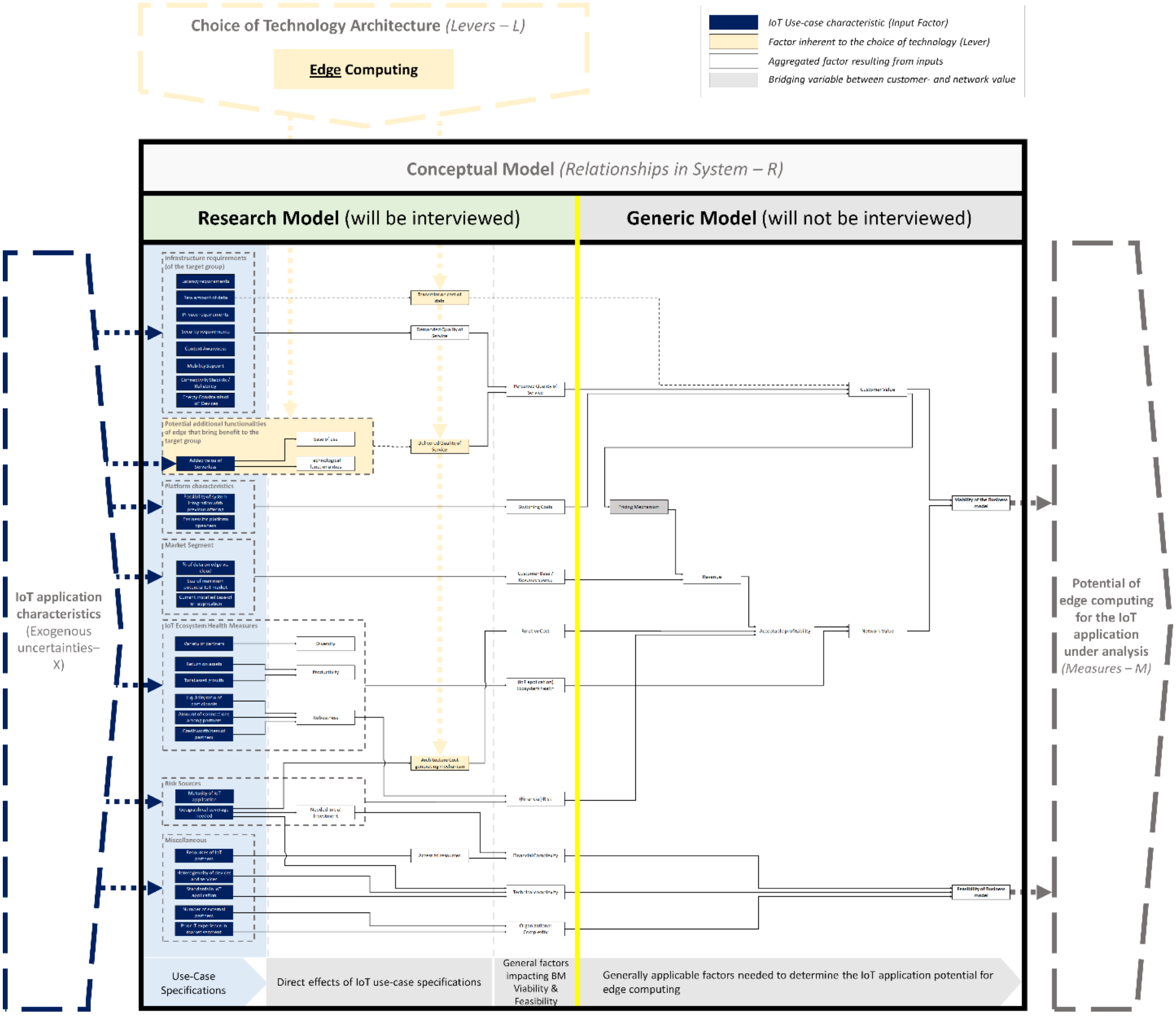


Figure 36: Division of the conceptual model into the research model and the generic model

A.2.1 Dividing the tool into 10 boxes

In order to structure the interview and guide the interviewee through the research model without providing an overload of information upon first sight, the tool has been divided into 10 boxes. The first nine boxes represent how the contextual factors, relevant for edge computing, impact the generic factors. This means that each of these first nine boxes contains the range of contextual factors which are hypothesized to have influence on the generic factor. The generic variable is in turn expected to impact the business model viability or the business model feasibility. These 9 boxes are used in order to validate the relevance of the contextual factors, identify new contextual factors that are not drafted in the initial design, and describe how these factors apply to the chosen use-case. The 10th box then contains a list of the nine generic factors and is used to test the comprehensiveness of these factors and rank their relative importance.

A.2.1.1 (Box 1) Variables impacting the perceived quality of service

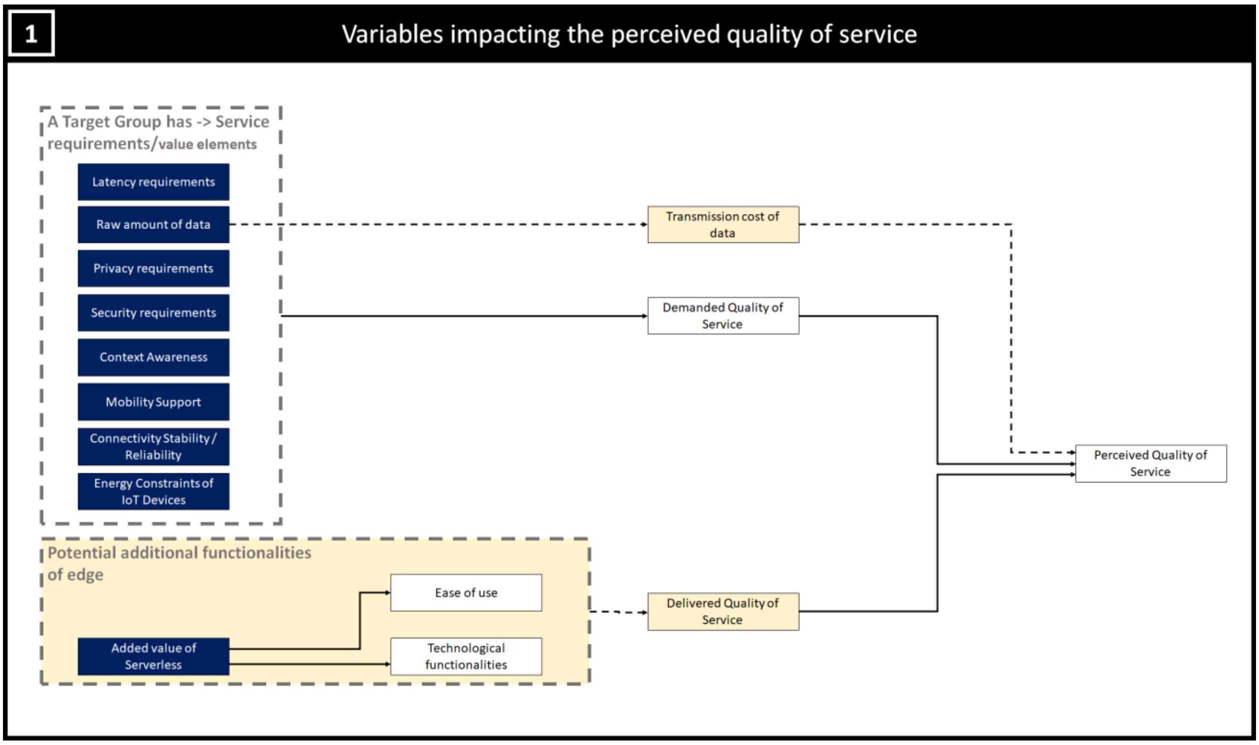


Figure 37: Variables impacting the perceived quality of service

A.2.1.2 (Box 2) Variables impacting the cost for switching towards an edge Infrastructure

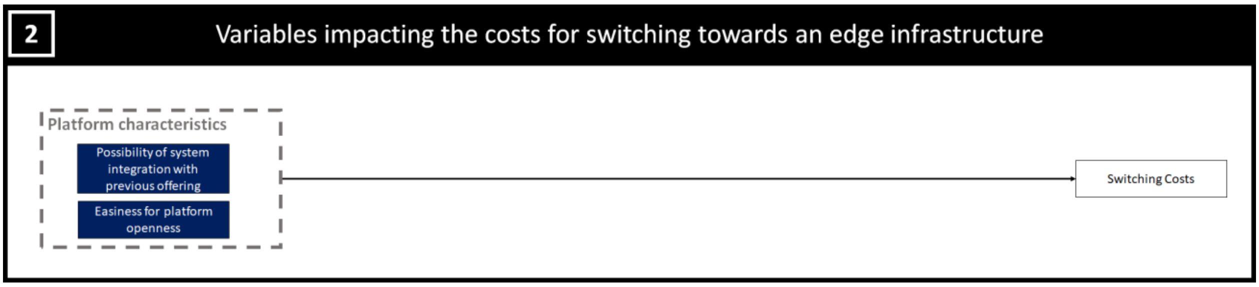


Figure 38: Variables impacting the cost for switching towards an edge infrastructure

A.2.1.3 (Box 3) Variables impacting the customer base/revenue source

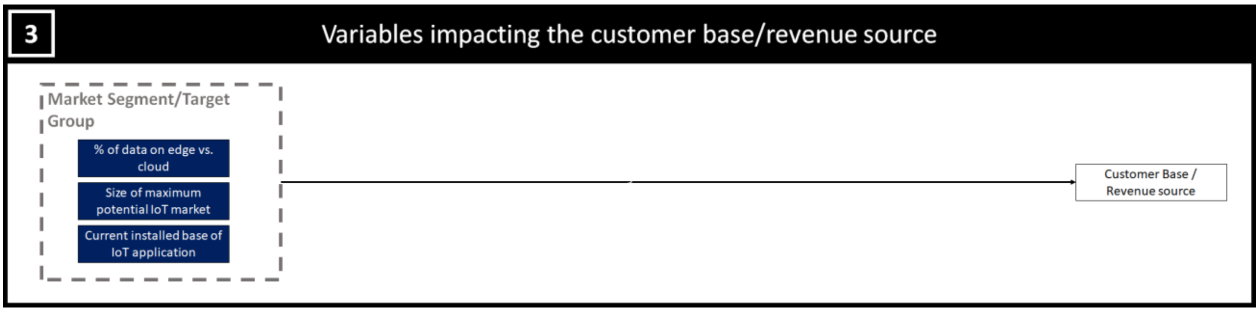


Figure 39: Variables impacting the customer base/revenue source

A.2.1.4 (Box 4) Variables impacting the relative cost of roll-out

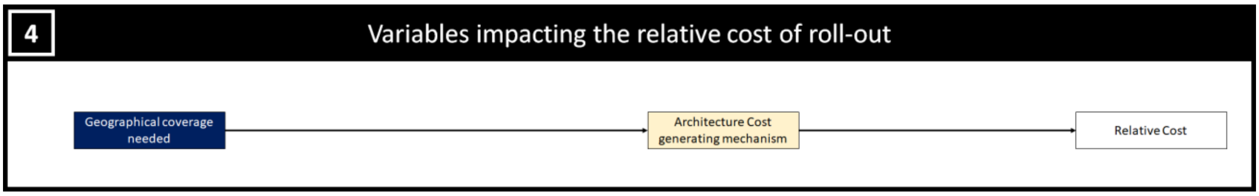


Figure 40: Variables impacting the relative cost of roll-out

A.2.1.5 (Box 5) Variables impacting the IoT application's ecosystem health

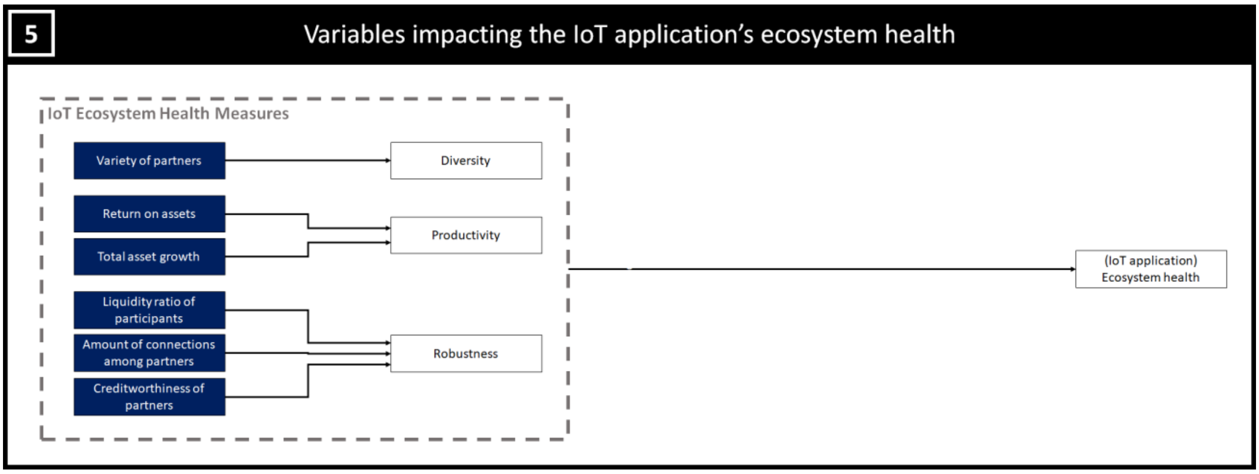


Figure 41: Variables impacting the IoT application's ecosystem health

A.2.1.6 (Box 6) Variables impacting the (financial) risk

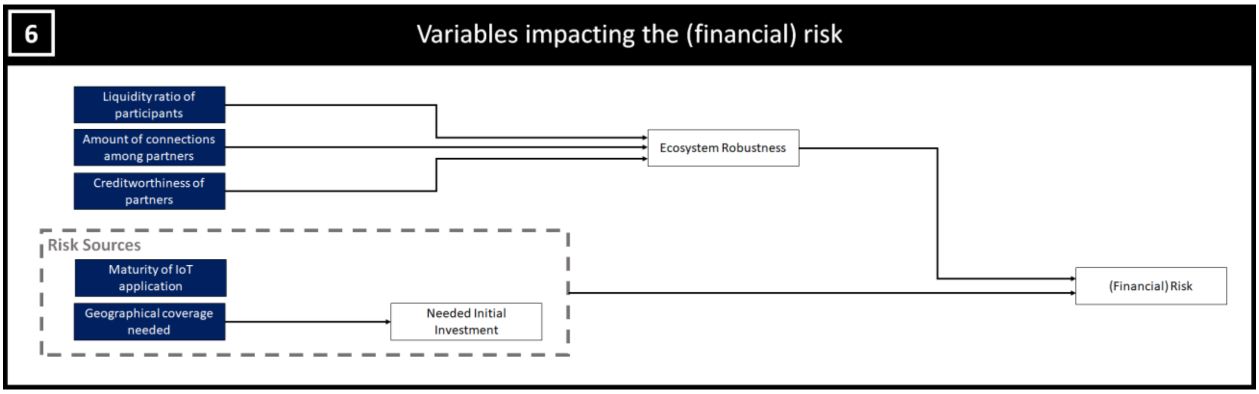


Figure 42: Variables impacting the (financial) risk

A.2.1.7 (Box 7) Variables impacting the financial complexity

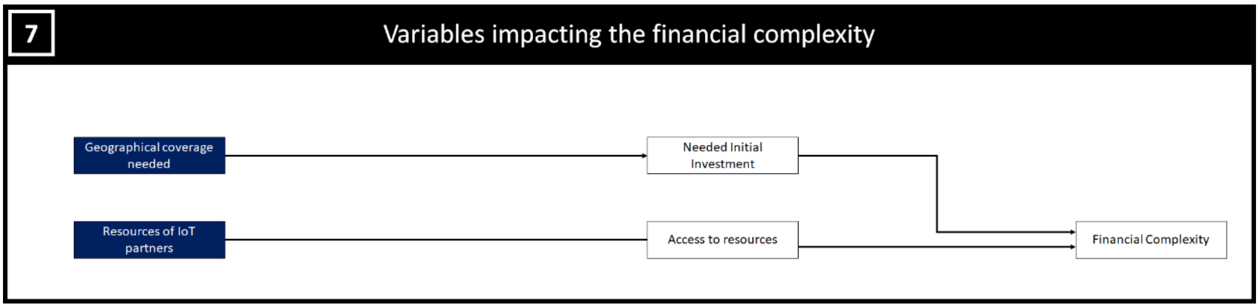


Figure 43: Variables impacting the financial complexity

A.2.1.8 (Box 8) Variables impacting the technical complexity

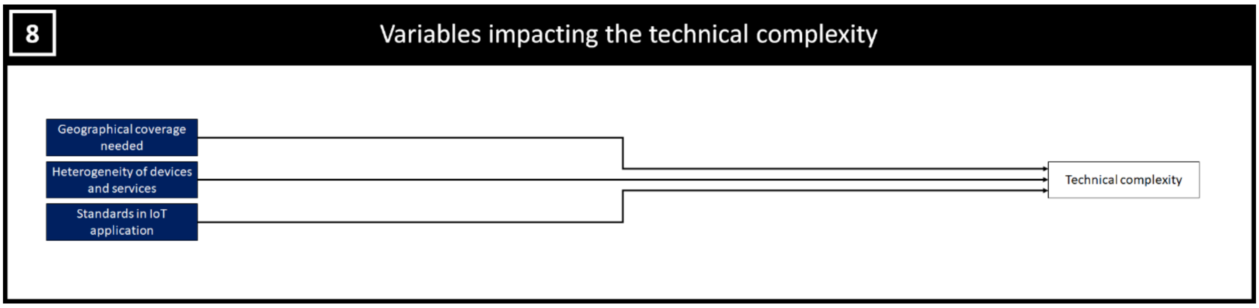


Figure 44: Variables impacting the technical complexity

A.2.1.9 (Box 9) Variables impacting the organizational complexity

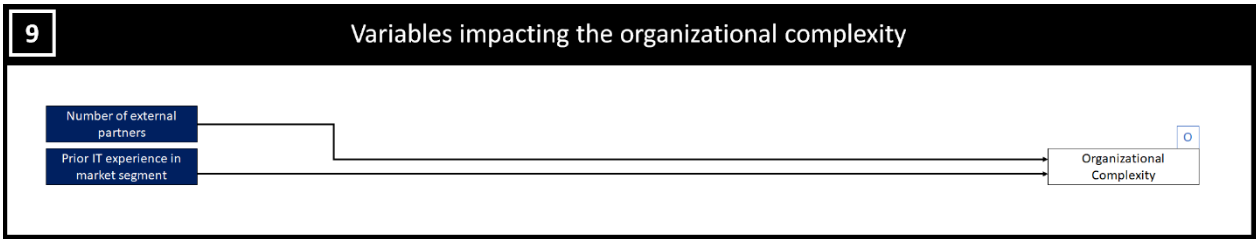


Figure 45: Variables impacting the organizational complexity

A.2.1.10 (Box 10) Generic variables impacting the business model viability and feasibility

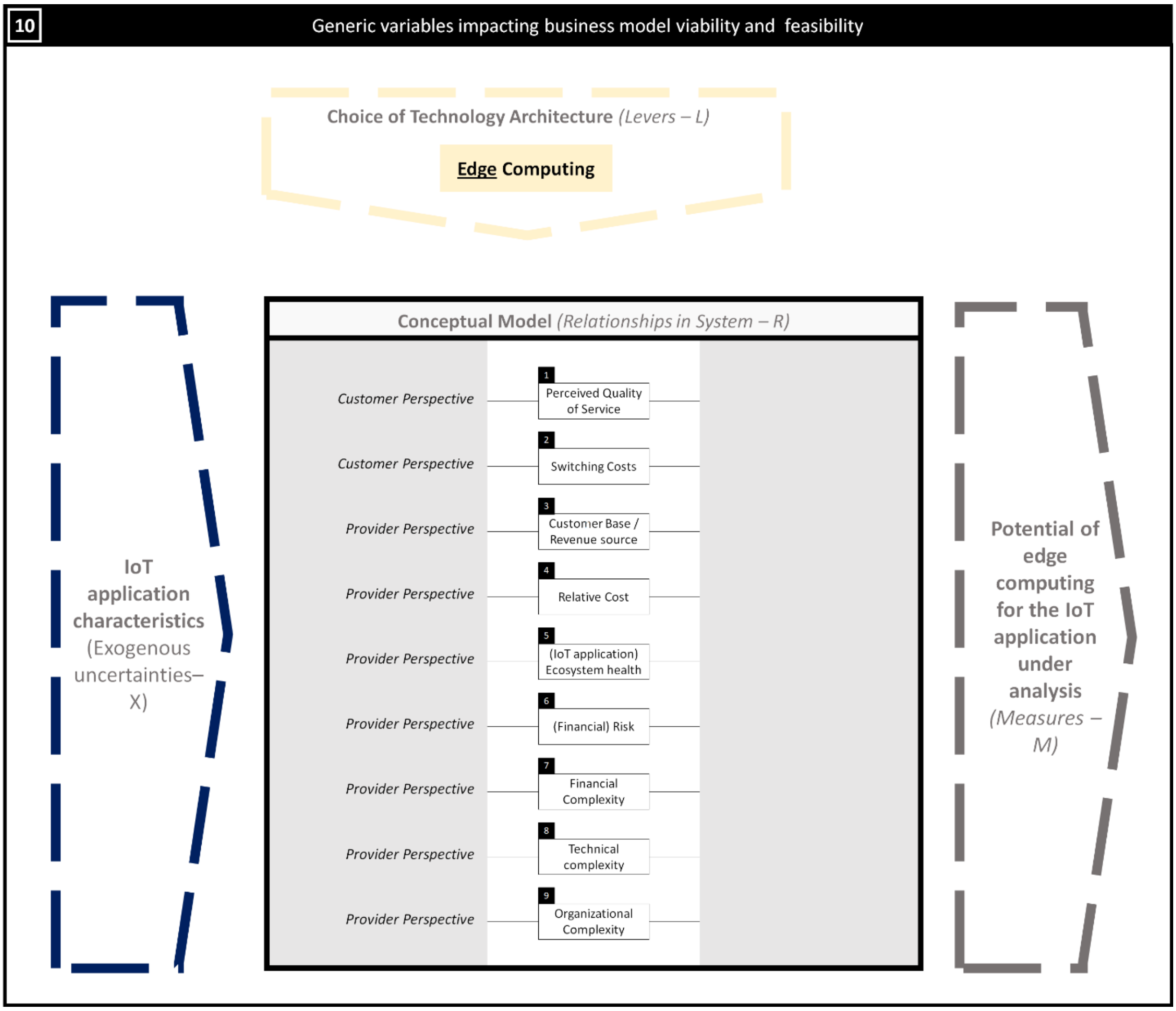


Figure 46: Variables factors impacting the business model viability and feasibility

A.3 Raw data of Best-Worst-Method

Table 31: Raw data of BWM for ranking the nine generic variables

	IN1	IN2	IN3	IN4	IN5	IN6	IN7	IN8	IN9	IN10	IN11	A.W.	M.W.	S.D.	C.V.
Perceived value of the infrastructure	0,282	0,315	0,083	0,126	0,302	0,179	-	0,324	0,250	0,251	0,319	0,243	0,266	0,0857	35,25%
Switching cost	0,176	0,031	0,110	0,076	0,044	0,051	-	0,068	0,054	0,020	0,059	0,069	0,056	0,0453	65,77%
Customer base / revenue source	0,088	0,128	0,166	0,076	0,198	0,179	-	0,136	0,107	0,231	0,137	0,145	0,137	0,0491	33,96%
Relative infrastructure cost	0,118	0,055	0,066	0,094	0,079	0,024	-	0,058	0,054	0,081	0,051	0,068	0,062	0,0261	38,40%
IoT application's ecosystem health	0,071	0,128	0,023	0,189	0,132	0,286	-	0,082	0,107	0,046	0,051	0,112	0,094	0,0786	70,50%
(Financial) risk	0,071	0,096	0,256	0,063	0,099	0,119	-	0,068	0,080	0,152	0,069	0,107	0,088	0,0592	55,19%
Financial feasibility	0,026	0,055	0,166	0,063	0,023	0,045	-	0,027	0,026	0,065	0,082	0,058	0,050	0,0431	74,66%
Technical feasibility	0,118	0,096	0,083	0,286	0,057	0,072	-	0,136	0,161	0,046	0,025	0,108	0,089	0,0752	69,66%
Organizational feasibility	0,050	0,096	0,047	0,028	0,066	0,045	-	0,102	0,161	0,108	0,206	0,091	0,081	0,0566	62,27%
KSI	*0,07056*	*0,06857*	*0,07533*	*0,09142*	*0,09433*	*0,07161*	-	*0,08424*	*0,07152*	*0,07325*	*0,09313*				

A.W. = Average Weight
M.W. = Median Weight
S.D. = Standard Deviation
C.V. = Coefficient of variance
- = No input
KSI = Consistency index

A.4 Explanation per Variable

For each variable that was drafted in the framework in the second design phase, this appendix contains an explanation about its meaning (i.e. definition) and interaction with other variables.

A.4.1 Variables impacting perceived value of the infrastructure

Perceived value of the infrastructure: Describes the value the user (which is the IoT application under analysis) perceives while using the edge computing service. The perceived value of the infrastructure is profoundly impacted by the match/mismatch between the *demanded*- and the *delivered quality of service* and the *business value of the IoT application* that is unlocked by the infrastructure.

Business value of IoT application: The IoT application under analysis delivers a certain value to the customer. Whereas this does not directly impact the infrastructure value a customer experiences, it does indirectly contribute to the overall value that unlocked by implementing the infrastructure that effectuates an IoT application. Depending on the value that is unlocked by the infrastructure, the *total infrastructure* value may indirectly be increased.

App that is unlocked by the infrastructure: Builds upon the premise that an edge infrastructure either unlocks-, enables or enhances the functionalities of an IoT application. By utilizing this IoT application, new *value is created*. However, a customer should first *invest in the IoT application's devices and development* in order to get it functioning. Subsequently, by implementing the infrastructure, new business value can be established, impacting the *perceived value of the infrastructure*.

- Created value with IoT app: The chosen infrastructure allows for the IoT application's functionalities to manifest, thereby unlocking new value .
- Investment cost for IoT and devices: On the contrary, the customer should not only invest in the edge infrastructure (covered in other variables), but also in the development and roll-out of the IoT application itself.

Demanded quality of service: Constitutes the performance of the technical infrastructure a customer, which is the IoT application under analysis, demands. The demanded quality of service is dependent on an IoT application's *infrastructure requirements*.

Delivered quality of service: Constitutes the performance that the technical infrastructure under analysis delivers. The delivered quality of service have to be aligned with the *infrastructure requirements* of an IoT application in order to create value.

Transmission cost of data: Depending on the *choice of infrastructure* and the *raw amount* of data that should be offloaded, a customer incurs cost for transmission of data towards the computational offloading platform. Whereas, for cloud computing, customers have to send the data towards a data center that is remotely located, and will thereby incur additional cost for transmission of data, with edge computing data (pre)processed locally, and thereby the transmission cost of data could be reduced. Therefore customers should take into account how the amount of data and choice of infrastructure impact the cost of data transmission.

Infrastructure requirements: Depending on which characteristics are inherently important for the IoT application to function properly, a customer has several requirements that drive the choice of technology. These requirements in turn result in a *demanded quality of service*.

- Latency and jitter: Distinct IoT applications may require different requirements on latency and jitter in order to function properly. An edge computing infrastructure can achieve lower end-to-end latency than a cloud computing infrastructure due to close physical proximity of edge nodes to the users (devices). Furthermore, by putting computational resources closer to the users, jitter (i.e. variation of latency) can be reduced. Therefore, an IoT application's requirements on latency and jitter is an important part of the *infrastructure requirements*.
- Raw amount of data: Distinct IoT applications may produce different amounts of raw data, which in turn needs to be processed, leading to different bandwidth requirements. Inherently high amounts of data may stress the bandwidth boundaries. Edge computing has the potential to decrease the ingress bandwidth into the cloud, by (pre)processing data intensive processes at decentralized level in close proximity to user. Therefore, an IoT application's raw amount of data is a relevant *infrastructure requirement*.

- Data privacy and secrecy: Depending on the IoT application, different levels of privacy and secrecy may be required. Privacy and secrecy refer to the requirements on unauthorized intrusion and the secrecy level of data from other parties. An edge computing infrastructure can relieve some of the privacy and secrecy concerns by (pre-)processing privacy sensitive data at lower (decentralized) level, before sending it to a centralized location. Subsequently, the relevant *infrastructure requirement* of data privacy and/or secrecy may drive an IoT application's choice of infrastructure. Furthermore, data that is highly privacy- or secrecy sensitive should be protected properly, thus driving up the *security requirements*.
- Security: Depending on factors such as privacy, secrecy, seriousness- and cost of failure among others, IoT applications have different levels of security requirements. Subsequently, security on the edge is a double edged sword. Whereas on the one hand edge computing decreases chances of complete system breach or failure by processing data decentralized and closer to the source, the security on the individual edge nodes their selves is lower. This increases the likelihood of individual edge node failure. Breach of the network of nodes is however less likely. Therefore, depending on an IoT application's security focus, *infrastructure requirements* may be impacted.
- Context Awareness: Edge computing may facilitate the requirements of context aware information that IoT applications may demand on varying levels. Edge computing facilitates this by providing additional contextual information (which is available at the edge node itself), by facilitating context-aware communication and analytics, and by increasing the speed to which computing capabilities can adapt to changes in the context. Subsequently, depending on the IoT application, context awareness may be one of the *infrastructure requirements*.
- Storage and computing capability: Different IoT applications may require different levels of computing capability, amounts of storage and durations of storage. On the cloud, computing power is almost endless, meaning huge amounts of data can be stored for long times at low costs, and computing capabilities can be scaled almost infinitely. These endless computing and storage capabilities provide a benefit as the cloud will not have result in any delays due to a lack of computing capacity. On the other hand, the decentralized edge computing resources are limited. Therefore, IoT applications that require heavy computations and long-time storage of huge amounts of data, may have more benefit from a cloud computing infrastructure. Therefore, the required storage and computing capability may impact the *infrastructure requirements*.
- Mobility support: In different IoT applications, the devices which are in need of computational off-loading may move around in varying locations and degrees. Edge computing can enhance the mobility support for IoT devices. IoT devices can either dynamically switch their task-offloading to the most suitable access point while mobbing around the mobile network, or an edge node could dynamically move with the IoT device in order to deliver constant task-offloading possibility. Therefore, edge computing can deliver off-loading capacity when the devices move around within- and between areas, where sometimes no connectivity to the broader network may be present. This is different from a static cloud computing data center which can only be accessed through a large scale network. Subsequently, the requirement of mobility support puts requirements on both the *connectivity availability* and the *infrastructure requirements*.
- Connectivity availability and stability / reliability: Depending on the IoT application, the stability and reliability of connectivity may be of differing importance. Whereas for some scenario's offloading capacity should always be available, for other instances short connection loss might not be problematic. On the other side of the token, depending on an IoT application's location and movement between locations (related to *mobility support*), connectivity may be rather a luxury than a standard. Edge computing can mask the unavailability of connectivity towards the cloud, by operating the crucial tasks at decentralized level in close proximity to the device. Therefore, connectivity may be enhanced with an edge infrastructure, thus displaying the relevance of this factor on the *infrastructure requirements*.
- Accessibility / reachability of the data: The data generated by the devices in distinct IoT applications may need to be accessed either locally or globally. Whereas the decentralized nature of edge computing facilitates local access of data, global accessibility is more complicated. Contrastingly, the centralized nature of cloud computing facilitates global access of data.

Therefore, IoT applications with data that needs to be centrally accessed on global level, may benefit from a cloud computing infrastructure. Subsequently, this displays that the accessibility and reachability of data are relevant *infrastructure requirements* that may guide a users' choice of infrastructure.

- Amount of updates and upgrades: Depending on the IoT application, software may be updated / upgraded to new or enhanced versions on different intervals. Whereas the centralized edge paradigm facilitates easy updating and upgrading of application software, the decentralized edge computing paradigm complexifies this. A bigger edge layer, with more edge nodes, significantly complexifies the process of updating and upgrading because all nodes have to be adjusted. Subsequently, depending on the amount of updates and upgrades an IoT application may anticipate, this *infrastructure requirement* may drive or stagger the choice of edge.
- Speed and uncertainty of scalability: Whereas cloud datacenters have extensive capacity, and resource usage may thus be scaled up rapidly, edge computing requires on-site nodes. Therefore, the decentralized nature of edge computing limits the speed of resource scale-up. As IoT applications may have different *infrastructure requirements* on the speed by which resources should be scaled-up, and the uncertainty about how fast this should happen, the choice of infrastructure may be driven by requirements on the (potential) speed of scalability.
- Energy constraints of IoT devices: Depending on the IoT application and corresponding presence/absence of power supply, IoT devices may be power constrained. The energy expended (joule/query) for transmission of data to an edge node is significantly lower than for transmission to the cloud. This leads to lower energy consumption at the end-devices. This means that IoT application may put *requirements on the infrastructure*, depending on the power constraints of its devices.

A.4.2 Variables impacting the switching costs for switching towards the edge

Switching costs: When a customer (i.e. the IoT application under analysis) decides to switch from situation A to situation B (towards an edge computing infrastructure), it incurs switching cost. If these switching costs are substantial, switching between the services will require a heavy resource commitment. The benefit gained by the new service could exceed the switching cost a customer incurs. Therefore, switching costs impact the *customer value*.

Interoperability: The extent to which distinct systems of the customer are already interoperable, or can easily be made interoperable, decreases the *switching cost*. Systems that may easily be made interoperable can integrate customers' old system with the new system and thereby allow for a cross-platform or multi-vendor solution. Interoperability thus decreases the *switching cost*.

Migration cost: This constitutes the direct cost a customer incurs when aiming to switch towards an edge infrastructure. Higher migration cost result in a bigger resource commitment, in turn increasing the *switching cost*.

Platform characteristics: There are several platform characteristics that influence the *interoperability*.

- Possibility of system- and process integration: The adoption of an edge infrastructure can be affected by the extent to which it can be integrated with a customer's existing infrastructure and corresponding processes. The possibility of system- and process integration partly determines the extent to which the whole system is *interoperable*.
- Easiness of platform openness: Platform openness has substantial effect on complementors' satisfaction for a platform. An open platform is built on *standards, APIs and libraries* that can be used without restrictions on vendor or platform type.
- Open standards, APIs and libraries of IoT app: The easiness of platform openness translates in the extent to which open standards, APIs and libraries may be used. This increases possibilities to make the system *interoperable* with those of other platforms and vendors.

Migration Factors: There are several migration factors that influence the *migration cost*.

- Complexity- and lead time of migration: Migration towards an edge computing infrastructure brings about a certain level of complexity and lead-time. Potential edge service providers pass on these complexities to the customer by means of additional *migration costs*. Subsequently, higher complexity and a longer lead-time of migration result in higher migration costs for the customer.

- Opportunity cost of downtime- or system failure during migration: Depending on how migration takes place, potential system failure or downtime during the migration might be inevitable. Depending on the IoT application, the opportunity cost of downtime- or system failure during migration may be high, resulting into considerable *migration cost*.
- Low initial investment trail-and-error possibility: In some cases, the potential *opportunity cost of downtime- or system failure during migration* of an IoT application, may be (partially) mitigated by developing the infrastructure so that it does not impact the overall system (e.g. a stand-alone concept version). Especially when this can be done with a low initial investment / resource dedication, the opportunity cost of system downtime may be reduced.

A.4.3 Variables impacting the customer base / revenue source

Customer base / revenue source: For a service provider it is important that the IoT application under analysis, for which efforts and investments will be done, and competencies will be developed, contains a substantial customer base and related revenue source. The edge infrastructure provider wants to build upon his competencies, standards and platforms in order to drive down the marginal costs and reproduce similar architectures over multiple customers. The customer base/revenue source can be derived from the *market segment* and the way *platform leverage- and data ownership can be translated into value*. Subsequently, the revenue source has influence on the question if an *acceptable level of profitability* is reached.

Market segment: The market segment of an IoT application contains needs, wishes and preferences, which have been explained in section A.4.1. The market segment however also contains different qualities which are relevant for the service provider. Depending on the properties of a market segment, a substantial and valuable *customer base and corresponding revenue source* may be present.

- Installed base of IoT app that may directly benefit from the infrastructure: A *market segment* includes an installed base. Whereas in general the installed base describes customers that already have or use similar services or earlier versions of the service, in order to determine the attractiveness of a market segment, it is more interesting to look at the installed base of the IoT application (i.e. devices that are already in place) that may directly benefit from the edge computing infrastructure. This could be devices of an (potential) IoT application that are already communicating through a cloud infrastructure, proprietary data centers, or are not interconnected yet. For a service provider it is interesting to identify this group, as they could directly benefit from the implementation of an edge infrastructure.
- Maximum potential market size of IoT app: Another property of the *market segment* is the maximum potential of the market. For edge service providers it may be relevant to look at the future potential and future marked size of an IoT application that may benefit from the edge infrastructure.
- Time to consume: In order to have a balanced portfolio of potential users for a service provider's edge infrastructure, it is relevant to look at the expected time to consume of the IoT application's *market segment*. Whereas some IoT applications might generate consumption quickly, other scenarios may only generate consumption in the far future. For service providers it is important to balance their portfolio of target market segments with fast- and slow- time to consume segments.
- % of data on edge vs. cloud, and additional data potential: As edge computing and cloud computing have distinct advantages that not only compete, but also complement each other, a typical edge architecture is hierarchical in nature and thus collaborates/federates with the cloud. Subsequently, it can be expected that the cloud paradigm will stay relevant as edge emerges. For edge service providers it is then relevant to look at the percentage of data that will (need to) be processed at the edge vs. the cloud in order to determine the edge market size. If an insufficient percentage of data needs to be processed at the edge, the market for this infrastructure will be small, thus making it less attractive to roll-out the edge infrastructure. On the other side of the token, if the implementation of an edge infrastructure, which only processes a small percentage of the data, leads to extensive additional potential of data-usage in the cloud infrastructure of the service provider, it may still be attractive to roll-out the edge infrastructure.

- Possibility of support / maintenance contracts: Next to immediate revenue resulting from edge roll-out, or consumption on a service provider's proprietary data centers, there is an opportunity for additional support and/or maintenance contracts. Depending on the *market segment*, service providers may support and maintain the edge infrastructures in varying degrees, thus adding another potential source of revenue which should be considered in determining the attractiveness of a market segment.

Platform ownership: An individual entity (in this case an edge infrastructure provider) could own the platform in the domain of the IoT application.

- Possibility of platform ownership: Depending on the IoT application, there might be a possibility for infrastructure providers to own the platform. A platform owner can decide in which direction the platform should go and the extent to which the platform will be opened up for other players. This can in turn effectuate *platform leverage- and data ownership that can be translated into value.*

Platform leverage- and data ownership that can be translated into value: The leverage- and value of data ownership which is created for the platform owner may in turn result into additional *revenue streams*.

A.4.4 Variables impacting the relative infrastructure cost

Relative Infrastructure cost: The relative infrastructure cost plays a prominent role in determining if a substantial the level of *profitability* can be generated with an IoT application. Depending on the *cost generating mechanism*, a relative infrastructure cost of edge can be derived. This relative cost can subsequently be used to guide the decision whether to roll-out an edge infrastructure.

Cost generating mechanism for infrastructure roll-out, ownership, operation and maintenance: Depending on the *factors influencing relative cost*, the chosen infrastructure will come with a *relative infrastructure cost.* The identified factors will not only impact the cost for initial roll-out, but also for system ownership, operation and maintenance.

Factors influencing relative cost: There are several factors that suffice as input for the *cost generating mechanism* and may thus impact the *relative infrastructure cost*.

- Required scale of the infrastructure: Whereas cloud computing is a centralized infrastructure, which can leverage economics of scale, the decentralized edge computing paradigm becomes significantly more expensive when increased in size. As edge nodes need to be placed in close proximity to the users, a larger scale of implementation leads to a higher amount of needed nodes which impacts the *relative infrastructure cost*. Furthermore, a higher amount of edge nodes leads to an increased complexity and cost for ownership and maintenance.
- Presence/absence of edge nodes and mobile network on site: Depending on the environment in which an IoT application operates, edge nodes and a mobile network might be present or absent on site. When a mobile network is lacking in general, cloud computing datacenters cannot be reached, meaning a general mobile network needs to be established, increasing the *relative infrastructure cost* for the cloud. Furthermore, depending on the computational resources that can be used for edge computation that are already present on site, the *relative infrastructure cost* of edge computing may be driven down.
- Geographical location of IoT app: The geographical location of an IoT application may complicate the delivery of people and resources. Whereas in cloud computing, knowledge and resources can be placed at any place of convenience, with edge computing, knowledge and resources have to be brought on site. Therefore, depending on the geographical location of an IoT application, service providers might experience varying complexities in bringing knowledge and resource on site with edge computing, in turn impacting the *relative infrastructure cost*.
- Protection necessity of edge nodes from their environments: Depending on the environment in which edge nodes will be placed, i.e. hostile vs. safe environments, proper cooling, physical protection and energy supplies need to be facilitated. On the other hand, cloud resources can be placed in safe- and conveniently protected areas. Therefore, the environment in which the edge node will need to be placed will impact the cost of *relative infrastructure cost*.

A.4.5 Variables impacting the (financial) risk

(Financial) risk: Next to the *revenue sources* and *relative cost*, the risk impacts if there is an *acceptable profitability*. A higher turn-over is required in order to offset a higher risk level. The risk is driven by the identified *risk influencing factors,* the *needed initial investment* and the *ecosystem robustness*.

Needed initial investment: A higher initial investment is related to higher capital commitment of a company. This can be risky for the edge providers as it could put undue strain on their (other) financing activities and alternative investment. Subsequently, a higher initial investment, and thus higher resource dedication, leads to a higher financial risk. Furthermore, dependent on the *financial arrangements,* a higher initial investment could result in a longer payback time, increasing the *risk*.

Factors influencing risk: There are several factors that influence the *(financial) risk*.

- Maturity of IoT application: One factor driving the risk is the uncertainty revolving around the IoT application under analysis. For edge providers, it is relevant to take into consideration the maturity of the IoT application and the respective uncertainties that come with their potential trajectories. Subsequently, the maturity of an IoT application may impact the *risk* that edge providers take.
- Possibility of iterative roll-out: For some IoT applications it may be possible to iteratively built-up the edge infrastructure. Such iterative process can lower the *(financial) risk* as the infrastructure owner can start small, with low resource dedication, and expand the system as the IoT application takes off and technical issues are resolved.
- Exposure / legal consequences of system failure: In case of system failure, depending on the IoT application, there may be varying levels of consequences. Whereas for scenario A the consequences might be moderate, for scenario B the consequences could seriously harm people or assets. Therefore, the *risk* involved at targeting certain IoT applications, could be influenced by the exposure or legal consequences in case of system failure.
- The de-facto standard for financial agreements: Depending on the de-facto standard for financial arrangements in the market of the IoT application, profits, investments, costs and *risks* may be shared among actors. A co-investment, of full investment of the customer could decrease the *risk* an edge provider takes for roll-out.

A.4.6 Variables impacting the IoT application's ecosystem (health)

IoT application's ecosystem (health): Different IoT applications are delivered within distinct ecosystems. Subsequently, depending on what the ecosystem can bring to the table, the value that is delivered by the IoT application can vary. The value an IoT application's ecosystem can bring to the edge providers can be measured by the *ecosystem health metrics* and the *resources and capabilities* of the ecosystem's participants.

Ecosystem health metrics of IoT application: The ecosystem health refers to the extent to which an IoT application's ecosystem is durably growing opportunities for its members and those who depend on it. The ecosystem health can thus contribute to the *network value* for edge service providers which depend on the IoT application's ecosystem. Therefore it is relevant to look at an IoT application's ecosystem health.

- Ecosystem robustness: A *healthy ecosystem* allows for survival of the firms populating it. Subsequently, ecosystems which are more robust are more likely to survive in a stable manner over time. For service providers it may be important to target robust markets, as the capabilities and partnerships they will built are intended to last for a longer period of time. Measures of robustness are the liquidity and creditworthiness of participants, the interconnectedness of partners and the centrality of the IoT application in their total business among others. Lastly the ecosystem robustness impacts the *risk* as ecosystems that are not robust generally contains a members whom are not likely to last (in the same structure), thus making investment in that respective ecosystem risky.
- Ecosystem productivity: A *healthy ecosystem* is productive in such wat that it efficiently converts inputs into valuable outputs. Furthermore, the ecosystem's productivity should improve over time, meaning that inputs are increasingly efficiently converted into output. For edge providers this is an interesting metric, as it provides an idea about the future prospects of an IoT application. Measures of productivity are return on assets and total asset growth (assets can be either financial or non-financial) among others.

- Ecosystem diversity: In order to enhance and develop capabilities through innovation and integration, a healthy ecosystem exhibits diversity, meaning it's participants should vary among each other. A diverse subset of players is stronger than what firms could individually effectuate, which could be of interest to analyze for edge service providers in order to get a sense about an IoT application's future prospects.

Resources and capabilities: Ecosystem participants may contain valuable resources and capabilities which may impact the opportunities the *IoT application's ecosystem* can bring to members dependent on it.

- Non-financial resources of ecosystem players: The non-financial resources of ecosystem players (e.g. knowledge, IP, brand name, etc.) constitute these *resources and capabilities*.

A.4.7 Variables impacting the financial feasibility

Financial feasibility: In order to determine if the implementation of the edge infrastructure is feasible for the IoT application under analysis, the financial feasibility should be assessed. The financial feasibility refers to the question whether one can find a financially achievable solution to realize the edge computing infrastructure. More specifically, depending on the variables; *needed initial investment, access to resources, the de-facto standard for financial agreements* and the *difficulty of billing*, an IoT application's financing activities are either feasible or not.

Needed initial investment: The initial investment relates to the capital commitment a company has to make. Depending on the lump sum that has to be invested, and the financial resources that are available, the financing activities may either be *feasible* (i.e. enough funding is available) or not. Therefore, large required initial investments into an edge infrastructure may complexify the arrangement of financial activities.

Access to resources: Distinct IoT application are composed of different stakeholders and players. Subsequently, the financial resources that can be accessed may differ considerably per IoT application. Depending on the financial resources that these players have, and the *de-facto standard for financial arrangements*, the *feasibility* of the financing activities may be impacted.

The de-facto standard for financial agreements: Depending on the de-facto standard for financial arrangements in the market of the IoT application, profits, investments, costs and *risks* may be shared among actors. A co-investment, or full investment of the customer could unlock a range of new financial resources, thus impacting the *financial feasibility* of edge roll-out.

Difficulty of billing: Depending on the *variability of IoT app's computational allocation between edge nodes- and/or cloud* and the *choice of infrastructure*, the difficulty of billing may be impacted. For cloud computing, use of the platform is in a pay-per-use manner. Whereas in the cloud, billing can be managed centralized, for the decentralized edge paradigm this is not possible. Therefore, the in a decentralized edge infrastructure, billing is inherently more complex. Furthermore, depending on how much an IoT application's computational processes are re-allocated among edge nodes and cloud centers, billing complexity may increase. If adequate billing of system use is not possible, use of the edge infrastructure might not be *financially feasible*.

Factors influencing financial feasibility: There are several factors that influence the *financial feasibility*.

- Financial resources of IoT stakeholders: In order to get *access to resources* of an IoT application's stakeholders, the prerequisite is that these partners are in possession of sufficient financial resources. Therefore, as stakeholders' financial resources may differ per IoT application, and therefore the access to additional financial resources may be impacted, it is relevant to assess this variable.
- Variability of IoT app's computational allocation between edge nodes- and/or cloud: Distinct IoT applications may require a different variability of computational allocation. As IoT applications mob around or require a variable amount of resources, computing speed, priorities, etc. the place where computation takes place could vary. Therefore, computation could take place in edge node X at time A, edge node Y at time B, and cloud center Z at time C. Depending on how fast- and how often the computational allocation changes in an IoT application, the *difficulty of billing* is impacted.

A.4.8 Variables impacting the technical feasibility

Technical feasibility: Next to *financial feasibility,* the technical feasibility plays a prominent role in the determination whether there is an achievable solution to roll-out the edge infrastructure. Subsequently, it's relevant to analyze the *factors influencing technical feasibility* and the *maturity of the infrastructure's elements needed to fulfill the requirements* in order to estimate to technical possibility to effectuate the desired edge computing infrastructure for the IoT application under analysis.

Factors influencing technical feasibility: There are several factors that influence the *technical feasibility.*

- Scale of implementation: Edge computing infrastructures that encompass a larger scale, with many distributed nodes, generally cope with exponentially increasing overhead-, management-. and orchestration issues. Therefore, ultra-largescale infrastructures may be too complex to roll-out. Subsequently, the scale of the implementation is one of the factors *influencing technical feasibility.*
- Presence/absence of standards and libraries in IoT app: The components which compose the IoT application, should seamlessly work together in one coherent infrastructure. The presence of standards can shield the complexity of effectuating a coherent infrastructure by simplifying communication between providers and requestors. Subsequently, presence of standards enhances the potential of collaboration and interoperability between systems and devices. On the other side of the token, absence of standards significantly complexifies a complete system roll-out, thus influencing the *technical feasibility.*
- Heterogeneity and modularity of devices, services, libraries, programming languages and standards in IoT app: Heterogeneity and modularity impacts the amount of devices, services, libraries, programming languages and standards that have to be integrated. Hence, low heterogeneity and modularity could lead to easy implementation, as the variety of devices, services, libraries, programming languages and standards that have to be integrated is only low. High heterogeneity could lead to use of inherently much interfaces, incompatible runtimes, complex integration and management of standards, etc. Thus decreasing the *technical feasibility.*

Maturity of the infrastructure's elements needed to fulfill the requirements: Depending on the *choice of technology* and the *infrastructure requirements* of an IoT application, there are varying levels of maturity for the infrastructure's modules that are needed to provide the demanded service. Whereas fulfilling requirements may be easy with e.g. cloud computing, for edge computing these techniques may not be mature yet. Immaturity of the infrastructure's elements may lead to complexities in the process of roll-out. Therefore, depending on the requirements, the maturity of the chosen infrastructure's elements may influence the *technical feasibility.*

A.4.9 Variables impacting the organizational feasibility

Organizational feasibility: Next to *financial-* and *technical feasibility*, the extent to which an organizationally achievable solution can be effectuated plays a role in determining the achievability to bring about the desired edge computing infrastructure for the IoT application under analysis. Therefore, the way in which the *factors influencing organizational feasibility* have effect on the achievability of the solution should be analyzed.

Factors influencing organizational feasibility: There are several factors that influence the *organizational feasibility.*

- Number of stakeholders: The organizational complexity increases with the number of stakeholders that have to be aligned- and managed in order to effectuate the desired edge computing infrastructure. If an edge provider has to manage a complex web of stakeholders in order to roll out the dedicated infrastructure for the IoT application under analysis, the complexity will increase, in turn potentially making roll-out *organizationally less feasible*.
- Stakeholders' internal complexity, coherency and responsibility clarity: Next to the external complexity which was related to *number of stakeholder* an edge provider has to manage, the internal complexity, coherency and responsibility clarity of partners involved in the IoT application may impact the *organizational feasibility*. The IoT application's players could have many loosely coupled departments inside their own firms. The goals and objectives of these departments may not be coherent, leading to inconsistent planning and action among them. Subsequently, the

alignment of these various departments may be inherently complex. Additionally, the touchpoints of edge computing with both the OT, IT and IoT paradigms could lead to unclarities about who is responsible for the innovation. This could complexify the internal processes. Therefore, the clarity of who is responsible for what, is another indicator *influencing the organizational feasibility*.

- Stakeholders' culture and vision towards innovation throughout the whole organization: Edge computing will introduce another change in the organization. Therefore, the culture and vision of a company towards such innovations may impact the way stakeholders' individually adopt and act upon the innovation. There are examples of companies which have been doing the same thing for over 40 years, not changing much. For such companies, the culture and vision should be changed into a more forward looking vision. In order to minimize the risk of employees defying the innovation, and thereby making roll-out *organizationally unfeasible,* it is important that not only the c-level suite has such vision, but throughout the whole organization, a coherent culture and vision supporting innovation should be present.
- Stakeholder' IT and IoT experience/knowledge: Depending on the knowledge, people and systems stakeholders in the IoT application already have in place, the *organizational complexity* of rolling-out an edge infrastructure may be impacted. A lack of either IT or IoT experience leads to a necessity of new development and/or acquisition of proper skills to utilize a novel edge infrastructure. Insufficient experience and knowledge could thus complexify potential roll-out.

A.4.10 Miscellaneous (generic) variables

Customer value: This variable constitutes the way an edge computing service is able to offer value that satisfies customer demands. This impacted by the *perceived value of the infrastructure* and the *switching cost* a customer incurs when switching towards the edge infrastructure.

Pricing mechanism: For a service to be adopted, the perceived customer value should exceed the price that has to be paid. Subsequently, this mechanism works in two ways. As a higher perceived customer value is generated by an edge computing infrastructure, a higher price can be demanded for delivering the service. This in turn impacts the profitability for the network of companies delivering the edge service. Therefore, the pricing mechanism is a bridging variable that can be used to divide the generated customer surplus among the *provider value* and the *customer value*.

Relative revenue: The relative revenue that service providers gain by offering an edge infrastructure in the IoT application under analysis, determines whether an *acceptable level of profitability* can be reached. The relative revenue in turn results from the *customer base/revenue source* and the *pricing mechanism*.

(Acceptable) profitability: The network of companies that deliver an edge computing infrastructure in the IoT application's market segment require a substantial and acceptable level of profitability. This can be determined by taking into account the *relative revenue, relative cost* and the *(financial)* risk a company takes.

Network value: This variable enfolds in the profitability and opportunities that are created for the service providers by the IoT application under analysis. Subsequently, the network value is impacted by the *(acceptable) profitability,* and the *IoT's ecosystem (health).*

Viability of business model: This variable refers to the extent that both the customer- and the network of companies participating in the a the value constellation of the edge infrastructure, gain significant with respect to the rolls they fulfill. Put differently, it encompasses the question whether there enough *customer value* and *network value* to effectuate a viable business model.

Feasibility of business model: This variable refers to the question whether it is *technically-*, *organizationally*, and *financially feasible* to provide an achievable solution for the required edge computing infrastructure in the IoT application under analysis.

Potential of the IoT application for edge computing: This variable can be derived by providing an answer to the question whether the IoT application under analysis constitutes both a *viable-* and *feasible business model.*

A.5 Applying the tool by means of ten constructive steps

A.5.1 Determining the perceived value of the infrastructure for the customer

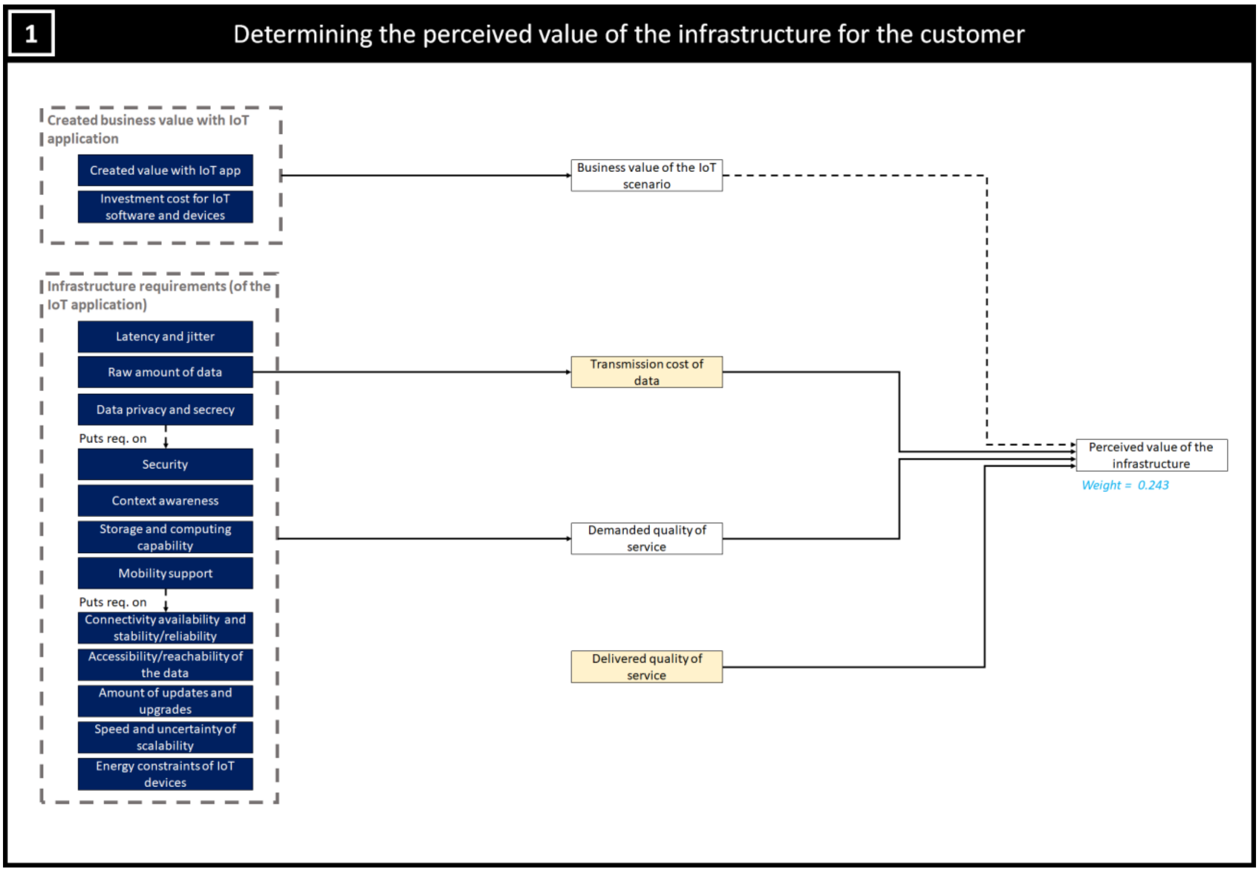


Figure 47: Determining the perceived value of the infrastructure for the customer

A.5.2 Determining the switching cost for a customer

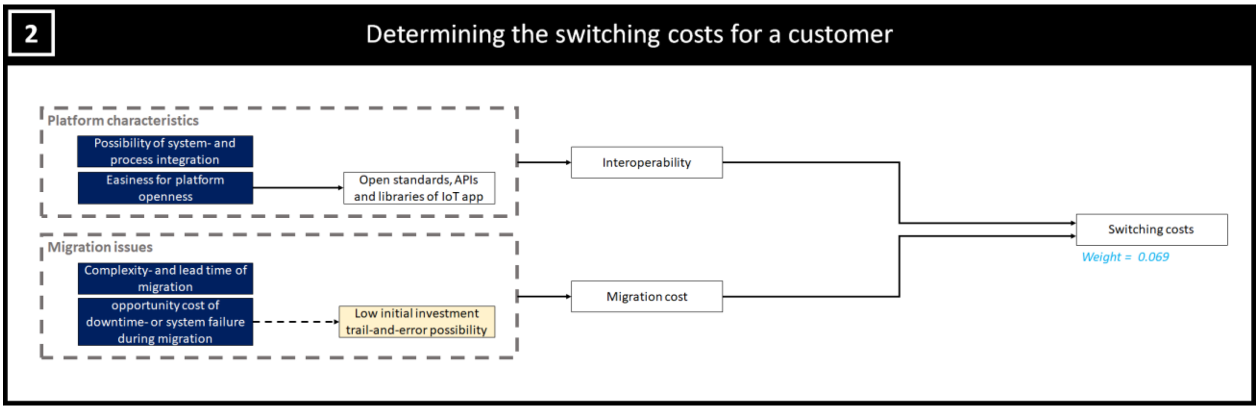


Figure 48: Determining the switching costs for a customer

A.5.3 Determining the customer base and how it will suffice as revenue source

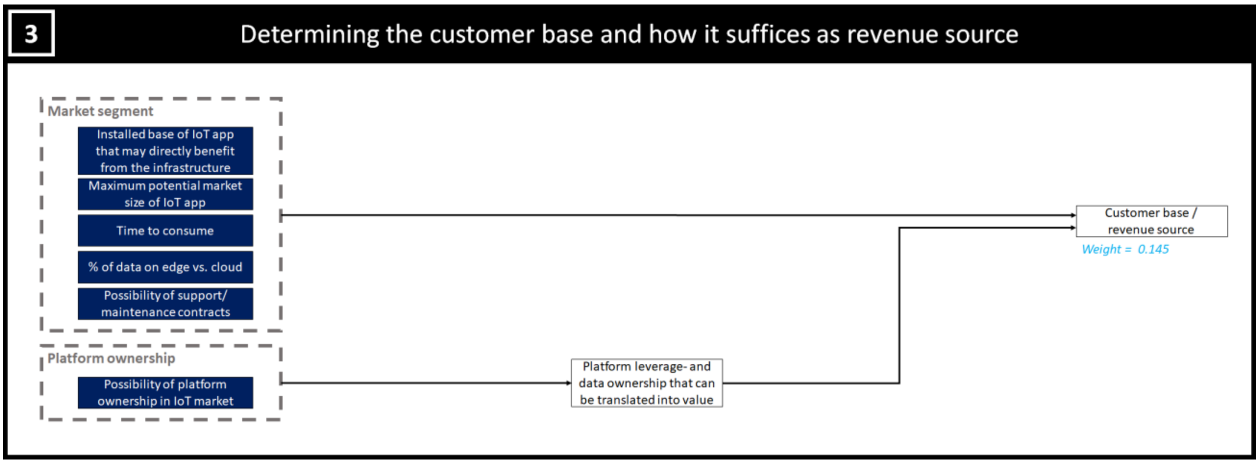


Figure 49: Determining the customer base and how it suffices as revenue source

A.5.4 Determining the relative infrastructure cost

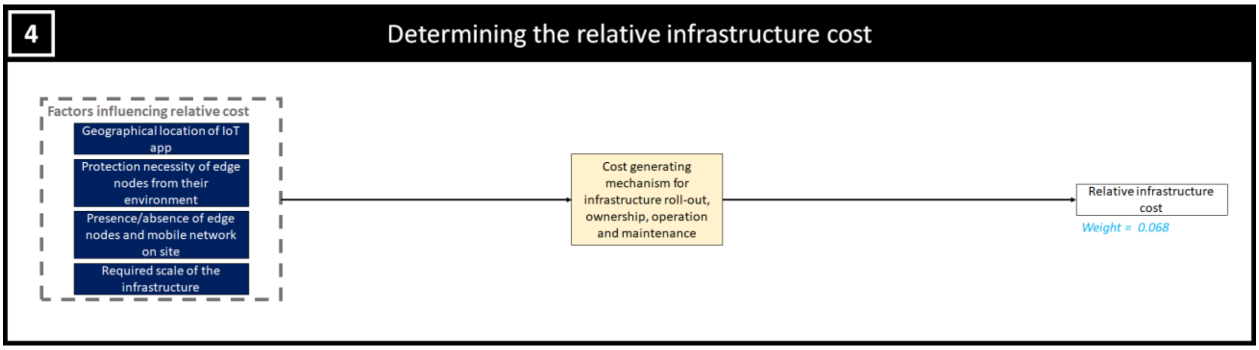


Figure 50: Determining the relative infrastructure cost

A.5.5 Determining the (financial) risk for the service provider

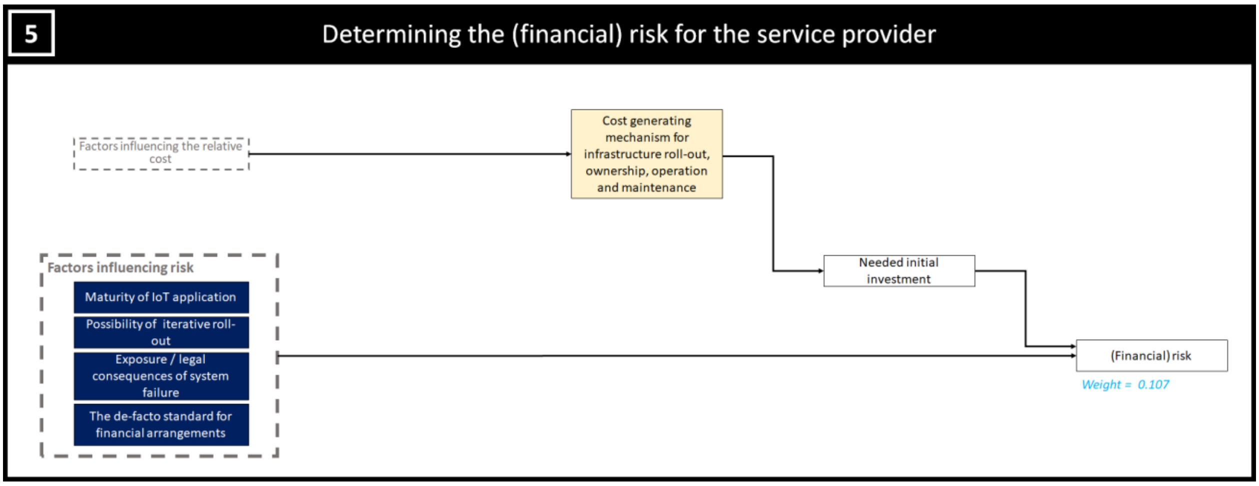


Figure 51: Determining the (financial) risk for the service provider

A.5.6 Determining the value generated by the IoT application's ecosystem (health)

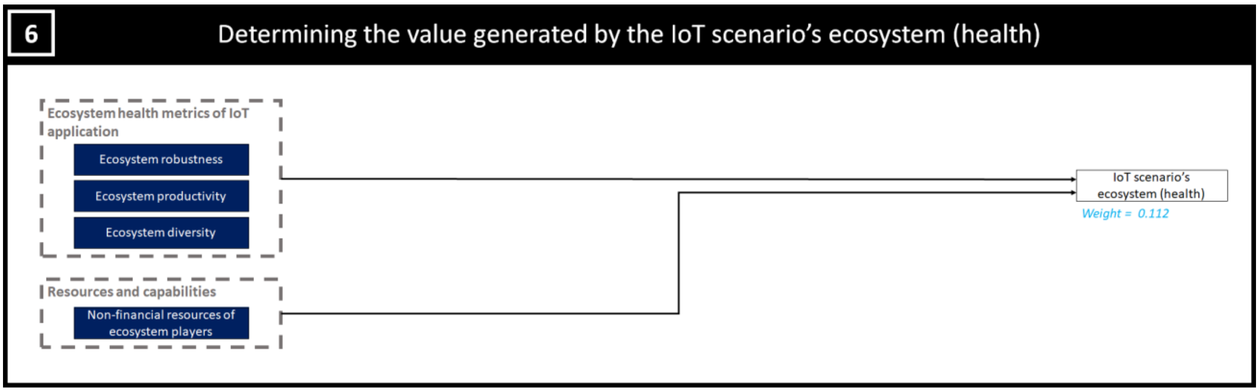


Figure 52: Determining the value generated by the IoT application's ecosystem (health)

A.5.7 Determining if the desired edge infrastructure is financially feasible

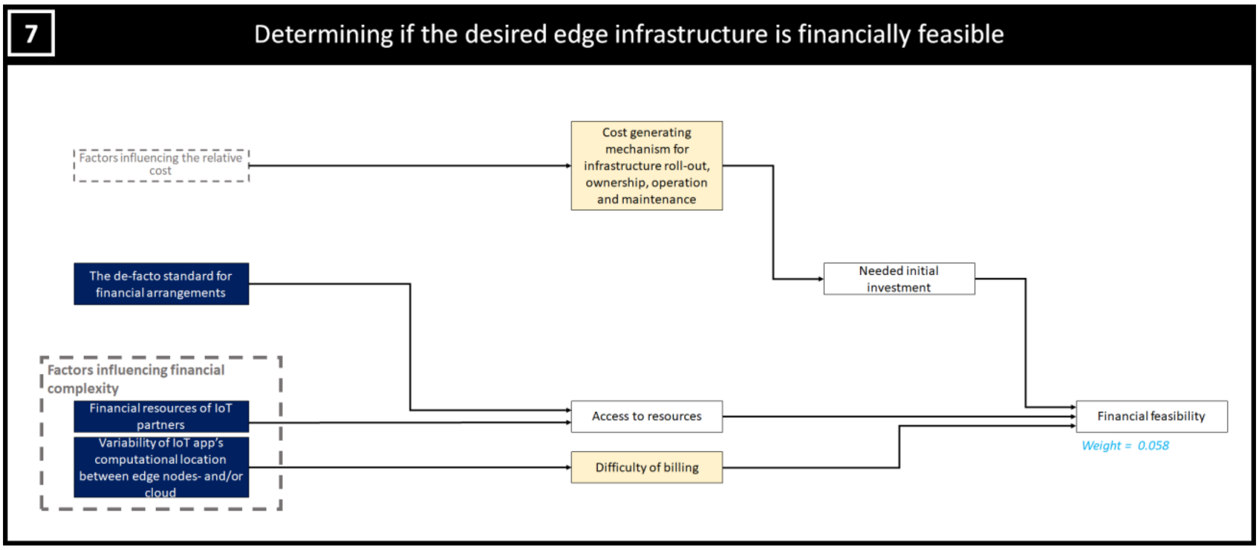


Figure 53: Determining if the desired edge infrastructure is financially feasible

A.5.8 Determining if the desired edge infrastructure is technically feasible

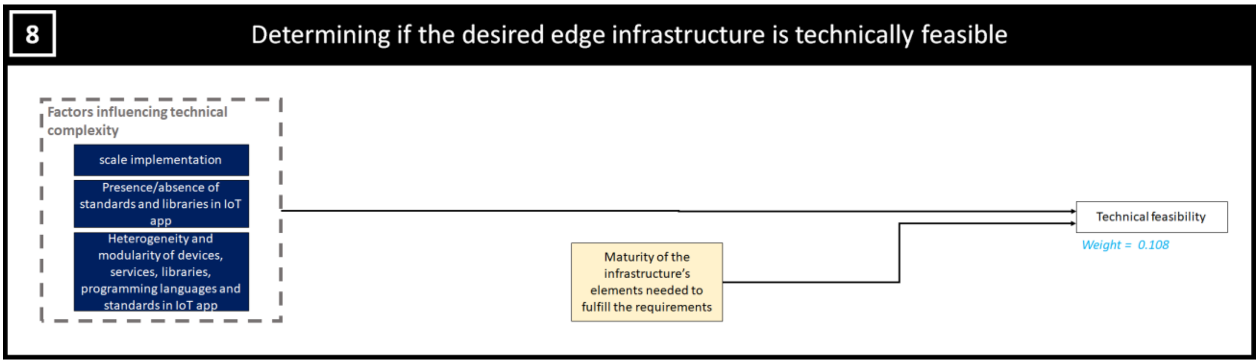


Figure 54: Determining if the desired edge infrastructure is technically feasible

A.5.9 Determining if the desired edge infrastructure is organizationally feasible

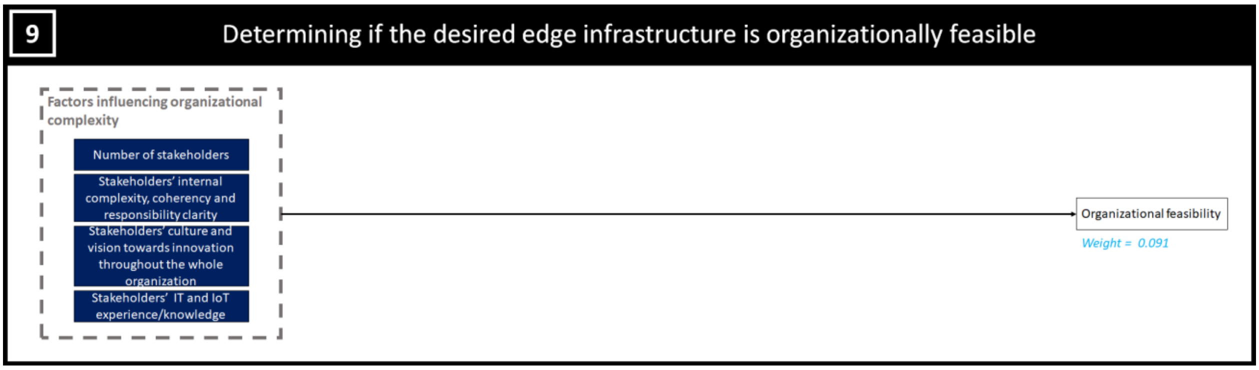


Figure 55: Determining if the desired edge infrastructure is organizationally feasible

A.5.10 Using the whole model, plus answers of steps 1-9, to derive to the final answer

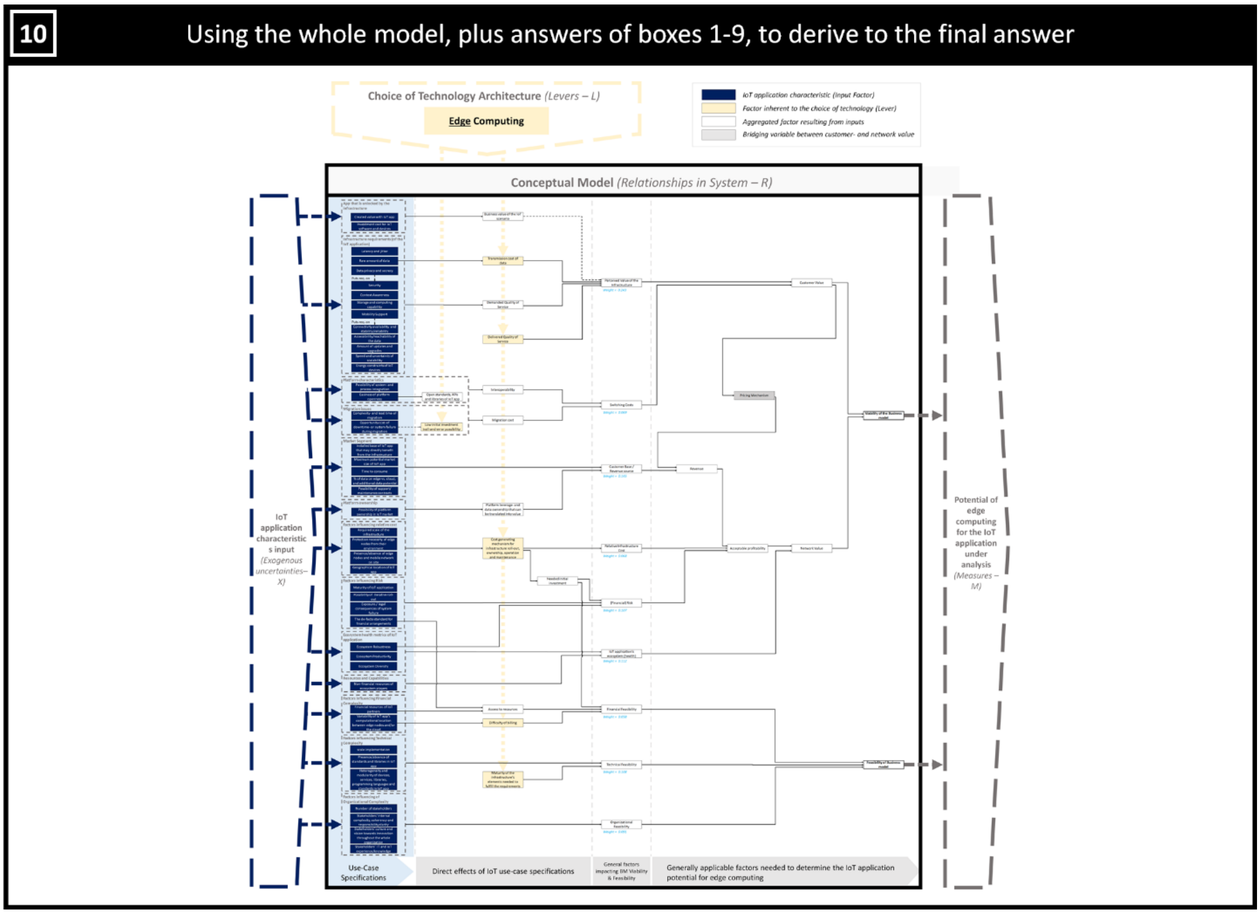


Figure 56: Using the whole model, plus the answers of steps 1-9, to derive to the final answer

A.6 Coding networks of demonstration phase

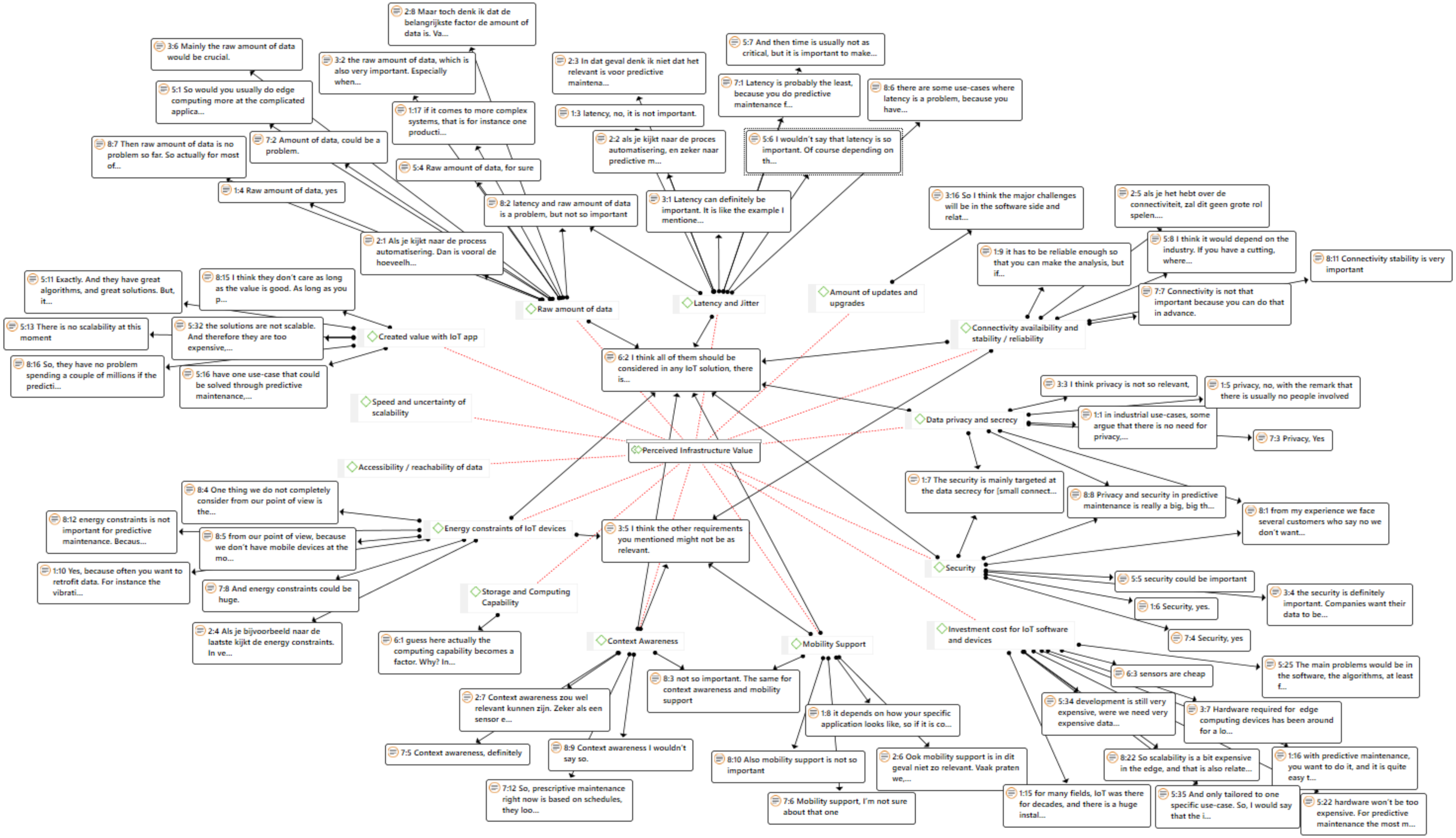
This attachment contains the coding networks for demonstration of the tool on predictive maintenance in industry 4.0. These networks have been extracted from the transcripts that are attached in A.7. Nine global themes were identified (corresponding to the nine generic variables of the tool). Hence, this appendix contains nine coding networks, each displaying interviewees input for one generic variable. Furthermore, Table 30 provides an overview about how the global themes are divided in organizational themes. The organizational themes were drafted based on the contextual input variables (i.e. IoT application characteristics) of the tool (design phase 2) that influence the generic variables (i.e. the global themes). Any remark of interviewees about the interaction of a contextual variable within the predictive maintenance domain has been coded. Also relevant remarks about the broader context of predictive maintenance, i.e. the industrial automation industry, has been coded. These remarks have been coded under the organizational theme that they influence. Lastly, it can be observed that interviewees quoted different organizational and global themes to a varying extent. These varying number of quotes per organizational theme are due to the chosen data gathering strategy, which is elaborated upon in Section 8.4. Implications that arise from this, are explained in section 9.3.

Table 32: Number of quotes per global and organizational theme

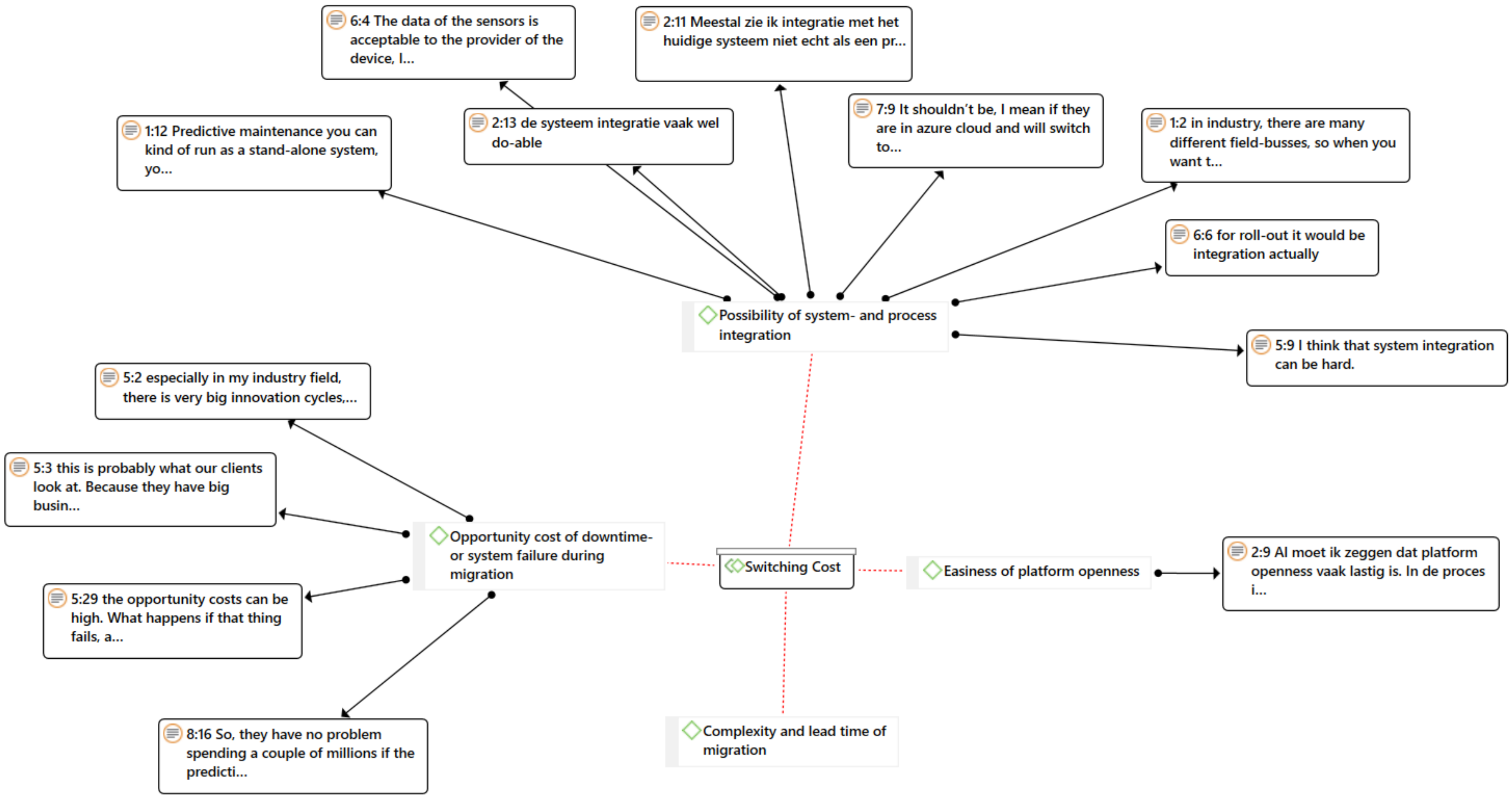
Global Theme	Organizational Theme	Number of Quotes
Perceived quality of service	Created value with IoT app	#6
	Investment cost for IoT software and devices	#9
	Latency and jitter	#10
	Raw amount of data	#12
	Data privacy and secrecy	#9
	Security	#9
	Context awareness	#8
	Storage and computing capability	#1
	Mobility support	#8
	Connectivity availability and stability / reliability	#7
	Accessibility / reachability of data	#0
	Amount of updates and upgrades	#1
	Speed and uncertainty of scalability	#0
	Energy constraints of IoT devices	#9
	Total:	**#89**
Switching costs	Possibility of system- and process integration	#8
	Easiness for platform openness	#1
	Complexity- and lead time of migration	#0
	Opportunity cost of downtime- or system failure	#4
	Total:	**#13**
Customer Base / Revenue source	Installed base of IoT app	#5
	Maximum potential market size of IoT app	#4
	Time to consume	#0
	% of data on edge vs. cloud	#2
	Possibility of support / maintenance contracts	#2
	Possibility of platform ownership in IoT market	#0
	Total:	**#13**
Relative infrastructure cost	Required scale of infrastructure	#3
	Protection necessity of edge nodes from their environment	#2
	Presence / absence of edge nodes from their environment	#1
	Geographical location of IoT app	#1
	Cost generating mechanism	#1
	Total:	**#8**
Financial Risk	Needed initial investment	#2
	Maturity of IoT application	#13
	Possibility of iterative roll-out	#0
	Exposure / legal consequences of system failure	#1
	The de-facto standard for financial agreements	#5

	Total:	**#21**
IoT application's ecosystem (health	Ecosystem robustness	#7
	Ecosystem productivity	#6
	Ecosystem diversity	#3
	Non-financial resources of ecosystem players	#0
	Total:	**#16**
Financial feasibility	Needed initial investment	#2
	Financial resources of IoT partners	#0
	Variability of IoT app's computational location between edge nodes- and/or cloud	#0
	Difficulty of billing	#1
	Total:	**#3**
Technical feasibility	Scale of implementation	#7
	Presence / absence of standards and libraries in IoT app	#8
	Heterogeneity and modularity of devices, services, libraries, programming languages and standards in IoT app	#14
	Total:	**#29**
Organizational complexity	Number of stakeholders	#3
	Stakeholders' internal complexity, coherency and responsibility clarity	#3
	Stakeholders' culture and vision towards innovation throughout the whole organization	#3
	Stakeholders' IT and IoT experience / knowledge	#3
	Total:	**#12**

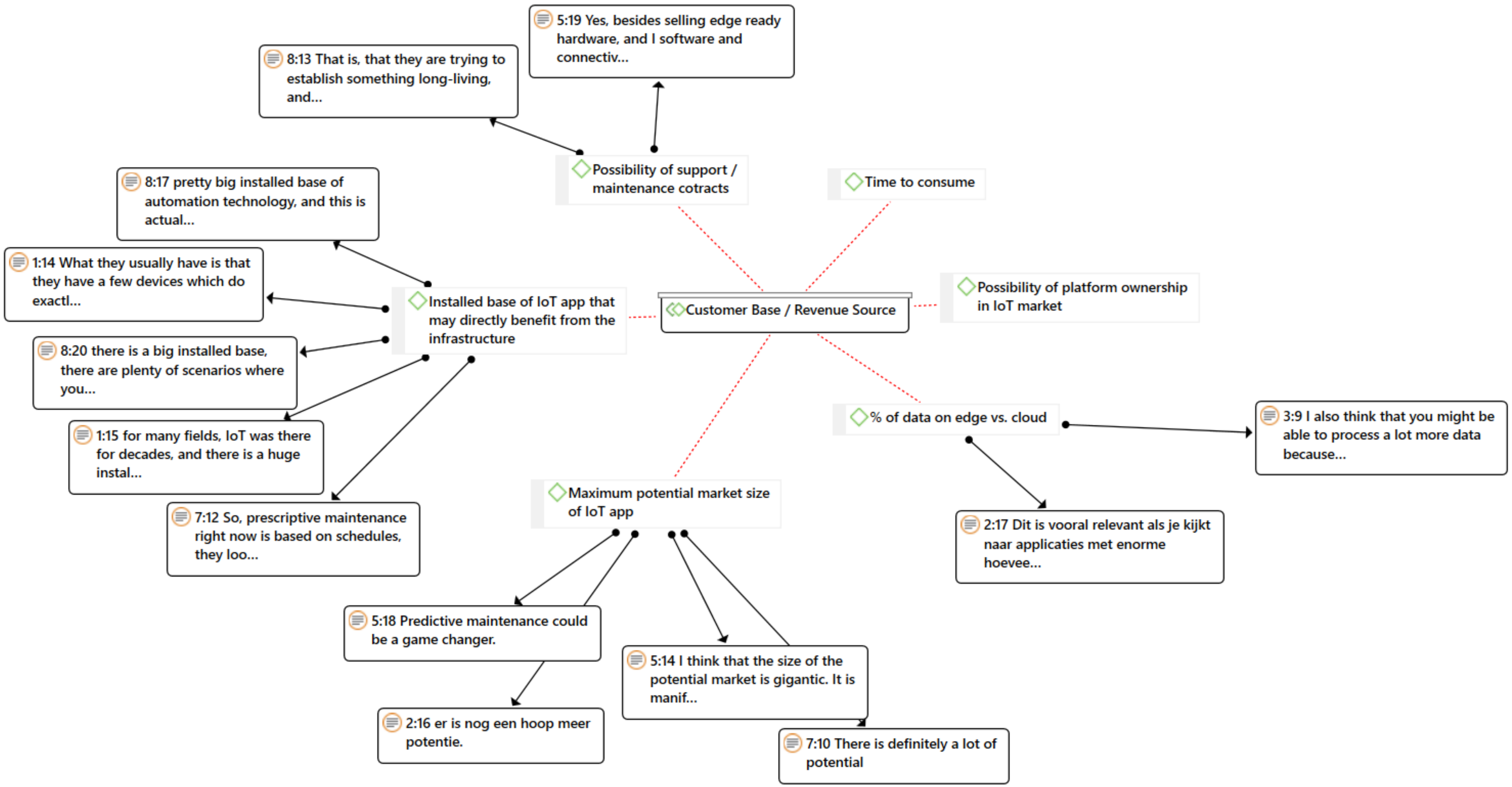
A.6.1 Perceived value of the infrastructure



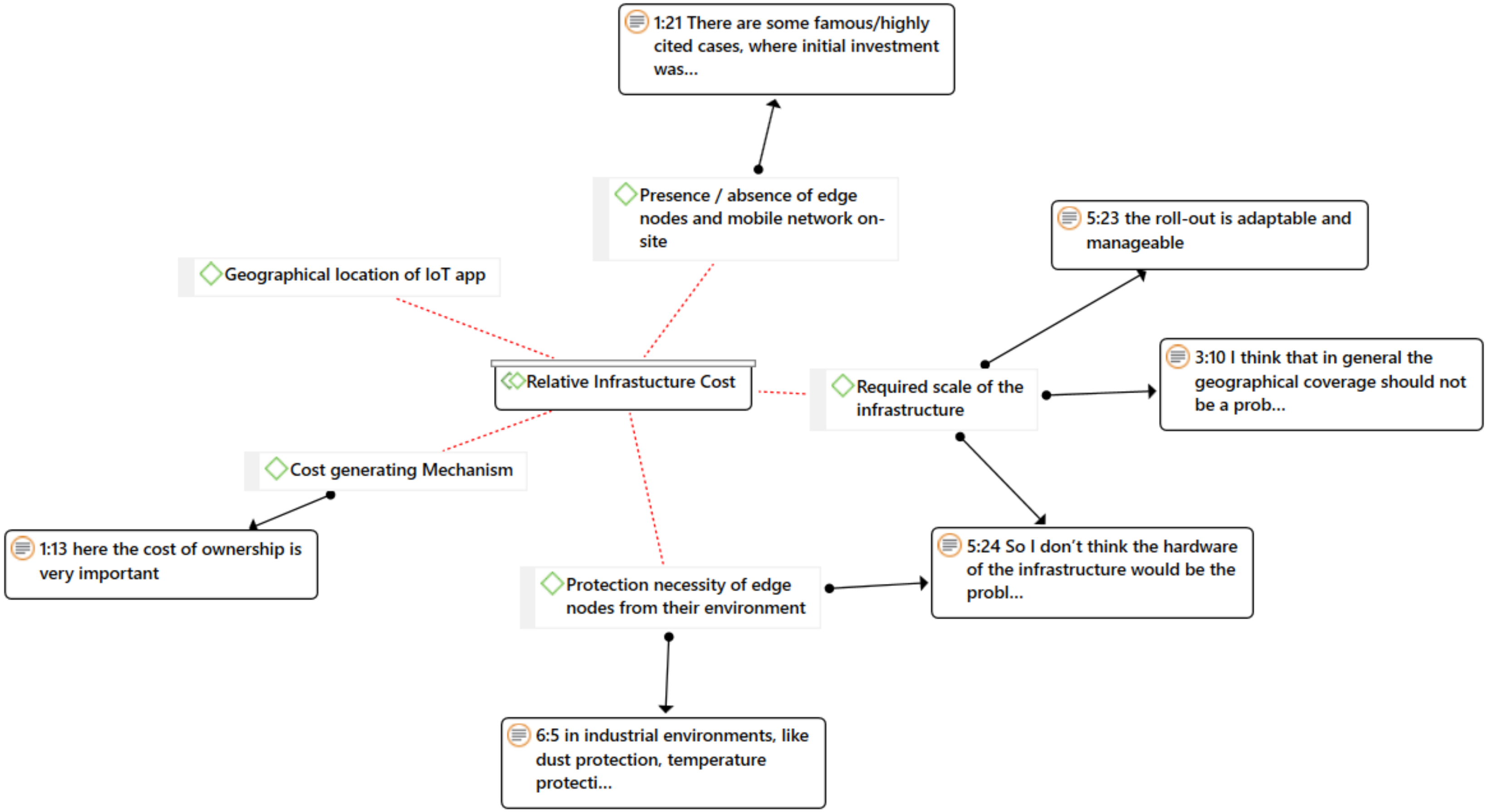
A.6.2 Switching costs



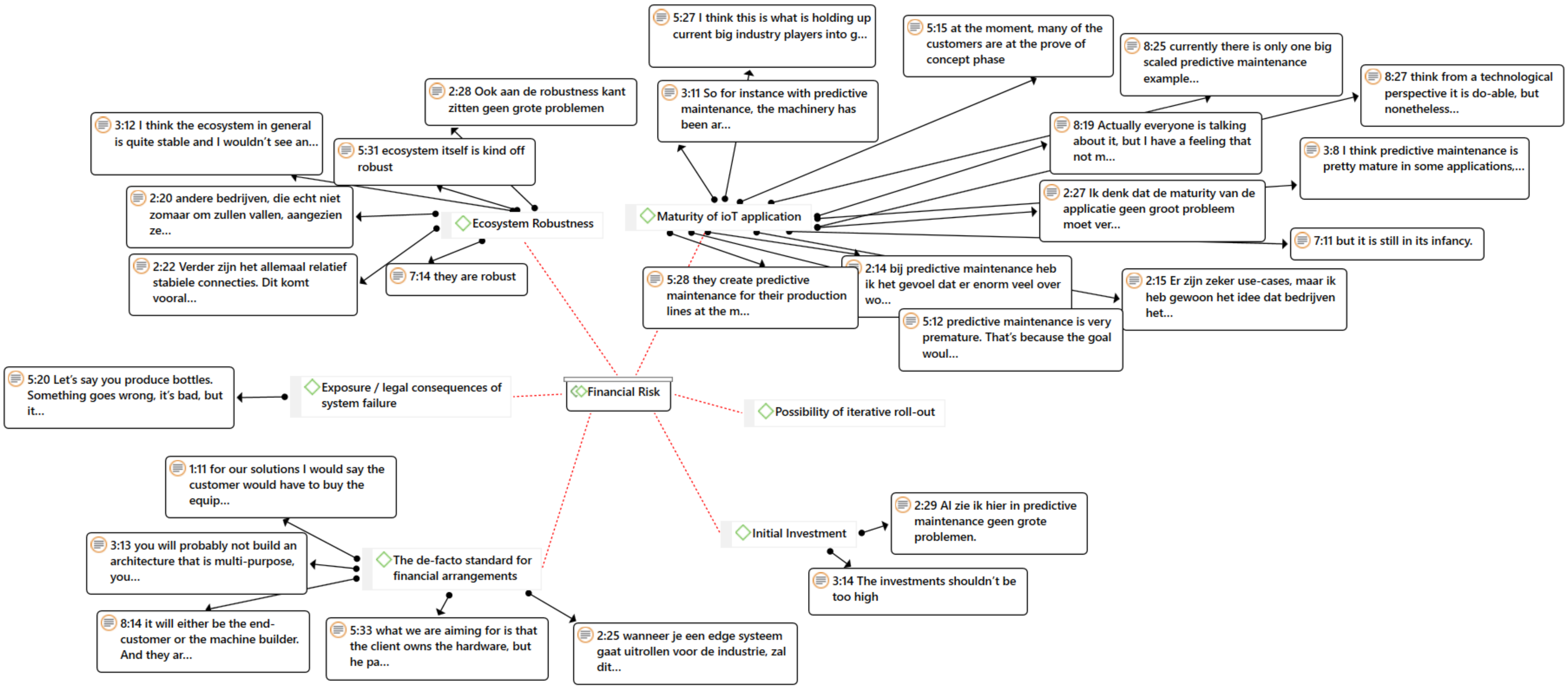
A.6.3 Customer Base/Revenue Source



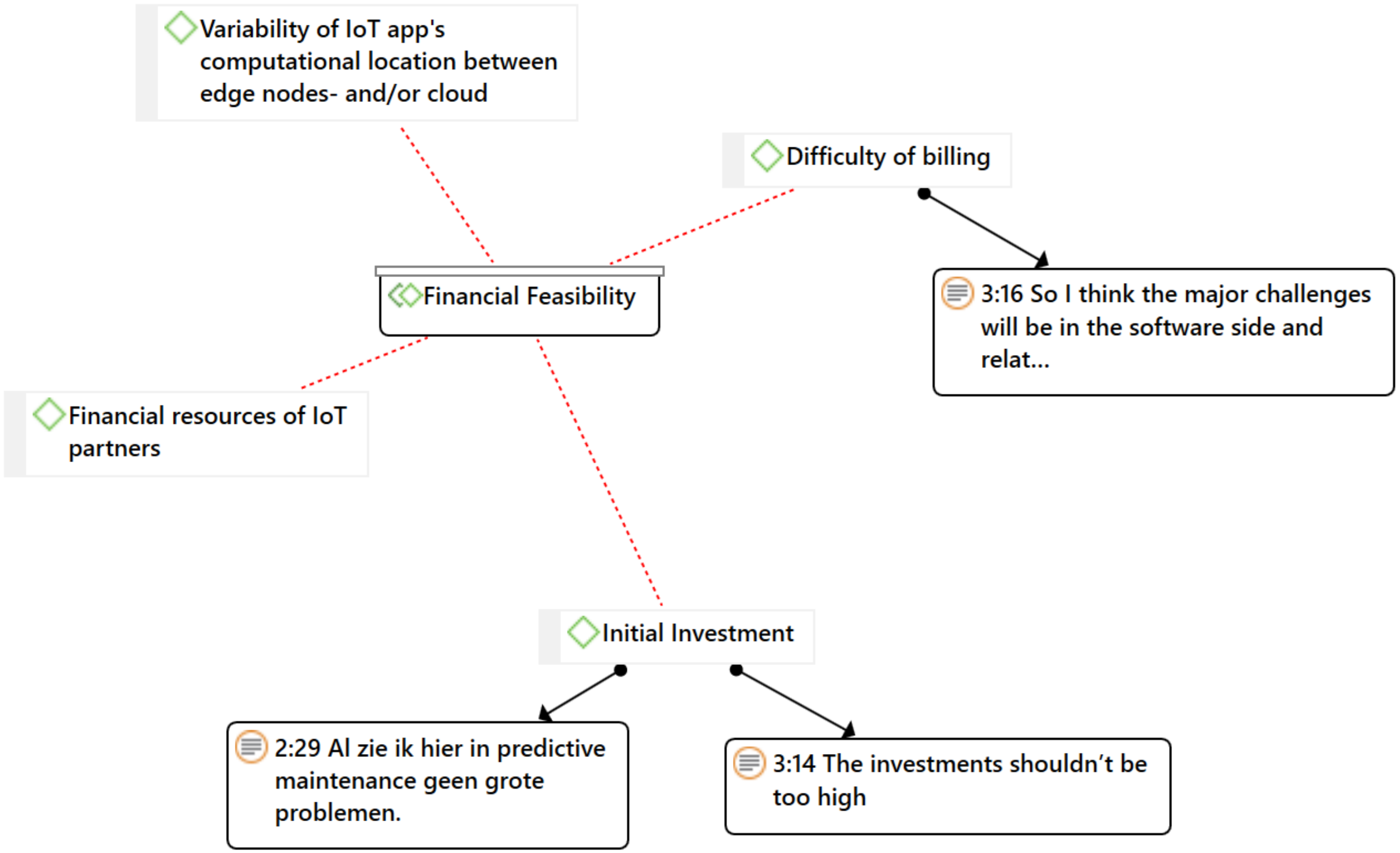
A.6.4 Relative infrastructure Cost



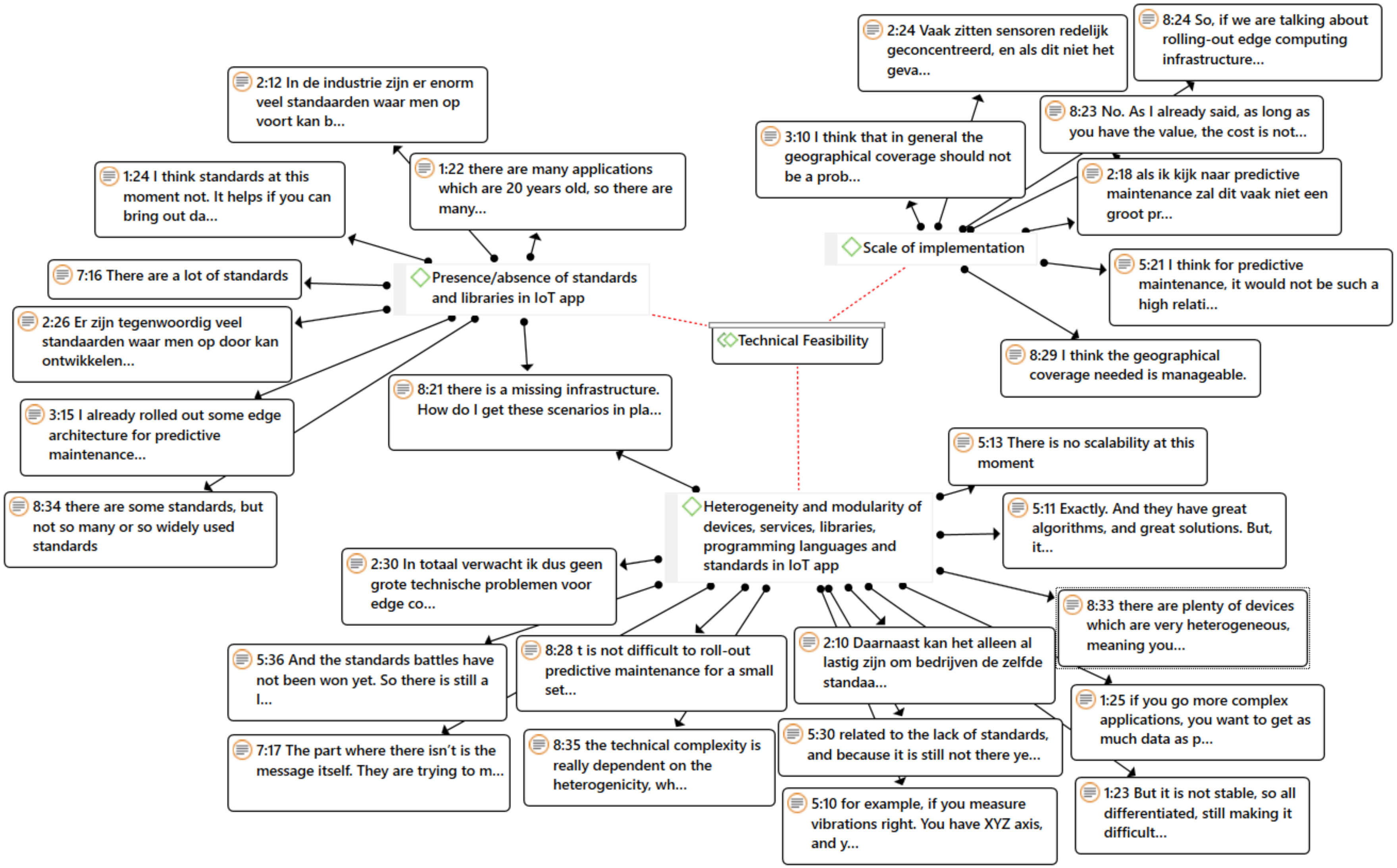
A.6.5 (Financial) Risk



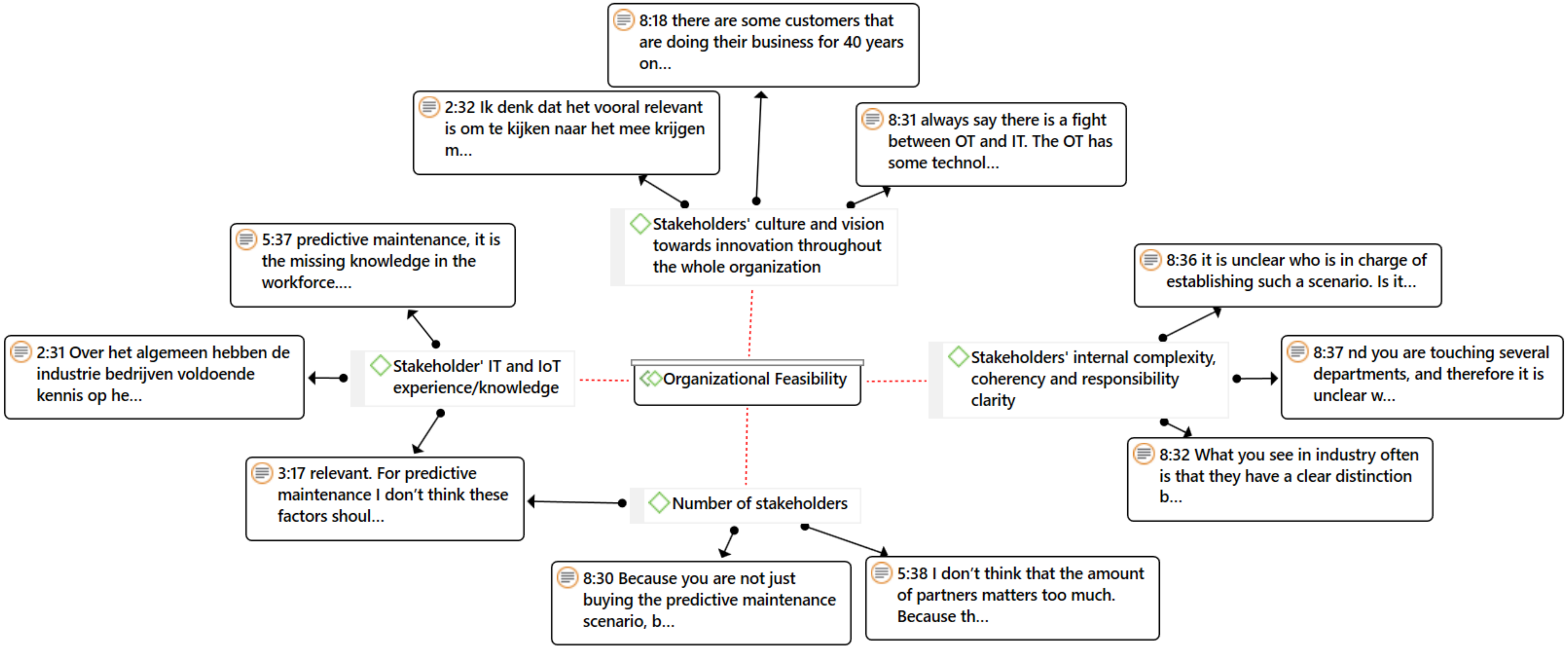
A.6.6 Financial feasibility



A.6.7 Technical feasibility



A.6.8 Organizational feasibility



A.7 Interview Transcripts

During the interview stage of this research, 11 experts have provided their valuable input. These 11 interviewees work at 7 different companies, located in 5 countries. Furthermore, interviewees had diverse backgrounds, making their input diverse. Table 33 provides a list of interviewees. In order to guarantee privacy, and thereby comply with the TU Delft ethics guidelines, names have been removed. Also, company names have been replaced with company types, as statements of the interviewees constitute their individual vision rather than the company's vision.

Table 33: List of interviewees

Initials	Company type	Role	Country	Concrete project experience in edge computing	Predictive maintenance expertise
Interviewee 1	[1] Network provider & Network equipment provider	Principal Researcher	Germany	√	√
Interviewee 2	[2] (IoT) application provider	Business Development Manager	Netherlands	√	√
Interviewee 3	[3] Consultant	Senior Manager	India	√	√
Interviewee 4	[4] Network provider	Director	Netherlands	√	×
Interviewee 5	[5] Edge and cloud platform provider & (IoT) Application provider	Ecosystem manager	Germany	√	√
Interviewee 6	[3] Consultant	Senior Manager	Poland	√	√
Interviewee 7	[3] Consultant	Manager	America	√	√
Interviewee 8	[5] Edge and cloud platform provider & (IoT) Application provider	Product Manager	Germany	√	√
Interviewee 9	[6] Network provider & Network equipment provider	Manager	Netherlands	√	×
Interviewee 10	[7] Edge and cloud platform provider	Partner development manager	Netherlands	√	×
Interviewee 11	[7] Edge and cloud platform provider	Partner technical strategist	Netherlands	√	×

A.7.1 Interview 1 – Network provider & Network equipment provider

Interviewee 1 = IN1
Michiel Huisman (Interviewer) = MH

MH: Did you have a chance to look at the documents, or not? Otherwise I will go through it for a bit
IN1: I quickly had a look at it the past 5-10 minutes, but not fully in detail. So I got the rough idea of the interview, the official part, the agreement, and the parts that you have for the questioning/
MH: Exactly, before we start-off, I have to formally ask you the following: I would like to ask you, are you okey if I record this interview? Afterward transcribe it, filter your name, etc., and send the transcription to you for approval.
IN1: Yes, that sounds good
MH: And of course if you want me to filter information, or if you want to withdrawal, you can let me know.
IN1: Okey
MH: So I send you a couple of documents, the first one is the protocol, and the second one is the conceptual model. So what I did, is instead of displaying the full conceptual mode, I cut it of in 10 parts. For the first 9 parts I want to validate if the factors which I identified indeed are relevant, and if there are other factors which I might have forgotten. And for the 10th part I want to rank the relative importance, as they are generic. And actually the factors that are on the right side of the first nine boxes, for instance the relative / perceived quality of service, the switching costs, which are a result from the contextual factors of edge computing, those are the ones I want to rank.
IN1: Okey
MH: So you said you already had a look at it for 5-10 minutes. Are there already some unclarities which you want me to elaborate upon.
IN1: For the details, when we come to the individual factors, and the keywords that you give, I want to discuss with you for some clarification, but in general it looks fine.
MH: Okey, sounds good. Then I suggest we just start-off at the first box, the relative / perceived quality of service.
IN1: Okey.
MH: So what I did there, is, at the left side of the box, I identified a couple of technical factors, technical requirements actually, which impact the demanded quality of service. These factors are for instance: latency requirements, raw amount of data, privacy requirements, etc. So these are 8 factors in total. Do you think there are any of these requirements which are not relevant for determining whether to go for edge computing or cloud computing?
IN1: So, I would say they heavily depend upon the use-case. One of the things I stumbled upon is the privacy requirements. For instance in industrial use-cases, some argue that there is no need for privacy, as there are no individuals involved. Hence, you don't have the requirements. So overall I don't know how broad use-cases you identified. Because for consumer stuff it definitely is important.
MH: It is good that you mention this. Actually, the first question is fully targeted at, could it be of relevance in any application selection. And then the second question will be about how the factors interact with the chosen application, which is predictive maintenance for industry 4.0. So first a generic question, and then a specific question.
IN1: Yeah
MH: So do you think, from those 8 factors on the left, that they might all be of relevance for the decision to go for edge in general
IN1: I have been thinking on the mobility support. It defines on how you define edge computing. There are these scenarios for instance that you drive around in your car, and the edge/cloud follows you along the road. It is a bit of a complex set-up I would say where edge computing gets a bit fuzzy. So, it is not wrong, I guess it just needs explanation about how it gets in there.
MH: Okey, so it might be a bit vague. I will include this. So do you think there might be other factors that might be relevant, which I did not include?
IN1: Sorry, but I stumbled upon the context awareness factor. Which is probably more a feature, if you need this in your application or not. Not sure if this is really a factor that is generally in there.
MH: Okey, is it then also true that context awareness could be applied through for instance through a cloud or other architecture?
IN1: I am not sure about what was exactly the definition.
MH: Ehm, context awareness is mainly about that a sensor and its network can gather data about its context, their environment, connection etc. and can use it in the progress.
IN1: Because I don't remember the definition by Anind Dey or something like this. The thing is, it is more a feature of the application, and there are many instances in which you don't need context awareness, because the context is static. It is not a factor, and you can have it on a non-connected mobile device for instance. Which could determine your location, so I think it is not a factor.
MH: Okey, thank you. And furthermore, are there any other factors which I might have forgotten, from your industry experience?
IN1: Yes, so what I am missing is interoperability.
MH: Okey, interoperability, what is it? I haven't read about it.
IN1: Ehm so, a problem is that there are many different platforms and technologies. Think for instance in industry, there are many different field-busses, so when you want to do industry 4.0 for instance, you also want to connect your shop-floor with the building automation system, or with the logistics, so the supply-chain management. And it depends on how interoperable the technologies are. So it comes down to the integration costs, and in some cases it might not even be technically possible, because it is a completely closed ecosystem.
MH: Okey, good one, I am not sure if I completely have that factor. But if you look at the model, part 8. I think what you mention could fit very well at the technical complexity. So if it would not be interoperable, it would be technically very hard to integrate the system, is that right?
IN1: Yes, somewhat. I would say that some solutions are more interoperable than others, so if you take some open standard to implement your system, it is better than picking a close system that is only supported by one vendor.
MH: Yeah, so it also has to do with the standards in the IoT application? Which eventually may make it interoperable with other systems, or not. Is that right?
IN1: Yes
MH: Okey.
IN1: Openness is what I would call it.

MH: Actually, at the second box. Sorry I am jumping around a bit. At the second box you see the platform characteristics. And you see that I identified the easiness for platform openness, which might be related to the kinds of things you are mention. But it is more vaguely defined. Which means I might want to separately refer to interoperability.
IN1: Okey, so maybe this is a good point to compare. So the openness is definitely something …[small connection loss]… switching costs. and interoperability has two aspects. So the switching costs is also one part. So for instance when you need a lot of hardware and integration efforts, it increased your costs. But there is also your perceived quality of service. So if you buy some consumer electronics, like your TV, your recorder, and so on, you need like 10 different remote controls for that. It is not a good quality of service.
MH: Yeah, I agree. So would you say it is also a part of technical complexity?
IN1: Yes, if you need a lot of gateways in order to integrate it with for instance other services, it might get technically complex.
MH: Okey, so any other factors at the first box I might have forgotten?
IN1: Something that comes to mind, under latency, you might want to include the term, jitter. This is important for industrial applications, and refers to deterministic behavior. So latency is okey if you can just take the delay into account. But if your data becomes available a second to late, it could be very bad for robots for instance.
MH: Okey
IN1: Just say something like latency/jitter in one box, because otherwise it might not be on the same level of detail as for instance security.
MH: Yeah, it makes it more specific. What I also wonder, in cases of industrial applications. When you look at the raw amount of data, which is linked to two things. On one side it is linked to the bandwidth. But on the other hand it can also be related to transmission costs of data. So if I would have to move much data to the cloud, it will cost me much money. But if I would move this data to the edge, I would not have to pay as much money to the mobile service provider to transmit the data all the way to the cloud. What's your feeling about this?
IN1: So the amount of data is indeed definitely a factor …[Small connection loss]….
MH: I think for one second we lost connection, could you repeat what you just said?
IN1: Data is definitely a very important factor for edge computing. But I am not sure if perceived quality of service is the right box for it.
MH: In what kind of other box would you place it?
IN1: It is difficult. You have the cost already on the right, so that is in there. Sorry, give me a second to look at the other factors. Yeah, so it is definitely related to the technical complexity. To give you an example, there are some machines that produce 2TB per hour.
MH: Okey, that's a lot.
IN1: Yeah, What I am kind-off missing is the operational costs, or the cost of ownership, or something like that.
MH: The total cost of ownership for the service provider or the application owner?
IN1: So the question is, who has to pay for this? So if this model is just the service, and you will pay for all the transmission cost as the provider, that's kindof good for the customer. If the customer, who wants to get some edge computing offering, let's say, has to pay for the transmission cost, then of course this is an important factor.
MH: Okey, so it is really case dependent.
IN1: Yes
MH: Okey, good. Then one other factor, in box one. The added value of serverless. So what I found in literature. Wait, are you familiar with the concept of serverless computing? …[Small connection loss]…
IN1: Yes
MH: So what I found in literature what that, in some cases, it might be easier to implement serverless for edge computing, or not even only easier, but more beneficial to implement serverless for edge computing than for cloud computing. So one of the philosophies behind edge computing is that you run functions as a service, which could enable you to do the control part of machinery on the edge more easily. But on the cloud you couldn't do the control, because it is to slow. So what I wonder, is if serveless computing can in that area bring additional benefits for edge, and thus be a reason to chose for edge instead of cloud.
IN1: Well, serverless is actually a quite new concept, and there is no consensus yet, on what it actually means. There is also quite the number of work out there that criticizes it. For instance I fear that now switches and the network itself has to become application aware. I mean, I can understand, serverless is kind off a hype at the moment, so I can understand you want to cover it. But, it is way, way more fuzzy than edge computing at this moment. So I don't really know if it helps to put it in the edge computing tool.
MH: So does that mean you do not see it influence the decision to chose for edge or not?
IN1: It is about how you scope it in your work. The consequence of serveless computing definitely has some impact, but it is mostly for the developers, because you don't have to know where it is running, you just have some infrastructure and it will happen. But then, for the deployment of how it will really look like for edge computing, so where does this compute come from. So one thing people say is that routers and switches will provide some computing power, the question then is, do they have to be application specific, and can you make the computing power application aware. This displays there are very much questions regarding serverless.
MH: So it means, that for comprehensiveness I might include it, but as it is so fuzzy, it might not find its real applications. This mean I have to make a note, that it might play a role, but it will probably be minor.
IN1: Yeah, so if it fits your use-case and so on, and there is some concrete solution for it, then I think it can be considered, but I fear that in many use-cases, you cannot base the decision on this concept.
MH: Okey, good, thank you. Last question for box one, if I were to apply the framework for predicative maintenance for industry 4.0 applications. I know this is kind off broad, but I decided to not make it to detailed yet. So which of the factors of box 1 do you think will influence the decision to go for edge vs. cloud architecture for predictive maintenance.
IN1: So, latency, no, it is not important. Raw amount of data, yes. privacy, no, with the remark that there is usually no people involved. Security, yes.
MH: could you elaborate this?
IN1: The security is mainly targeted at the data secrecy for [small connection loss]… for the system. So for instance if it is for the factory. This data basically specifies how you set up your factory, how you can produce the product, etc. So the factory owners are very sensitive about data leaks and so on, so security is a high concern.
MH: Okey, that's clear. And the next one, context awareness, is more a feature like you said right?

IN1: Yea.
MH: And how about mobility support?
IN1: Again it depends on how your specific application looks like, so if it is completely mobile. Let's say you take some equipment to customers [i.e., the monitored equipment is moved around, not static like, e.g., elevators], you might need mobility support.
MH: okey, clear. How about connectivity stability/ reliability of the connection?
IN1: Ehm, it is so, so. In the end of course, it has to be reliable enough so that you can make the analysis, but if you have some gaps, I would say it is not so critical for predictive maintenance.
MH: And the energy constrains of the devices?
IN1: Yes, because often you want to retrofit data. For instance the vibration sensors that you just glue on, sometimes you don't have a power supply for that, so this is relevant.
MH: And the potential of serverless, does it have any relevance for predictive maintenance?
IN1: I would say no. Again, if it helps you to reduce the amount of data through some clever pre-processing, that you kind of get for free, because it is somewhere in the network. But there is the fuzziness problem.
MH: Okey, thank you, then I think we can tick off box 1. So we can continue to the second box, which looks quite a bit easier I guess. So this box is related to the switching costs, and I identified two factors. The first one is about system integration with the previous offering. So for instance you might be able to combine your current system with the edge system. Let's say you have an cloud architecture, and implement edge, you can use it simultaneously, so it is interoperable. And the second one is the easiness of platform openness. How do you see these factors, in general, interacting? Do you think they influence the decision to adopt edge computing or not?
IN1: I would say they definitely play a role. I cannot completely distinguish these characteristics that you mention.
MH: So, for the openness, it is more that the platform which will be made is open for other developers to develop on the same standards and build upon each other's concepts. While the possibility of integration with the previous offering, is mainly targeted that the edge system is interoperable with the previous, let's say cloud offering, instead of being a completely stand-alone concept
IN1: So this is also an instance of openness.
MH: Does that mean you would say openness covers both?
IN1: Yeah, but you can leave it like this, it is just an idea. Just make a note, maybe other say the same things. But, for now, what I am kind of missing is the cost of the equipment that you need to get. Edge computing means you have hardware locally. Either you own it, or you lease it, or it is part of the price.
MH: So is it related to investment costs of the customer?
IN1: In the business model it could be that the equipment still belongs to the operator that delivers the service. But, for our solutions I would say the customer would have to buy the equipment and use it locally.
MH: Ah, I can understand, so in your business model, the equipment costs for the user might increase the switching costs. And for predictive maintenance, are these factors both of relevance?
IN1: Predictive maintenance you can kind of run as a stand-alone system, you can integrate it with your device management, but it could also be separate
MH: Ah, so interoperability is not a major problem. And do you see any problem for the switching cost, for any people wanting to use edge computing for predictive maintenance. Or, what is usually the biggest barrier you see for the switching costs?
IN1: For switching you mean that you don't use cloud computing, but edge computing, is that right?
MH: Yeah, so people chose not to switch to edge computing, because the barriers to switch might be to high. So because of e.g. the cost are too high.
IN1: From what situation are you switching?
MH: It could be from either your proprietary data center, or from cloud computing architecture.
IN1: Could you repeat the question? I have to sort my thoughts a bit.
MH: So, for predictive maintenance, what is making the biggest switching costs, wanting to use edge computing there. So what is a big reason, which increases the switching cost from their previous offering towards edge computing, why they might chose not to switch.
IN1: Yeah, here the cost of ownership is very important.
MH: Okey, clear, let's go to the third box. This one is not from the consumer perspective, but from the provider perspective. And regarding that, this box describes that it is important that there is a substantial customer base. So one of the things which important is that there is a sufficient target market, right?
IN1: Uhu
MH: So I listed three things; first, there should be a substantial installed base. E.g. there should be a substantial people using the IoT application at this moment. The second describes the potential of the application's market. And then the last one describes how much data you would push to the edge vs. what could still be done at the cloud. So what is your feeling, how do you think these factors interact with the decision for providers to target at an IoT market for edge computing?
IN1: Mh, it's hard to say. I think that one thing that is important is to describe how much you can push to the edge, so that would be the first one in the box.
MH: So, for example, for Siemens, is it more important to look at the current installed base, or at the potential market, what do you usually target on?
IN1: It depends on if they already do edge computing. What they usually have is that they have a few devices which do exactly which they need to do. In that sense, there is no installed base. It could be that they have some local data centers, like some edge cloud. If that's what you are hinting at, otherwise I am not sure what could be the installed base.
MH: Ah, it could be I explained it a bit wrong. It is actually about how large scale the IoT application itself is rolled out. So not the edge infrastructure. So e.g. when you look at autonomous vehicles, there is a very small installed base. But there is a huge potential. Which means that, on short term it is very hard to gain revenue from there. Because, the roll-out is still far in the future. That is what I tried to cover.
IN1: Okey, then I would say, for many fields, IoT was there for decades, and there is a huge installed base. For instance, for building automation, e.g. airports and hospitals. They have a huge amount of sensors and actuators. For me that was not called IoT, but it has all the characteristics of IoT. Depending on how you define it, so probably not Internet protocols, so you have those sensors and actuators, which allow you to bridge the real world and virtual world.

MH: Yes, so the current installed base then usually the main determinant to look at the market for edge computing? You see for instance at airports that there is a huge amount of devices, which need to transmit data, and there you want to roll-out edge computing. So maybe you are targeting less then on the future applications?
IN1: Yes, so now I think I better understood what you actually mean with installed base. So with this understanding I would also go ahead and put current installed base as the top criteria.
MH: Okey, yes, that is good. And for predictive maintenance? I heard different things, some say predictive maintenance is already very big, others say it is already very wide-spread. What is your feeling about that?
IN1: This is now interesting, because it somewhat contradicts what I just said. The thing is that, with predictive maintenance, you want to do it, and it is quite easy to do it, because you can just install sensors at a low cost. And that already gives you the predictive maintenance. So one of the classic examples is the elevators, where you can just install some vibration sensors, which can tell about the mechanic and tell where exactly is the problem in the elevator shaft. So maybe the installed base then is that there is some cyberphysical system in the field, and that is where you might want to apply it.
MH: Another thing is, how much data would you put to the edge? Is it the far majority, or just a part for pre-processing, or how can I see that?
IN1: This heavily depends on the use-case. So for elevators, you wouldn't do this in the edge. It is a low amount of data, and you want to compare as many systems as possible. So the thing is, these elevators exist around the globe. And many of them are similar, or have the same set-up. Then you can actually compare the data. Therefore, you would rather do it in the cloud. But, if it comes to more complex systems, that is for instance one production cell that looks like this, or one robot, then you would do it locally. Then also the complexity would be involved there, because you have much more data, you would likely push it to the edge.
MH: Okey, I understand. Let's go to the fourth box. So the geographical coverage the edge computing infrastructure system should provide in order for the IoT application to function properly. And according to that, there is a certain cost related for the service provider to roll-out. And if you have a bigger geographical coverage needed, eventually, it will lead in higher cost relative to cloud computing. What's your view on that?
IN1: Let me repeat it, if I understood it correctly. If, local deployment is geographical so dispersed, or huge, that it is in the end not much different than cloud computing, because it is not some localized source of data. So, I imagine it like a pipe-line, that goes through a whole continent. There is not a very good base, where you would put your edge device, because it is all over the place.
MH: Or, for example, if you want to do edge computing for autonomous vehicles, you would have to put edge devices everywhere in the country. Which means you have to put mini data-centers all around in the country, which would be very expensive. Whereas, If you would do it in a smaller region, the relative cost, might not be as big.
IN1: It is in the depends area again. So for instance, for these vehicles. For people who already have this huge coverage like mobile network operators, they could do it, and there are actual use-cases. I think I mentioned earlier that your edge could follow you around in your vehicle. Of course there then is the problem that if you leave some areas, where the operator is not available anymore, it might not scale, but it is till something that might be lucrative. Because it already has the compute power distributed.
MH: Okey. Do you think there is another factor impacting the cost of roll-out from the service provider perspective?
IN1: Yes, so let's take it the other way around. If you would need to start, having edge notes across the whole country. And you don't have that yet, and you have to start doing it, you have to think about it twice.
MH: Because it is a huge investment you mean?
IN1: Yes
MH: Is it related to box 6? Which relates to the initial investment, leading to financial risk.
IN1: Well, let's go back and stick to what is written in box 4. So, the relative cost is of course higher when you are covering a whole country. Let's say the network is already there, so you can just buy a (network) slice, then it is way cheaper to have a central cloud, than deploying your hardware everywhere around the country.
MH: I can totally imagine. Other factors impacting the relative cost of edge computing?
IN1: Hard to say, I think the geographical aspect is kind of complete.
MH: Yea, so it is the major part?
IN1: Yes, so it is related to cloud which is centralized, and of course the edge which is decentralized, it is already in the definition.
MH: Okey, then it should at least cover the most important aspect, which is fine. Then we can go to the fifth box.
IN1: I think you usually ask for the predictive maintenance before you go to the next box.
MH: Oh yes, you're correct, sorry.
IN1: So it definitely plays a role. So I mentioned the elevator example. Here it doesn't make any sense to make a mini data-center at all elevators. It makes much more sense to collect the data in a central place, where you can correlate it.
MH: Perfect, thank you. Let's go to the fifth one now than. I think it will need a little bit explanation. What I aim to say here is about the IoT application's ecosystem. So, the companies which are involved in the IoT applications, which could for instance be autonomous vehicles, predictive maintenance. Those companies have to form an healthy ecosystem, in order for the IoT application to prosper. So what I tried to identify here is, based on the three factors, diversity, robustness and productivity, what is the ecosystem health. And in turn, this health impacts also the risk of the architecture provider. Because, if the ecosystem of the IoT application is healthy, then you might have a smaller chance that the IoT application will fail. Do you understand a bit what I mean?
IN1: Uhu.
MH: So how do you think that applies for the service provider perspective when selecting IoT applications?
IN1: It is hard to say what is the ecosystem here. The provider, I could have my solution, and I take care of it, and I roll it out with the different customers. Ehm.
MH: It is mainly the ecosystem of the customers. So which have the IoT application. So for instance if it would be about autonomous vehicles, it would mainly be the Uber, Waymo, those kind of companies, the ecosystem of companies, if their ecosystem is healthy.
IN1: Okey, so now I understand that part. Yes, so from that perspective, if you go through. Of course variety of partners, if one goes away, there should be other of which you can still make some money, or your offering makes sense. Return on assets, what do you mean?
MH: It is mainly a financial analysis. So for instance, are the companies profitable, how are their investments, are they growing, is that what you look at in the general sense? Also other things we look at like, are they creditworthy, etc.
IN1: Okey, so this is not my area, so I don't know if these are actually the indicators which you would look at in the first perspective. So, I would have expected something you look at a higher level. For example, how well these ecosystems... Sorry, I am

missing the words here. But still, There is definitely something here. Let's say you have some niche, and there is only a small amount of companies here. And these companies might go away. Then you don't want to go there, because there is a huge risk you develop something for a niche which might go away.
MH: Okey, so maybe I should state it a bit less detailed. Especially regarding the left side factors, because they are very specific measures to look at of course.
IN1: They are different from the classic measures that I saw so far, so yea, maybe there can be some improvement. Overall, this factor here, I think it is a valid one, and makes sense.
MH: So, do you have any idea what would be measures which you would look at? Or is this really not your expertise field, because then we can just continue, that is also fine.
IN1: So yeah, I cannot use any proper terms from this field. You have the growth in there, so if this is a growing industry sector. It makes sense. If it is stable is also good, you wouldn't do it if it is declining. The number of companies, or partners active, is also valid. No, I wouldn't know any new ones.
MH: That's fine, I think it is also a bit in the formulation. I will look at this again. And, how do you see this applying to predictive maintenance? Let's for now just look at the more generic factors. So, diversity, productivity and robustness of the ecosystem.
IN1: Robustness, is quite important here. Definitely diversity. Let's go to the elevator example again. When you have machinery out there in high numbers, it makes sense to develop algorithms to do this. So you would choose for a stable/robust ecosystem.
MH: And the productivity of the companies? Or at least the ecosystem, is it big, is it growing, that kind of things.
IN1: In order to find some other use-cases, you would roll it out where it is robust, where you know it is also something in the future. And then if you expand it, you would also see if it is easily do-able. And then you would see that there is something growing for the future.
MH: Okey, good.
IN1: And diversity I think is not so important in the sense, if it at least is robust. For instance, I think the elevator market is not so diverse. I think there is only 3 worldwide.
MH: SO this means robustness would be most important?
IN1: Yes. But I think diversity might also be a bit in robustness, because if one goes away, there should be other ones.
MH: Let's go to box six. It is actually the ecosystem robustness, I took, so from the previous one as well. And I see that having impact on the financial risk. So, if the ecosystem is not robust, so the parties are not creditworthy, they do not have a high liquidity, are not connected, then you have a huge risk, because you are developing capabilities in an IoT field which might break-up any moment. That is one point impacting the financial risk. The other point is the geographical coverage, and the related initial investment. So if you have a huge geographical coverage needed, you have a huge initial investment, which increases your risk. And then on the other side, you have the maturity of the IoT application. Let's say the IoT application is very immature, and you develop capabilities in this field, you might have a big initial risk.
IN1: Yes… I cannot distinguish this well enough from the ecosystem robustness. I guess if the technology is immature, the ecosystem might not be as robust.
MH: This might be a bit related, yes. But, I think the ecosystem looks at if the network of companies is stable. So it could be that IBM is rolling out an IoT application, and maybe some other partners of IBM. So, the ecosystem is very robust, because all the companies have been around for a long time, etc. etc. But at the other hand, the application they are developing is still in the development phase, and thus very immature. So the network of companies could be very robust, but still the IoT application is very immature.
IN1: So you make the division between the network of companies or a specific technology or product, let's say then it makes sense.
MH: Actually I wasn't fully aware of this distinction, so it is a good thing to look at.
IN1: I think it would help to clear this up, what is really the ecosystem? So for me, I have this technical view. For me an ecosystem is a technological ecosystem. I see you are talking about companies, which I also see as being part of the ecosystem.
MH: Yes, I will reconsider. Do you think there are any other factors which might influence the financial risk for the service provider?
IN1: I think there might also be political things. For instance, if you could rely on the network, or anything like that.
MH: So you're talking about the institutional side? Could you elaborate?
IN1: I am not sure, it is just something I thought of.
MH: I do think you have a valid point here, so that is why I am asking a bit further. The political side might definitely be relevant, but I did not look at this yet.
IN1: What I mean is, we have the companies there, we have specific products or applications, and still you then have the political environment, which you could define as part of the ecosystem. Also the countries, the infrastructures of the countries. Legal frameworks, of what is allowed.
MH: So that could also relate to the stability of policies revolving around the IoT application.
IN1: On the other hand, I can imagine that is always a factor, so maybe it is not so important to answer the question of edge vs. cloud computing.
MH: That's right. Well, I will certainly look at it. And how do you think this applies to predictive maintenance?
IN1: So what we also see is, what is deployed now. So initial investment is quite important. There are some famous/highly cited cases, where initial investment was very low. You install some sensors, you have the network anyways, and you just implement some cloud platform. And also the ecosystem robustness is important.
MH: Okey, let's go to the seventh one. We might have to speed-up a bit for 7, 8 and 9, because the 10th one is very important. So on the right side is the financial complexity. It might look like it is related to the financial risk, but it is more about where does the money come from. So if the initial investment is high, not only the risk is high, but you also have to be able to get the money and convince people to give you the money. And on the other side are the resources of the IoT partners, so if you look at the IoT system again. It is also important to look at the resources they have. Can the co-invest? This can help in getting the resources you need. If they do not have these resources, and the initial investment is high. Then you might still have medium risk of finance, but it is hard to gather the resources.
IN1: Yes, roughly.
MH: Maybe I explained a bit vague, if there is any things I can clarify, please let me know.
IN1: Does it mean you need to get funding for something you do yourself? So there was a case, where a company got money in order to set-up an IoT network, is it something like that? And what is the IoT partner, is it the customer?
MH: Yes the partner is the customer, I maybe should have put the ecosystem here, it is exactly the same.
IN1: Ah okey, clear

MH: So do you think there are any other factors impacting the financial complexity?
IN1: Yeah, something like equipment providers. Especially since you can build the cloud in areas where you have a good supply-chain and know how to run it. But at the edge you implement it where the customer is located. There you might have more problems shipping it there, or might not have the right manufacturers.
MH: And how do you think this applies to predictive maintenance? We did already discuss it a bit. Co-investment and the needed initial investment is very important.
IN1: I would not know really sure, so for this let's continue in order to finish in time.
MH: I agree. So regarding the technical complexity. You already gave some feedback which might impact that. But, I identified 3 main factors, which I think affect the technical complexity. First, the geographical range increases the complexity, because you need much more edge nodes. The second one is the heterogeneity of the devices and services. So for instance if you have an application with many different services and devices, which are operated on the same edge nodes, it might get a whole lot more difficult. On the other hand you have the standards, if the IoT services are based on very common and standardized protocols, it might become a lot more easy to apply edge computing to that.
IN1: So one thing which is very important is the availability of libraries in order to develop the software. Also open-source might be important.
MH: Ah, open source, I could imagine.
IN1: a good case study or example is that there are many applications which are 20 years old, so there are many instances around. So on the core I think there is much information about it available. But it is not stable, so all differentiated, still making it difficult.
MH: Good, any other factors?
IN1: The features that might be required. So what are your exact requirements from box 1? They of course have an impact on the complexity. So for instance if you have high real-time requirements, your complexity might go up.
MH: Does the complexity of edge computing rise more than if you would do cloud computing?
IN1: that's difficult, because it would not be even possible with cloud.
MH: Ah, that's true. And how does this apply to predictive maintenance? These factors.
IN1: I think standards at this moment not. It helps if you can bring out data standardized. But if you want to do the application, you have to train models, and have data sets and so on. The heterogeneity of devices, yeah okey, if they are all from the same standard, it is easier. So, it is hard to distinguish.
MH: So, maybe it is related to each other.
IN1: But yes, those two definitely play a role. In predictive maintenance, if you go more complex applications, you want to get as much data as possible, so from different kind of phenomena, and yeah that increases your complexity, because you have to do approaches like sensor fusion.
MH: Let's go to the ninth one. So it is about the organizational complexity. So the first one relates to the amount of companies that participate in the IoT ecosystem. So if you have to align everything with let's say seven companies at the same time, you have a huge complex stakeholder management. Whereas, if you just roll it out. For Siemens for instance, just having to roll it out with only one IoT partner, organizationally speaking it would be way easier to roll-out. And on the other hand, it also depends on their prior experience in the IT segment. Have they already done stuff with edge? Have they already migrated data to the cloud? This would mean their systems would be more ready, and their people are more trained, and they better know what to expect.
IN1: Uhu.
MH: Those are two factors I identified for organizational complexity. How do you feel about that?
IN1: sounds reasonable. What came to mind is that, maybe you should not only look at the amount of partners, but also at the complexity within partners. For instance if a company has much separate departments, it might be way more difficult then if it is very integrated, or if it is a small company.
MH: Okey. And how do these factors apply to predictive maintenance?
IN1: Yes, I guess it is a factor. Let's assume you have companies owning the building. The building belongs to a different organization. Then you have the mobile operator in place. Then you have the cloud provider and so on. It could be easier if you could just provide some box, some edge node and have your software running there.
MH: Let's go to the 10th one then. So these are nine factors which we identified earlier as well, at the first nine boxes, which were at the right side.
IN1: Uhu.

A.7.2 Interview 2 – (IoT) application provider

Interviewee 2 = IN2
Michiel Huisman (Interviewer) = MH

MH: Voordat we beginnen ga ik je formeel vragen of je het oke vindt als ik dit gesprek opneem, transribeer en gebruik voor mijn scriptie.
IN2: Dat is goed
MH: Top, natuurlijk wordt je naam eruit gefilterd. Ik zal wel een korte bio over je achtergrond schrijven als je dat niet erg vindt.
IN2: Het lijkt me inderdaad gebruikelijk dat de namen gefilterd worden. En ik kan me inderdaad voorstellen dat het handig is als je iets schrijft over de achtergronden van je interviewees.
MH: Precies, uiteindelijk is het natuurlijk belangrijk dat ik een breed scala aan mensen, met diverse achtergronden heb geïnterviewd. Maar goed, ik wil nogmaals zeggen dat ik het enorm waardeer dat je de tijd neemt om dit interview met mij te doen.
IN2: Natuurlijk.
MH: Goed, ik heb je dus van te voren een aantal documenten doorgestuurd. Heb je toevallig de kans gehad om hier al even naar te kijken?
IN2: Ja, ik heb inderdaad al even naar de documenten gekeken.
MH: Super, heb je het document met het conceptuele model voor je?
IN2: Ja, die heb ik voor me. Al moet ik zeggen dat het model op de eerste pagina veel is om in een keer in me op te nemen.
MH: Exact, dat dacht ik dus ook. Daarom dat ik op de tweede pagina het model in 10 stukjes heb opgeknipt.
IN2: Ah, ik zie het.
MH: Mooi. Ik zal je even uitleggen wat ik ongeveer van plan ben om te vragen. Er zijn dus 10 boxen in totaal.
IN2: Ik zie maar 4 boxen.
MH: Ehm, zie je er maar 4? Laat me even kijken.
IN2: Oh nee, wacht, ik zie er 6.
MH: Ehm, in dat geval moet ik even checken of ik het goede document naar je heb gestuurd. Zijn er geen boxen 7, 8, 9 etc aan de linker kant?
IN2: Aah wacht, ik zie er inderdaad 10, geen stress.
MH: Mooi! Gelukkig heb ik dan inderdaad de goede gestuurd, ik schrok al even. Naja, er zijn dus 10 boxen. In de eerste 9 daarvan zal ik je vragen gaan stellen over drie hoofd onderdelen. Eerst ga ik je vragen of de factoren die ik heb geïdentificeerd, inderdaad relevant zijn voor het bepalen van de potentie van een IoT applicatie in general. Daarna ga ik je vragen of er nog factoren zijn die wel relevant zijn, maar die ik nog niet heb geïdentificeerd.
IN2: Exact, ik heb hier en daar al wat dingen gezien die wellicht ontbreken.
MH: Heel goed. En dan als laatste ga ik je vragen hoe deze factoren relevant zijn voor predictive maintenance in industry 4.0. Ik weet dat dit een relatief kader is, maar dat heb ik opzettelijk zo gekozen.
IN2: Ja precies, ik zag al in je mailtje dat het een heel breed onderwerp is, en toen dacht ik al "Hier gaat hij wel op glad ijs". De potentie van een applicatie kan natuurlijk per case verschillen ook binnen predictive maintenance kan dit een hoop verschillen. Daarnaast is het ook heel belangrijk om te definiëren wat Industry 4.0 nou precies voor jou is, en wat predictive maintenance nou precies voor jou is. Om daar trouwens gelijk op aan te haken, ook in de definitie van edge computing is nog een hoop onduidelijkheid. Een kennis van mij die voor Endress+Hauser werkt vertelde namelijk dat zij ook bezig zijn met edge computing. Echter, zij definiëren edge computing weer heel anders dan sommige anderen. Voor hen is het al edge computing wanneer je data aan het processen bent om apparaten die dicht bij de installatie staat. Als je bijvoorbeeld data al voor een deel processed op sensor level, voordat je het naar de cloud stuurt, kan het voor hen al edge computing zijn. Het is dus heel belangrijk om deze definities goed te krijgen.
MH: Dit ben ik helemaal met je eens. En als je naar de literatuur kijk valt er inderdaad ook te zien dat er een hoop onduidelijkheid heerst over de definitie van edge computing. Sommige onderzoekers zeggend dat edge computing een specifieke infrastructuur is, terwijl andere onderzoekers weer benoemen dat het meer om een filosofie gaat. Daarom heb ik zelf een working definition opgesteld. Ik zeg natuurlijk niet dat dit de beste definitie is, maar het helpt mij in ieder geval om mijn onderzoek op een gestructureerde manier uit te voeren.
IN2: Precies, ik begrijp volledig dat je dit nodig hebt.
MH: Ik zie edge computing dus meer als de filosofie waar de service van cloud computing, dat kan dus SaaS, PaaS, of IaaS zijn, naar de edge wordt gepusht. En dit kan dan ook op verschillende manieren uitgerold worden. Daarom denk ik dat wat je kennis van Endress+Hauser benoemde inderdaad een onderdeel zou kunnen zijn van cloud computing.
IN2: Okey, wellicht is het interessant om later ook met hem te spreken, hij heeft hier ook zeker een hoop over te zeggen.
MH: Lijkt me een goed plan, bedankt. Goed, maar om even terug te gaan naar het framework. De eerste 9 boxen zijn dus toegespitst op die drie vragen die ik net illustreerde. In de 10^{e} box ga ik je dan vragen om de 9 factoren die resulteren uit de eerste 9 boxen te rangschikken aan de hand van hoe belangrijk ze zijn. Dit gaat via een gestructureerde methode, en ik zal je verder uitleggen hoe dit precies zit voordat we aan dit onderdeel beginnen. Voordat we naar de 1^{e} box gaan, zijn er nog vragen over het framework in zijn algemeenheid?
IN2: Laten we voor nu maar gewoon bij de eerste box beginnen en dan komen de vragen vanzelf wel.
MH: De eerste box is ook gelijk de moeilijkste, dus vanaf hier wordt het alleen maar makkelijker. Het doel van deze box is om te meten welke specificaties van IoT applicaties invloed kunnen hebben op de relative / perceived quality of service. Een IoT applicatie kan bijvoorbeeld bepaalde service requirements hebben waardoor de waarde voor de keuze van edge computing t.o.v. cloud computing toeneemt. En de relatieve quality of service kan dus uiteindelijk invloed hebben op de potentie van een IoT applicatie voor edge computing. Dus mijn eerste vraag is, als je kijkt naar de service requirements in de box links boven. Ehm volgens mij zijn dit er 7
IN2: 8 als het goed is.
MH: Oowja, 8 factoren inderdaad. Denk je dat al deze factoren, in de generieke zin, invloed zouden kunnen hebben op de beslissing van een consument om voor een edge architectuur te gaan in plaats van een cloud architectuur.
IN2: Als je kijkt naar de process automatisering. Dan is vooral de hoeveelheid data die verstuurd wordt een enorm probleem met een cloud architectuur. Bij simpelere applicaties is dit nog wel te managen, maar wanneer je naar moeilijkere applicaties gaat, dan

wordt dit al heel snel een stuk meer. Dan heb je veel apparaten die allemaal verschillende data points doorsturen. Wanneer je al deze datapoints door wil sturen naar de cloud kan het simpelweg teveel worden.
MH: Oke, en hoe zit het met de latency requirements, kan dit ook een rol spelen?
IN2: Ja, dit kan zeker een rol spelen. Echter, als je kijkt naar de proces automatisering, en zeker naar predictive maintenance, dan zal het probleem hier vaak wat minder liggen. Bij predictive maintenance wil je van te voren aan kunnen geven of een sensor of ander device kapot gaat of niet. Dit is echter iets dat je al verder van te voren aan kan zien komen. Daarom maakt het niet uit of je heel snel kijkt, maar is het ook prima als je een paar keer per uur kijkt, of zelf een paar keer per dag. Bij latency zie ik namelijk voor me dat het om een aantal seconde snelheid gaat.
MH: Dat is correct, eigenlijk gaat het zelfs over milliseconden.
IN2: In dat geval denk ik niet dat het relevant is voor predictive maintenance.
MH: Helder. Maar, in de generieke zin, voor andere applicaties dus, zou het wel relevant kunnen zijn?
IN2: Ja, dat wel.
MH: Top. En hoe zit het met privacy dan?
IN2: Dit is zeker belangrijk. Als je weer kijkt naar de proces industrie, dit is waar we het de vorige keer ook al over hadden, dan zijn bedrijven erg voorzichtig met de data privacy en secrecy. Wat daar ook aan verbonden zit zijn natuurlijk de verschillende regelgevingen. In Rusland bijvoorbeeld geldt er hele andere regelgeving voor de opslag van data dan in Nederland. Daarom mogen Russische bedrijven bijvoorbeeld alleen maar hun data op de cloud in Rusland zetten. De data privacy kan dus een enorm grote rol spelen. Het is voor bedrijven belangrijk dat de inrichting en besturing van hun installaties niet inzichtelijk is voor anderen. Het is voor hun dan ook niet onderhandelbaar om dit soort dingen los te laten. In zulke processen is veiligheid alles.
MH: Kan ik me inderdaad voorstellen. En hoe zit het dan met security?
IN2: Security is natuurlijk altijd iets wat belangrijk is. Bedrijven willen gewoon dat hun data veilig is en dat er niemand bij kan.
MH: Zou dit ook betekenen dat, als edge computing hogere veiligheid levert dit een reden is voor bedrijven kan zijn om op de edge te processen.
IN2: Ja dat zou zeker het geval kunnen zijn. Echter, als je naar predictive maintenance kijkt. Dan denk ik toch echt dat de hoeveelheid data die voornamelijk een reden creëert om naar de edge te gaan. Of, dit is in ieder geval wat ik waarneem in de proces industrie.
MH: Helder. En hoe zit het dan met de andere vier factoren, de context awareness, mobility support, connectivity stability en reliability en de energy constraints of IoT devices? Zouden deze allemaal relevant kunnen zijn?
IN2: Ik denk zeker dat deze relevant kunnen zijn, maar het hangt natuurlijk wel erg van de case af. Als je bijvoorbeeld naar de laatste kijkt de energy constraints. In veel gevallen verwacht ik hier geen problemen. In de meeste gevallen is er gewoon een energie toelevering en zal dit dus geen probleem vormen. Alleen wanneer je op een remote locatie zit en er geen energie toelevering is kan dit wel het geval zijn. Daarnaast kan je vaak al voorspellen, wanneer je een batterij in een sensor hebt, wanneer deze leeg gaat. Dan is het een kleine moeite om deze te vervangen. Daarom zal het in deze gevallen ook geen grote rol spelen. Alleen, wanneer een engineer bijvoorbeeld naar een boorplatform moet toe vliegen met een helikopter om daar een batterijtje van een sensor te vangen, dan zal het wel relevant zijn.
MH: Kan ik me voorstellen. En hoe zit het dan met de overige factoren voor predictive maintenance?
IN2: Nou, als je het hebt over de connectiviteit, zal dit geen grote rol spelen. Als een netwerk er voor een klein tijdje uit ligt, en je hierdoor geen analyse kan doen, zullen er over het algemeen geen grote problemen optreden. Ook mobility support is in dit geval niet zo relevant. Vaak praten we, in ieder geval in de proces industrie, over sensoren die op één plaats gemonteerd zijn en dus niet rond bewegen. Daarom is deze factor niet relevant. Context awareness zou wel relevant kunnen zijn. Zeker als een sensor extra data van zijn omgeving kan ophalen en dit kan gebruiken voor de predictive maintenance kan dit toegevoegde waarde hebben. Maar toch denk ik dat de belangrijkste factor de amount of data is. Vanuit mijn ervaring zie ik vaak dat de hoeveelheid data gewoon een bottleneck wordt, en dat er daarom wordt gekozen voor en dergelijke edge architectuur.
MH: Helder. En als je dan naar deze factoren kijkt he. Heb je dan het gevoel dat er een factor mist?
IN2: Nou, als je naar dit soort dingen kijkt zijn er natuurlijk altijd drie dingen, the people, the process and the technology. Wat ik hier nog mis is de people factor. Ik heb gezien dat het opleiden van mensen, en de beschikbaarheid van mensen een enorme kostenpost kan zijn. Dus uiteindelijk zal dit ook een enorm belangrijk onderdeel zijn.
MH: Dit ben ik met je eens, en dit is ook al voor een stukje benoemd in de andere factoren, maar wellicht nog niet voldoende. Echter, hoe denk je dat dit relevant is voor de perceived quality of service?
IN2: Nou, als je uiteindelijk niet de juiste mensen hebt, of dat de juiste mensen regelen enorm duur is, dan zal het enorm duur worden en ook heel moeilijk worden om het uit te rollen. Dit heeft uiteindelijk ook weer impact op de perceived quality of service.
MH: Ik begrijp je punt en zal er naar kijken. Zijn er verder dingen die ik vergeten zou kunnen zijn?
IN2: Ik denk dat het vooral belangrijk is dat de people factor meegenomen wordt, maar het kan ook zijn dat dit bij een van de andere factoren weer terug komt.
MH Oke, top, om dan maar door te gaan, ben je verder bekend met het concept van serverless computing?
IN2: Zou je dit kunnen toelichten?
MH: Uiteraard. Ik zal het even een beetje proberen te versimpelen. Bij serverless heb je bijvoorbeeld op de machines zelf alleen maar function calls staan. Dit betekent dat je alleen maar functies oproept en naar de cloud / edge stuurt. Deze machines hebben verder alleen geen informatie over de onderliggende infrastructuur, of hoe deze functies er precies uit zien. Wat ik heb gevonden is dat dit met cloud computing een redelijk lastig concept kan zijn, maar dat het voor edge computing beter uit te rollen is, en meer voordelen zou kunnen brengen. Wat is jouw gevoel hier over.
IN2: Dit zou zo kunnen zijn, ik moet je eerlijk zeggen dat ik dit nog niet zoveel ben tegengekomen in de proces industrie.
MH: Oke top, laten we deze factor voor nu dan maar even overslaan. Dan denk ik dat we box 1 nu wel redelijk hebben behandeld. We zijn ondertussen ook al wel redelijk lang bezig, dus ik ga de rest een beetje versnellen als je dat niet erg vindt. Zoals ik in het begin ook al zei, de eerste factor is het moeilijkste, dus het is niet erg dat we hier lang mee bezig zijn geweest, maar het is wel belangrijk dat alle boxen uiteindelijk in ieder geval even aan bod zijn gekomen.
IN2: Begrijpelijk.
MH: Als we dan naar de tweede box gaan, the factors impacting the switching cost, heb ik eigenlijk twee factoren geïdentificeerd. Voordat ik die twee factoren uitleg, leg ik natuurlijk even uit wat ik precies bedoel met switching costs. Dit zijn de kosten die een klant maakt wanneer hij/zij van de huidige offering, wat bijvoorbeeld een cloud architectuur is, naar een nieuwe offering gaat. En factoren die dit dan kunnen beïnvloeden zijn de possibiliy of system integration with the previous offering, dus, als een klant momenteel een cloud architectuur heeft, dan zal de integratie van het edge platform met deze architectuur invloed hebben op de

kosten die hij/zij moet maken om daar naartoe over te schakelen. De tweede factor is de easiness of platform openness. Dit heeft met name te maken met hoe open een IoT applicatie kan zijn. Als er bijvoorbeeld standaard bibliotheken zijn voor het programmeren van functies op de edge, kan dit de integratie naar een nieuw edge platform een stuk makkelijker maken. Verder kunnen developers makkelijker op elkaar door bouwen, en dit verhoogt in principe weer de waarde. Dus, als je naar deze factoren kijkt, kunnen ze dan denk je relevant zijn voor de beslissing van een klant om van een huidige architectuur naar een edge infrastructuur te gaan?
IN2: Ik denk zeker dat ze relevant kunnen zijn. Al moet ik zeggen dat platform openness vaak lastig is. In de proces industrie zijn bedrijven vaak minder bereid om hun ideeën te openen. Daarnaast kan het alleen al lastig zijn om bedrijven de zelfde standaarden te laten gebruiken. Een mooi voorbeeld is Emerson. Er was een geval, nog niet zo lang geleden, waar de industrie een bepaalde richting in wilde, maar Emerson was niet bereid om met deze standaarden mee te gaan. Dit maakte het geheel enorm lastig.
MH: Dat begrijp ik. En als je kijkt naar deze factoren, heb je dan het idee dat ik iets ben vergeten?
IN2: Nogmaals, het gaat altijd over the people, the process and the technology. En wat ik hier nog mis is the people. Waar je je niet in moet vergissen is dat het enorm moeilijk kan zijn om de juiste mensen te vinden om zo iets op te zetten, of om zo iets te laten werken. Dit geldt al helemaal als je op een remote locatie aan de slag bent. Zie daar maar eens de juiste mensen te krijgen. Dus wat belangrijk is, is dat je de juiste mensen in dienst hebt, en anders kunnen de switching costs drastisch stijgen.
MH: Ik ga er naar kijken. Zijn er verder nog factoren die invloed kunnen hebben?
IN2: Als je kijkt naar switching costs, dan denk ik vooral dat de people factor erg van belang is. Meestal zie ik integratie met het huidige systeem niet echt als een probleem.
MH: En hoe zit dit met predictive maintenance dan?
IN2: In de industrie zijn er enorm veel standaarden waar men op voort kan bouwen. Dus daar zijn vaak niet zoveel problemen. Daardoor is de systeem integratie vaak wel do-able. Verder, zoals ik al zei, het is wel moeilijk om platform openness te bereiken. Ik denk vooral dat het belangrijk is om hier de people factor te integreren, want zonder de juiste mensen gaat het gewoon niet gebeuren.
MH: Helder. Dan stel ik voor dat we naar de 3e box toe gaan.
IN2: Prima.
MH: In de 3e box verschuift ons perspectief van customer perspectief naar provider perspectief. En wanneer we dan kijken naar hoe een provider het potentieel van een IoT applicatie kan inschatten voor edge computing, dan is één van de eerste dingen die je tegen komt de customer base. Voor een provider is het natuurlijk van belang dat de IoT applicatie zelf groot genoeg is uitgerold, en dit kan je aan de hand van drie dingen meten. Aller eerst de huidige installed base van de applicatie. Dus eigenlijk, hoe groot is de IoT applicatie op dit moment al uitgerold. Verder is het ook belangrijk om te kijken naar de potentiele schaal van een IoT applicatie. Bijvoorbeeld bij zelfrijdende auto's, is er momenteel nauwelijks een installed base, maar er is een enorm potentieel. Dit zou voor een service provider kunnen betekenen dat het alsnog een interessant applicatie is om op te focussen. Ik zeg niet dat het perse zo is, maar het zou wel een reden kunnen zijn. Dan, als laatste kijk je naar het percentage aan data dat je naar de edge kan pushen. Ik verwacht dat er toch altijd een soort interplay zal zijn tussen de edge en de cloud, en dat er altijd een deel is dat je op de cloud zal willen blijven doen. Daarom, om de potentiele markt van edge computing in een bepaalde IoT applicatie in te schatten, is het van belang dat er gekeken wordt naar het percentage aan data dat naar de edge gepusht kan worden. Dus als je naar deze factoren kijkt, denk je dat ze relevant kunnen zijn voor een provider in zijn/haar beslissing om hun edge infrastructuur uit te rollen voor een bepaalde IoT applicatie.
IN2: IK denk zeker dat deze factoren relevant kunnen zijn. Echter, zoals ik eerder ook al tegen je zei, bij predictive maintenance heb ik het gevoel dat er enorm veel over wordt gepraat, maar er nog weinig harde use-cases zijn uitgerold.
MH: Betekent dit ook dat de current installed base nog niet zo groot is?
IN2: Er zijn zeker use-cases, maar ik heb gewoon het idee dat bedrijven het over doen laten komen alsof er al een hoop meer is gedaan dan wat daadwerkelijk het feit is.
MH: Dat snap ik. En als je naar deze factoren kijkt, wat zouden nog belangrijke factoren kunnen zijn die ik vergeten ben?
IN2: Vooral de potentie om maintenance services te leveren. Als je kijkt naar het verdien model van bedrijven die een dergelijke infrastructuur uitrollen, dan is de extra services die ze leveren vaak het grootste deel van de verdienste. Wat ik hier dus mis is een onderdeel dat de potentie van additionele services beschrijft die geleverd kunnen worden, en daarmee bedoel ik vooral maintenance services. Dit is natuurlijk vooral belangrijk als je kijkt naar je revenue sources, en minder als je kijkt naar de customer base. Dus hier gaat het ook een stukje over de definitie.
MH: Goeie, ga ik naar kijken. Zijn er verder nog factoren?
IN2: Nee, ik denk dat dit in grote lijnen wel beschrijft hoe je de markt grootte kan inschatten.
MH: Super. En hoe denk je dat deze factoren hun relevantie vinden in predictive maintenance.
IN2: Zoals ik eerder ook al aangaf. Ik heb het gevoel dat er een hoop over predictive maintenance wordt gepraat, maar nog wat minder wordt gedaan. Toch is er daadwerkelijk een flink aantal use-cases die uitgerold zijn, maar er is nog een hoop meer potentie.
MH: Oke, en als je kijkt naar hoeveel data je naar de edge wil pushen?
IN2: Dit is vooral relevant als je kijkt naar applicaties met enorme hoeveelheden data. Dit wil je in ieder geval kunnen pre-processen om daarmee de druk op het netwerk te verminderen. Als je kijkt naar kleinere applicaties, dan wil je geen edge algoritme gebruiken. Ik vraag me trouwens sowieso af of predictive maintenance een goede use-case is voor edge computing.
MH: Daar hoop ik op het einde van dit project ook achter te komen. Maar goed, dan denk ik dat we de derde box redelijk hebben afgewerkt, en stel ik voor dat we naar de vierde box toe gaan.
IN2: Is goed.
MH: Als we dus naar de vierde box kijken, dan gaat het over de kosten die een service provider maakt om een architectuur uit te rollen. Wanneer je een grotere geografische coverage nodig hebt voor je IoT applicatie, zullen de kosten van edge computing dus ook toenemen. Kijk bijvoorbeeld naar autonomous vehicles. Hiervoor moet je landelijk een netwerk uitrollen. Hiervoor heb je dus enorm veel nodes nodig, wat uiteindelijk erg duur kan worden. Denk je dat deze factor relevant is?
IN2: Dit is zeker relevant. Echter als ik kijk naar predictive maintenance zal dit vaak niet een groot probleem zijn. Misschien als je kijkt naar lek detectie, wat een enorm lange leiding is, dan kan dit duur worden, maar over het algemeen loop je hier niet tegen aan. Wat ik wel mis is een factor die de locatie van een applicatie aangeeft. Dit relateert ook weer aan de people factor. Wanneer je een IoT applicatie op een locatie hebt waar geen expertise is, kan het erg moeilijk en kostbaar worden om de juiste mensen daar aan het werk te krijgen. Ik zie dit zeker als een factor die extra kosten kan realiseren.
MH: Helder. Dan stel ik voor dat we naar de vijfde box toe gaan. Deze heeft nog een beetje toelichting nodig. De factoren aan de linker kant van de vijfde box zijn te specifiek. Dit heb ik ook al met mijn vorige interviewee besproken, dus laten we deze voor nu

even gebruiken om inzicht te krijgen in hoe de drie factoren; diversity, productivity en robustness tot stand komen. Wat ik dus in de literatuur heb gevonden is dat het ecosysteem van de IoT applicatie waar een service provider op zou kunnen targeten belangrijk is in het bepalen van de potentie. Laat me eerst definieren wat ik bedoel met een IoT ecosystem. Hiermee beschrijf ik het netwerk van bedrijven dat een IoT applicatie uitrolt. In het geval van bijvoorbeeld zelfrijdende auto's bestaat het IoT ecosysteem dus uit bedrjiven zoals Tesla, Waymo, Uber, etc. Voor de service provider is het dan belangrijk om te weten hoe "healty" dat ecosysteem is. En de healthyness van een ecosysteem kan dus gemeten worden door middel van drie factoren. Allereerst doormiddel van de diversity, dus zijn de bedrijven complementair aan elkaar en kunnen ze elkaar zwakte punten opvullen en sterkte punten versterken. Als tweede de productiviteit, dus in hoeverre is zijn de bedrijven winstgevend en groeiend. En als derde kan gekeken worden naar de robustness. Dit houdt vooral in dat de bedrijven niet falliet gaan, en dat de IoT applicatie blijft voortbestaan. Denk je dat deze factoren relevant zijn voor een service provider wanneer zij de afweging maken om edge computing uit te rollen voor een bepaalde IoT applicatie of niet?
IN2: Jazeker, ik denk dat dit belangrijk is. Wat ik je wel mee wil geven is dat in de industrie, veel bedrijven helemaal niet zo winstgevend zijn. Kijk bijvoorbeeld naar GE, die hebben momenteel een redelijk moeilijke tijd. Ook andere bedrijven, die echt niet zomaar om zullen vallen, aangezien ze zo groot zijn, hebben een moeilijke tijd. Wat denk ik belangrijk is om naar te kijken, is hoe core de IoT business is voor een bedrijf. Het kan bijvoorbeeld dat het netwerk van bedrijven allemaal grote bedrijven zijn, die winstgevend zijn en echt niet zomaar zullen omvallen. Echter, het kan dat hun IoT divisie, die jij analyseert het niet goed doet. Als deze divisie dan niet core is voor het bedrijf, dan is het erg waarschijnlijk dat deze wordt afgesneden.
MH: Kan ik me voorstellen. Denk je dat de factor "amount of connections among partners" dit niet al meet?
IN2: Voor een deel wel, maar het gaat niet alleen om de connecties. Bedrijven kunnen ook partnerships hebben op een breder vlak waar het IoT onderdeel een klein deel van is. In dit geval zegt het aantal connections alsnog vrij weinig.
MH: Zou dit betekenen dat je een extra factor zou toevoegen die iets verteld over hoe core de IoT technologie is voor de partners?
IN2: Ja, dat zou ik zeker doen.
MH: Oke. En als je kijkt naar deze factoren voor predictive maintenance, hoe staat dit dan?
IN2: Zoals ik al aangaf, niet alle bedrijven zijn even winstgevend, maar generiek gezien zie ik hier geen problemen. Verder zijn het allemaal relatief stabiele connecties. Dit komt vooral omdat bedrijven in deze sector al erg lang met elkaar samen werken.
MH: Helder. En zou je zeggen dat de bedrijven divers zijn?
IN2: Het hangt er van af hoe je dit ziet. Als je kijkt naar het soort bedrijven dat vergelijkbare applicaties biedt, dan zijn dit veelal vergelijkbare bedrijven. Echter, als je kijkt naar de bedrijven die vaak samen moeten werken om bepaalde applicaties te bewerkstelligen, dan is dit relatief divers. Er komen natuurlijk partijen kijken die de apparaten produceren, die leidingen leggen, bedrijven die zich bezig houden met de IT architectuur, enzovoorts, enzovoorts.
MH: Oke, klinkt logisch. Laten we naar de zesde box toe gaan.
IN2: Prima.
MH: Een andere factor waar men naar kijkt is het financiële risico dat een service provider loopt. Aan de ene kant is dat natuurlijk afhankelijk van de robustness van een ecosysteem. Als de partijen die zich toewijden aan een ecosysteem een grote kans hebben om bankroet te gaan. Of, zoals je net al aangaf, ze zich terug trekken uit een applicatie. Dan is het geen goed plan om competenties te bouwen voor die IoT applicatie. Dat kan namelijk betekenen dat het leven van zo'n applicatie maar van korte duur is. Wat daar dan ook weer aan gerelateerd is, is de maturity van een IoT applicatie. Wanneer een IoT applicatie nog voornamlijk in de concept fase is, en dus nog in de baby schoenen staat, dan zit er een groter risico aan vast. Er zijn namelijk veel meer onzekerheden over de potentie, het business model, etc. De laatste factor die ik heb geïdentificeerd is de geografische coverage die benodigd is voor de IoT applicatie. Zoals we net al bespraken, grotere geografische coverage leidt tot hogere relatieve kosten. Maar, daarnaast wanneer je meer nodes uit rolt, nemen de totale kosten natuurlijk ook toe. Wanneer je dus bijvoorbeeld voor autonome auto's een edge netwerk wil uitrollen, heb je een enorme investering nodig. En zoals we natuurlijk allemaal weten vanuit de basis principes van finance, een hoge investering leidt ook tot een hoger risico. Denk je dat deze factoren inderdaad van belang kunnen zijn?
IN2: Dat kunnen ze zeker zijn. Voor een bedrijf is het belangrijk om naar het financieel risico te kijken. Wederom wil ik je hier herinneren aan de people factor. Als er niet genoeg kennis beschikbaar is, of als de juiste mensen niet beschikbaar zijn, loop je een financieel risico omdat het of niet haalbaar is om de architectuur uit te rollen, of extreem duur wordt omdat je de juiste mensen moet zien aan te trekken op moeilijke locaties.
MH: Dat snap ik, zijn er andere factoren die ik wellicht vergeten zou kunnen zijn?
IN2: Ik denk dat dit grofweg wel beschrijft wat relevant is op dit vlak.
MH: Mooi. En als we dan kijken naar predictive maintenance, hoe spelen deze factoren dan een rol?
IN2: Geographical coverage hebben we al voor een deel besproken. Vaak zitten sensoren redelijk geconcentreerd, en als dit niet het geval is, wil je vaak ook geen edge computing gebruiken. Daarnaast, wanneer je een edge systeem gaat uitrollen voor de industrie, zal dit echt aan de hand van een contract gaan. Je rolt dan een dedicated systeem uit voor een klant. Dit betekent dat het voor de provider niet uit maakt hoe groot de investeringskosten zijn, want er wordt aan de hand van een contract een edge architectuur uit gerold.
MH: Betekent dit ook dat de klant dan de system owner is?
IN2: Dat kan soms het geval zijn, maar niet altijd. Als je bijvoorbeeld naar de Siemens cloud kijkt, dan is de cloud van Siemens, maar bedrijven kunnen het gebruiken. Voor de edge kan dit anders liggen, zeker als je een dedicated edge netwerk gaat uitrollen voor één klant. Daarom denk ik ook dat de contractuele afspraken, bijvoorbeeld, wie is de owner, etc. een rol zullen spelen in het financiële risico dat een provider zal lopen.
MH: En hoe zit het met de andere factoren?
IN2: Ik denk dat de maturity van de applicatie geen groot probleem moet veroorzaken. Er zijn tegenwoordig veel standaarden waar men op door kan ontwikkelen, dus hier zitten niet heel veel onzekerheden. Ook aan de robustness kant zitten geen grote problemen.
MH: Top. Laten we naar box 7 kijken, nog drie te gaan! Ik stel voor dat we in een nog iets sneller tempo er doorheen gaan om ervoor te zorgen dat we alle boxen langs kunnen gaan. Het is voor mij namelijk erg belangrijk om uiteindelijk de 10e box gedaan te hebben.
IN2: Dat is goed.
MH: Goed, de zevende box spitst zicht toe op de financiële complexiteit.
IN2: Hoe is dit anders dan het financiële risico?

MH: Goede vraag. Het financiële risico heeft vooral te maken met het risico dat een bedrijf loopt het geld, of de moeite niet terug te verdienen. De financiële complexiteit spitst zich dan toe op hoe moeilijk het is om de financiën rond te krijgen. Bijvoorbeeld, wanneer je een hoge investering moet doen, kan het erg complex worden om de financiën rond te krijgen. Het kan zijn dat er simpelweg niet genoeg kapitaal beschikbaar is binnen het bedrijf, of dat het moeilijk is om het kapitaal hiervoor te krijgen. Aan de andere kant kan, en dit relateert ook al een beetje tot een onderwerp waar we het eerder over hadden, zou het kunnen dat partners in het IoT ecosysteem mee investeren in de architectuur. Dan heb je dus een soort co-investment en co-ownership structuur. Als meerdere partijen dan investeren kan het makkelijker worden om de totale som bij elkaar te krijgen. Denk je dat dit relevant kan zijn in de overweging?
IN2: Ja, dat denk ik wel. Al zie ik hier in predictive maintenance geen grote problemen.
MH: Dat is goed om te horen. En zijn er factoren die ik wellicht vergeten zou kunnen zijn?
IN2: Ik denk dat dit, dit onderdeel redelijk goed beschrijft.
MH: Super, laten we dan naar de volgende box gaan. Dit beschrijft de technische complexiteit. Er zijn dus een aantal factoren die het technisch gezien complex kunnen maken om een edge architectuur uit te rollen. Allereerst, als je een grotere geografische spreiding hebt, zullen er meer edge nodes geïnstalleerd moeten worden. Deze nodes moeten op hun beurt weer samen werken om gezamenlijk één service te leveren. De management en orchestration van deze nodes kan het uitrollen van een edge netwerk dus complex maken. Aan de andere kant kan de heterogeniteit van services en devices die gebruik maken van het netwerk extra complexiteit opleveren. Deze devices hebben allemaal verschillende requirements en manieren van communiceren, en maken het netwerk daarmee op zijn beurt veel complexer. Als laatste, kan een gebrek aan standaarden het enorm complex maken om een edge netwerk op te zetten. Met een gebrek aan standaarden kan het bijna onmogelijk worden om zo'n dergelijke structuur uit te rollen. Wat is jouw gevoel over deze factoren?
IN2: Ik denk standaarden het probleem van heterogeniteit van devices kan oplossen. Daarom denk ik dat je deze twee factoren beter samen kan pakken.
MH: Goed punt. En verder?
IN2: Ik denk dat je grootste technische complexiteit zit in het hebben van standaarden. Als je deze hebt wordt alles gelijk een stuk makkelijker.
MH: En zijn er nog factoren die ik ben vergeten
IN2: Ik wil nog een keer terug komen op het people vlak, maar ik denk dat we dit beter kunnen doen bij het volgende punt.
MH: Dat ben ik met je eens. Voordat we naar de volgende box gaan wil ik je nog vragen hoe deze factoren hun relevantie vinden voor predictive maintenence.
IN2: Zoals ik al zei, er zijn behoorlijk veel standaarden, dus dit hoeft geen probleem te zijn. Ook de geografische range moet managable zijn. In totaal verwacht ik dus geen grote technische problemen voor edge computing voor predictive maintenance.
MH: Top, dan gaan we naar de 9e box. Deze box beschrijft de organizational complexity. Wat ik hierin heb geïdentificeerd is dat er voornamelijk twee factoren zijn die van belang zouden kunnen zijn. Allereerst het aantal partijen waarmee je samen werkt. Als je dus met enorm veel partijen samenwerkt krijg je een enorm complexe stakeholder management. Aan de andere kant, als er geen expertise is betreft IT architecturen, en er is bijvoorbeeld nog geen ervaring met cloud enzovoorts, dan kan het moeilijk worden om een edge architectuur uit te rollen. Zie jij deze factoren als relevant?
IN2: Zeker. Echter, ik denk dat het niet alleen relevant is te kijken naar het aantal stakeholders waar je mee samen werkt, maar ook om te kijken hoe complex de organisaties intern zijn. Veel grote organisaties hebben allemaal losstaande departementen die allemaal weer anders acteren. Soms kan alleen dit al veel moeilijkheden met zich mee brengen. Daarnaast is het ook van belang dat je de mensen met je mee krijgt. Soms kan je nog zo'n mooie technologie hebben, maar als de mensen in de organisatie er niet achter staan gaat het gewoon niet gebeuren.
MH: Dit kan ik me voorstellen. En hoe zouden deze factoren toepasbaar zijn op edge computing?
IN2: Over het algemeen hebben de industrie bedrijven voldoende kennis op het vlak van IT, dus hier zitten zeker geen problemen. Het aantal stakeholders waar je mee samen moet werken verschilt wel echt per project. Ik denk dat het vooral relevant is om te kijken naar het mee krijgen met de mensen binnen een organisatie. Nu zal dit voor predictive maintenance wel mee vallen, aangezien het relatief weinig effect heeft op de organisatie zelf, maar voor andere applicaties is dit wellicht anders.
MH: Helemaal goed. Dan weet ik voor de eerste 9 boxen genoeg, en zou ik graag naar de 10e box toe willen gaan.
IN2: Dat is goed.

A.7.3 Interview 3 – Consultant

Interviewee 3 = IN3
Michiel Huisman (Interviewer) = MH

MH: Before we start-off, I would like to formally ask you something. I would like to ask if it is okey for you if I record this interview, transcribe what we said, send it to you for approval, and use it afterwards. I will filter your name of course.
IN3: Yes, that's okey
MH: Perfect, then I will start the recorder now. So, I believe there were already a couple of remarks you send me through e-mail right?
IN3: Yes
MH: Give me one second, I will open them. Okey, so what you mentioned where that the factors to control licensing, upgrades, updates and billing methods where still missing. I think we will arrive at those points later, but it is definitely worth mentioning. For now, would you be okey if we proceed with the interview regularly?
IN3: That's fine. You send me three documents right?
MH: That's right. So one of the documents contains the interview protocol, which describes what I want to get out of the interview etc. another document contains the conceptual model, which I want to discuss with you. And the last document was mainly as a reference. If there are some parts you don't understand, you can mainly look for the definitions there. So, did you have the chance to look at the documents for a couple of minutes? Because otherwise I will just explain it by myself, that's fine as well.
IN3: Yes, I took a look at the documents.
MH: Perfect, well let me at least shortly recap what it is about. Do you have the conceptual model document in front of you.
IN3: Give me a sec.
MH: Okey
IN3: Alright, I have it in front of me now
MH So, on the first page is the complete conceptual model which might be quite mind blowing when it appears on your screen at once. So, what I did was cut up the model in 10 parts, which you can see on the second page of the document. So what I want to do with you is go through these 10 parts individually. Then, in the first nine parts I will ask three kinds of questions. First, I will ask if the factors which I identified are indeed of relevance. Second, I will ask you if I might have forgotten some factors that are relevant. And third, I will ask you how these factors apply to the chosen use-case, which is predictive maintenance. So, before we start-off, are there any unclarities about the model in general, which you want me to elaborate beforehand?
IN3: Well, I believe the first box is about the quality of service right, how do you mean that?
MH: It is mainly about how the service requirements of a certain IoT application impact the perceived quality of service, which might ultimately impact the potential of an IoT application for edge computing.
IN3: I don't understand why it is only about the quality of service, is the value not more important?
MH: You're right, maybe I should define it more as value adding elements, or something like that.
IN3: Yes, I think that might be better.
MH: So, if you look at the top left of the box, you see another box describing 1,2,3 … I think 8 factors
IN3: Yes, 8 factors
MH: Which might impact the perceived quality of service, or the value which is created with an edge computing architecture. So, do you think these factors could all find their relevance in general. So, when someone in general would be wondering to do edge computing instead of cloud, could these factors influence their decision?
IN3: Let me see. The first 4 factors would definitely be relevant. Let me give an example. For instance latency is very important for some applications. When you need to instantly measure and react to things happening in your pipelines, you cannot have any latency issues. Then there also is the amount of data. For some applications, there is so much data that needs to be processed, that you cannot send it to the cloud. So it would definitely be a huge factor. Also I think privacy could be of influence. There are many instances in which companies do not want to have their data to be available to other companies.
MH: Ah okey, and how about security?
IN3: Yes, that one is also important, but I think the latency and the amount of data are in general very important for the decision
MH: Okey, good. And how about context awareness?
IN3: I am not entirely sure what you mean with context awareness.
MH: With context awareness I mean the contextual data about the environment, connectivity, etc. which can be used in the process.
IN3: Okey, I am not sure if it applies.
MH: Let me rephrase it a bit. Do you think context awareness is something that could be enabled by an edge computing architecture, which could not be established with for instance an cloud computing architecture.
IN3: Well, context awareness is not something that is enabled by an architecture, but is realized by the sensors gathering data. So, you have for instance a sensor, which gathers data about the environment, and this data can be processed locally on the node using edge computing improving the time it takes to become aware of the local context without reaching to the cloud.
MH: I understand, so, it would mean the choice of architecture does not influence whether or not one can transmit contextual information.
IN3: If you put it in that way it might have effect in time it takes for becoming contextually aware as processing is close to source of data
MH: So it is not like edge allows for contextual awareness to work, it is more in the amount of data that is transmitted?
IN3: Yes, because with an edge architecture you might be able to process the data more quickly, or you can pre-process the data on the edge nodes before you send it to the cloud based on application requirements which may either improve time to become contextually aware or reduce data sent to cloud due to edge processing.
MH: I understand. Would that mean you would place contextual awareness as a part of raw amount of data?
IN3: As raw amount of data is already considered as another parameter in this study, time to become contextually aware may be direct advantage of edge computing.
MH: perfect, and how about the next one, the mobility support?
IN3: I am also not completely sure what you mean with this one.

MH: Okey, let me explain. With mobility support I mean, whenever you have an application that moves around, you can deliver for instance the offloading services all the time. Do you understand?
IN3: Okey.
MH: So for instance when you have the application of autonomous vehicles, instead of only being able to offer the service when you stand still, edge computing can help with delivering the service while driving around.
IN3: so that would mean you have to reconnect to different connection points and services. I can imagine this being quite difficult for edge computing, because you have to provide edge nodes at all kinds of different points.
MH: I can imagine, but what I mean to say is, is this something which would be something that can only be established by edge computing and not by cloud computing, because then it may influence the decision.
IN3: I think you can also deliver the service of mobility support with cloud computing. It mainly depends on how you connect your device to the local access point/gateway and mobility/roaming support offered by the technology, time it takes to transfer to new AP/Gateway and latency of the network, but it depends less edge vs. cloud. What is also relevant is to look at when you roll it out with a 4G or a 5G network. 5G standards have multiple scenarios supported like vehicle to everything where mobility is considered. The scenarios also include Enhanced Mobile Broadband (eMBB) , Critical Communications (CC) and Ultra Reliable and Low Latency Communications (URLLC) and Massive Internet of Things (mIoT) which should be considered in the study. These improvements may allow at least certain class of applications to be served by cloud as latency, network QOS and bandwidth improve. The advantage of edge computing is when data can be processed in a local area network and data sources/edge computing platforms are within the LAN network and data does not traverse long network circuits. In this way edge computing may provide better performance on Wi-Fi or Wired LAN vs 4G/LTE/5G where available while 4G/LTE/5G shall be more suited to applications requiring wide area mobility support as their coverage is wider.
MH: that's true, but what I think would mainly be relevant is to look at whether 5G will collaborate or compete against edge computing What is your feeling about that?
IN3: It will probably collaborate. I think 5G will be one of the biggest users of the edge infrastructure, as it aims to solve similar aspects. Therefore, in order to locally store and process data, 5G will make heavy use of the edge infrastructure especially for edge network function virtualization (NFV).
MH: Good, that's also what I thought. But, in that case for my framework itself it might be less relevant right?
IN3: That's correct, with improvement in network technology where processing of data may happen becomes less relevant for certain classes of applications. However the amount of shall increase to 170 ZB by 2025 out of which 90 ZB is going to be IoT data and systems and architectures required to transport, process and store this data will work more efficiently it is done closer to source of data. This optimization will translate to ability to support more end applications with lower investments in network infrastructure.
MH: Okey, and what about the connectivity stability and reliability. Do you think edge computing can provide a benefit here?
IN3: Yes I think so. If you lose connection with the cloud, you can use local edge nodes to do the processing.
MH: So would that mean it could be a reason why you chose for edge computing?
IN3: Yes. But it would not be about better connection in general, because your connection to the cloud will remain the same, but it will be more about that you will always have access to the compute power.
MH: I understand. And how about the energy constraints of IoT devices. What I found in literature was that an edge computing architecture could actually lead to less energy consumptions of IoT devices. Therefore, you might want to choose for edge computing instead of cloud.
IN3: I don't think this is the case, because you will still use the same connection method. For instance, if you would transfer data through Wi-Fi, it doesn't matter if you send it to the cloud or to the edge, because you will need to connect with the network anyway. I think in some cases edge computing might actually even make it worse, because you push some of the compute power back to the devices themselves, if they are smart, and in that sense they would consume more energy due to increase in processing power. Also, if you would connect on WiFi for instance, it would not make a difference if the data is then send to the cloud eventually or the edge, because you will still need the same connection.
MH: You do definitely have a point there, I will check again what they said in literature. Because I read something about that the energy which is used by the IoT devices for transmission of data could be reduced by as much as 40% when choosing for edge instead of cloud.
IN3: I don't think that's likely, because you will still use the same network connections.
MH: Clear. Then, do you think something is missing here?
IN3: I think what is missing is related to what I e-mailed you about the difficulty of billing, licensing, etc.
MH: You have a valid point there, but I think that is mainly relevant for the provider right? This part is fully focused on the customer perspective, so we will come to that later okey?
IN3: That's fine.
MH: So, any other factors that you think might be relevant for customers which have to decide between edge or cloud?
IN3: I mainly think that latency and the raw amount of data are very important. Let me give an example again. There was one case in which a client had to implement an edge computing infrastructure because the amount of data he had to process was so much, that it was not possible to send it all to the cloud. Therefore we had to implement an edge architecture.
MH: Clear. So you do not think there are other factors that might be relevant?
IN3: No, I think it covers the important parts.
MH: Good, let's continue to the light yellow box then. This one explains the value of serveless, are you familiar with this concept?
IN3: Yes I am.
MH: Perfect. Well, let me explain what I found. So serverless is heavily related to the concept as function as a service, as you might know. Which means that, instead of having difficult code on your system, all you have is a couple of function calls which your system does. Furthermore, you do not have to understand the underlying code or the underlying architecture. All you have to know is the array of codes. Let's say you have 10 robots in a factory. These robots can than only have a range of function calls, and the functions themselves are stored at the edge nodes. Then it is possible to do the control part in the edge computer instead of on the single robots. This might not have been possible with cloud, because you have for instance latency issues and so on. The added value of serverless is then that you have to write the functions only once, for the edge nodes, and then all you have to do for the robots is call the functions, which could in turn make it way easier to implement. Also, as you only call the functions, you don't need to dedicate resources for computation beforehand and pay for these resources. All you have to pay for is the functions which you actually use, and thus only the resources which you use.

IN3: Okey
MH: So my question is, might this in general be a relevant characteristic because of which customers might chose for edge computing instead of cloud computing.
IN3: Yes I think it can be relevant. But, I think what is important to mention, is that there should be libraries available which you can put on the edge nodes, this whole process has to be standardized, otherwise it might be difficult.
MH: I can understand. So, I see we are already talking for quite long, which is fine, but let's try to continue for a bit, because otherwise we might get some time issues.
IN3: Sure
MH: So, when we look at the first 8 factors, the service requirements with regards to predictive maintenance. Which of these factors do you think might be relevant?
IN3: Latency can definitely be important. It is like the example I mentioned earlier. For some applications you need to be able to measure really fast if something is wrong, so you cannot have any response time delay. Then there is the raw amount of data, which is also very important. Especially when you are talking about more complicated kinds of applications, the raw amount of data might be a crucial factor. I think privacy is not so relevant, but the security is definitely important. Companies want their data to be protected, and they don't want any defaults with that regard. I think the other requirements you mentioned might not be as relevant. Mainly the raw amount of data would be crucial.
MH: Okey clear. Well, in that case, let's continue to the second box, and again, I will try to speed up the process a bit in order to make it in time. Is that fine for you?
IN3: Yes.
MH: So the second box is mainly related to costs customers experience when going from their current IT architecture towards an edge computing architecture. And for that, I identified 2 factors. The first one is the possibility of system integration with their previous architecture. So let's say they currently have an cloud infrastructure, if the edge infrastructure will be compatible with that, it might decrease the switching costs. Second, I found that if the platform is open, i.e. there are all kinds of libraries available and to the extreme it might even be open source, then it might be easier to switch for customers. What's your feeling about these factors, do you think they are relevant?
IN3: Yes, I think they can both be relevant. Apart from this switching cost shall be directly proportional to number of edge computing devices/locations. Larger the number higher the switching cost as the edge computing may not be able to match the cost of cloud computing at least initially. I also think what is especially relevant is if there are standards and libraries on which they might develop.
MH: Okey, and do you think there are any other factors that might be relevant?
IN3: I think especially the openness of the platform/API can be very relevant. For instance, if you don't have any standard libraries on which you can develop, you will need to develop them yourselves.
MH: Sounds reasonable. And how do you think these factors apply to predictive maintenance? Do you see any difficulties there?
IN3: It heavily depends per application. But in general. Hardware required for edge computing devices has been around for a long time, so there is much information about it , There is more work on software to manage and orchestrate large edge computing network connected to a central cloud and run advanced processing algorithms like ML/AI on them which can be a challenge in predictive maintenance.
MH: Perfect. Then I suggest we continue to box 3.
IN3: Good.
MH: So, now we are shifting from the customer perspective towards the provider perspective.
IN3: You mean the service provider of edge computing?
MH: Exactly. So, one of the important factors for a service provider to select an application is the customer base, would you agree?
IN3: Yes.
MH: So in order to determine if there is a substantial customer base, I identified three characteristics which could be relevant. And I know they might not be ordered logically, so I will change this, but we start at the bottom of the three. So, the application itself should be quite wide-spread. If we look for which application we want to build competencies in order to realize the architecture, there should at least be enough applications in order for us to repeat the process, otherwise we are developing competencies in a very niche-like environment. On the other hand, we can also look at the potential of an application. Let's say autonomous vehicles, they are not wide-spread yet, but the potential is huge right? Then lastly, we should look at what amount of data we can push towards the edge, because this will ultimately determine our market size as well. So do you think all of these factors are relevant?
IN3: Yes, I think all of them can be relevant. The only think I was thinking about is that, it is especially important how much data you will have on the edge. And that does not only relate to the percentage, but for instance, because you have an edge architecture you might be able to process more data, this then means that you have more data in total that you process than before, and thus the distinction between the % of data which you put on the edge is not complete.
MH: So it is also about the extra amount of data you might be able to process?
IN3: Yes, because of the edge computing architecture, you can handle more data, and so you might process data which you didn't do so before.
MH: Sounds logical, any other missing factors?
IN3: No, I think this mainly covers it.
MH: Okey, and how about predictive maintenance, what is the current market, what is the potential, etc.
IN3: I think predictive maintenance is pretty mature in some applications, but might be less mature in others. But generally speaking it should be fine. I also think that you might be able to process a lot more data because of the edge architecture.
MH: And how about the % of data on edge vs. cloud?
IN3: Well, if you have an application which does not process a lot of data, you wouldn't necessarily need edge.
MH: Would it also mean you pre-process mainly on the edge and do the larger processing arrays still at the cloud.
IN3: Yes, could be.
MH: Okey. I see we are quite limited in time, so I suggest we try to speed-up even a bit more. So let's go to the fourth box. I guess this is the easiest one as well. So what I found is that the geographical coverage that you need is a big factor influencing the relative cost of an edge computing architecture over the cloud computing architecture. So the bigger the geographical coverage, the higher your cost, because you need to put edge devices everywhere.
IN3: Sorry, I can't completely tell the difference between switching costs and relative costs.

MH: So the switching costs are for the customer which may or may not switch towards edge computing. And the relative cost is for the service provider, which wants to roll-out the edge computing architecture. So do you think this factor is relevant?
IN3: I definitely do think so.
MH: And do you think that there might be other factors which are relevant?
IN3: I think the most important one is the geographical coverage needed, because if you need a lot more devices it can get very expensive.
MH: And how do you see this for predictive maintenance?
IN3: I think that in general the geographical coverage should not be a problem
MH: Perfect. Let's continue to the next box then. This one will need a little explanation. So, what I aim to measure here is the health of the ecosystem of companies which deliver the IoT application. So for instance, for autonomous vehicles, an Uber, Waymo, Daimler, etc. are all building this applications. Together they make up an ecosystem of companies that provide the IoT application. What's important is that this ecosystem is healthy. And please don't look to the left side factors, these are to specific, but what's important are the three factors diversity, so is there a big variety of partners, the productivity, so are the companies profitable, and the robustness, so how likely are the companies to go bankrupt or to pull-out of the IoT application. Do you think these factors are relevant?
IN3: Yes I certainly think. Let's for instance look at the robustness. I can see that companies should have sufficient liquidity and creditworthiness and they should be interconnected. I can imagine that this is all important when a service provider wants to roll-out their architecture.
MH: Okey, and are there any factors missing?
AH: What I think is also important is that the ecosystem is technically functioning well. So for instance with predictive maintenance, the machinery has been around for a long time and it is very stable. This is important, because if it is not technically working, it might not be a good application.
MH: I agree, but this might be covered a bit in the next one as well, but we will discuss this later. And how about for predictive maintenance?
AH: I think the ecosystem in general is quite stable and I wouldn't see any problems.
MH: Okey perfect. I see we have about 15 more minutes before we have to start on the 10th box which is very very important. So let's do box 6 till box 9 a bit in a rush okey?
IN3: Fine.
MH: So, what is also important for the provider is that there is not very much financial risk, because if the risk is high, they might be reluctant to invest. So for instance, when the IoT ecosystem is not robust, there might be a big likelihood that companies go bankrupt or pull out of the IoT applications. Furthermore, if you have to roll-out a huge architecture, then the initial investment will be huge, meaning that you bare a bigger risk, because if it will not take off, you have invested quite big-time. Lastly, there is the maturity of the IoT application, so if the application is still in concept phase, there might be big risks of the application not taking off at all. So do you think these factors are relevant?
IN3: I definitely think so. One thing I want to mention is that for predictive maintenance you will probably not build an architecture that is multi-purpose, you will build a dedicated system which provides a certain solution, so for the service provider the risk might not be as high in this case. But for other applications this can of course be very different.
MH: Sounds reasonable, any factors that I might have forgotten?
IN3: I think the financial risk is very important, because what I see is that one of the major things holding back edge computing is that companies find it too risky to invest. This means that they are not willing to invest yet, and this is holding them back.
MH: Okey, good, let's continue to box 7 then. This is the financial complexity. So when you have a bigger geographical coverage needed, you need a higher investment, for which you need to lobby at your departments, etc. And this might increase how complex it is to get everything financially around. Furthermore, in some instances, you might co-invest in an architecture with participants in the IoT ecosystem. This might make it easier to get the financials right. How do you feel about these factors.
IN3: I definitely think they are relevant. What might also be relevant is that when you have built nothing at all yet, you need a higher investment in total, so that could also increase your investment costs.
MH: Could you elaborate?
IN3: Well, if you don't have any standards or libraries available, you need to create that from scratch, this means your investments become higher as well.
MH: That's true, thank you. And for predictive maintenance, do you think this poses any major problems?
IN3: I don't think so. The investments shouldn't be too high, and co-ownership should be possible.
MH: Okey good. Let's go to the 8th one then. The technical complexity. Do you think these factors are relevant?
IN3: Yes they definitely are, especially the standards. If there is a lack of standards, there might be a huge increase in complexity. Furthermore, I would like to add the things I pointed out in the e-mail here. So what might make edge computing very technically complex is when you want to control the licensing, upgrades, updates and billing methods. Because in the cloud you can do all of this very centralized, which makes it a lot easier. But in the edge, as everything is distributed, it might get a whole lot more difficult. Also I think that the difficulty in general will not be on the hardware level, but will instead be at the software level. So, mainly managing and orchestrating all the devices might get very complex. On the hardware side I don't foresee any major problems.
MH: Okey, and how about these factors for predictive maintenance?
IN3: I don't think it will be incredibly complex in general. As I mentioned in our previous call as well, I already rolled out some edge architecture for predictive maintenance in a smart cities. So I think the major challenges will be in the software side and related to the things I said in the e-mail.
MH: I can imagine. Okey, I think it is time to go to the final box if we want to finish on time. So, the last box is on the organizational complexity and there are two factors very related. First, the number of partners. So, if you would roll-out your architecture for a smart city, which includes smart traffic lights, smart parking, camera's etc. then your stakeholder management gets a whole lot more difficult then when you roll it out for let's say predictive maintenance for a single factory. And on the other hand the previous experience with IT might also complexify it. If the company doesn't have any architecture already, or people have no knowledge regarding cloud/edge or whatsoever, it might get very complex to do this. What's your feeling about this?
IN3: I can imagine these things being relevant. For predictive maintenance I don't think these factors should provide to be a problem, but I can see them being a problem in other instance.
MH: Okey, great, then let's continue to the last part, part 10.

A.7.4 Interview 4 – Network provider

Interviewee 4 = IN4
Michiel Huisman = MH

MH: Goed, dus op de eerste pagina staat het gehele model, en op de tweede pagina staat het model opgeknipt in 10 stukjes, om het overzichtelijker te maken. Je kan het model eigenlijke vanuit twee perspectieven bekijken, als je een potentiele business case wil hebben. Dan moet je genoeg customer value hebben, maar er moet ook genoeg value voor het netwerk zijn. Dus bijvoorbeeld voor een KPN die het gaat leveren, of een Google, etc. dan moet er ook gewoon een betere business case achter zitten. Dus eigenlijk is een van de eerste dingen waar je naar zou kijken, simpelweg de user requirements. Als je kijkt naar een IoT applicatie, die heeft bepaalde requirements, en daar kan een fit of geen fit zijn met edge computing. Dus vanuit de literatuur heb ik 8 requirements kunnen vinden die hier aan gerelateerd zijn.
IN4: Oke.
MH: Dus generiek gezien wil ik je voor de eerste 9 boxen 2 soorten vragen stellen. Aller eerst, denk je dat alle variabelen belangrijk zijn? Of misschien die niet belangrijk zijn. Dan als tweede, denk je dat er andere belangrijke factoren zijn. En dan voor de 10e box wil ik ze ranken. Hier staan namelijk de 9 factoren die we uit de eerste 9 boxen halen.
IN4: Oke, even kijken naar de tijd, of we dat gaan halen. Anders moeten we nog een tweede sessie doen. Ik heb hierna wel een meeting staan, dus we moeten even kijken hoe ver we komen.
MH: precies, ik denk dat we in een uur wel een heel eind moeten kunnen komen. Dus, als we terug gaan naar de eerste box, dan heb ik 8 requirements geïdentificeerd. Komen deze je bekend voor?
IN4: Even kijken, latency requirements zeker. Raw amount of data, wat bedoel je daar precies mee?
MH: Je hebt natuurlijk aan de ene kant je bandwith requirements, en aan de andere kant hoe meer data je bijvoorbeeld moet versturen naar de cloud, hoe duurder het wordt. En als je het dan op de edge doet, kan je die kosten bijvoorbeeld weer naar beneden krijgen.
IN4: Ja, dat is zeker waar. Met de operators hebben we heel lang op de bandbreedte gezeten, en de Amazon’s en de Google’s meer op de opslag. Ik moet zeggen dat de data in de data pakketjes al heel minimaal is. Wij maken nu gebruik van een cumulosity platform, dat is een Duits product, en KPN maakt daar ook gebruik van. Daarnaast maken we gebruik van, Node Red, dat is van IBM, en daarin processen we data. Dus wat we doen, is een gedeelte lokaal processen en een gedeelte bij de operator.
MH: Heeft dit te maken met de content delivery networks, CDNs?
IN4: Wat we dus doen, is dat we bijvoorbeeld een meet instrument hebben in het land, bijvoorbeeld een ammoniak meter in het land, dat is letterlijk wat we doen, en die geeft dat door aan een sensor, via LoRa in dit geval, dat is een KPN netwerk, en dan naar het cumulosity platform, en dan krijg je vanaf daar door wat de waarden zijn natuurlijk. De grootste moeilijkheid die daar dan in zit is om het te vertalen naar waardevolle data. Wij doen dat hier lokaal. Dus we krijgen het binnen via het LoRa netwerk, dan processen we het lokaal, en dan pas sturen we het door naar de klant. Ja, zo doen we het nu. Het is zeker relevant hoor, want als je veel AWS gaat gebruiken, als je bijvoorbeeld kijkt naar een bedrijf zoals Ocean Drive, dan vallen de kosten best wel mee. Dan heb je best wel goedkoop al best veel bandbreedte, maar in sommige gevallen kan het ook weer heel duur zijn.
MH: Ja precies.
IN4: Privacy en security requirements zijn enorm belangrijk. Daar lopen we op dit moment echt tegen aan, dat is echt een issue. Waar we vooral tegenaan lopen is time to market.
MH: Oke, time to market.
IN4: Wat dus een probleem voor klanten is, is dat je niet kan leveren.
MH: Denk je dat een edge computing infrastructuur de privacy en security meer kan verbeteren, of dat het juist lastiger wordt.
IN4: Als je een edge infrastructuur hebt haal je het natuurlijk meer naar jezelf toe, dus dat kan wat zijn.
MH: Wat ik namelijk bijvoorbeeld vond is dat, wanneer je privacy gevoelige data hebt, let’s say, je hebt overal camera’s in Amsterdam, of hier in Woerden, dan kan je lokaal de data al processen en de privacy gevoelige data er al uit halen, en dat daarmee faciliteren.
IN4: Wij zijn momenteel vooral bezig met het aan de praat krijgen er van. Dus, dan doen we het vooral in de pilot fase. Dus we hebben met iedereen afgesproken dat de informatie en security nog niet helemaal top is, is iedereen daar zich van bewust? En als er dan iets van die data lekt, dan is dat geen groot probleem en is het wat veiliger. Maar, we doen bijvoorbeeld ook trillingen van spoor rails in Den Helder. Die hebben we dubbel gedaan, daar hebben we een soort van edge computing kan je het bijna noemen, op het spoor. Je hebt daar namelijk bedrijven die doen dat real-time op het spoor. En die hebben SMS alerts er in zitten, en als die dan aangeven dat bijvoorbeeld het spoor X millimeter is verschoven, dan wordt er een SMS gestuurd naar ProRail en NS, dat er iets moet gebeuren. Het is alleen meer omgekeerd. Er wordt lokaal heel veel data verzameld, maar ze geven alleen een signaal door, en ze weten eigenlijk niet wat er aan de hand is, alleen dat er ergens een rode bel af gaat.
MH: Ja, precies, het is eigenlijk meer een stand-alone systeem dus.
IN4: Ja, heel groot en dubbel uitgevoerd etc. Die apparaten kosten echt 20-30.000 euro en worden daar dan neergezet. Wij hebben daar dan bijvoorbeeld een meter tegenover gezet van een paar tientjes, die gewoon real time doorgeeft naar jou thuis van, dit is er nou precies aan de hand. Die hebben we er naast gezet, en dat werkte eigenlijk best wel goed.
MH: Dus dan heb je en meer data en het is goedkoper.
IN4: Precies, alleen dan heb je wel weer meer een probleem met security en privacy. En daarom nemen wij vaak een grote provider zoals KPN en Vodafone in dienst, die enorm veel mankracht hebben. Maar die hebben enorm veel problemen met de veiligheid en security van IoT. Ze hebben ondertussen nu wel wat er aan gedaan, ze hebben een security officer in dienst nu, en die heeft ook wel eens dit soort dingen niet goed gekeurd.
MH: Dus security en privacy zou wel heel belangrijk kunnen zijn.
IN4: Zeker. Dingen zoals latency enzo moet je gewoon doen, maar dan is security nog steeds wel echt een ding.
MH: En context awareness? Wat ik heb gevonden is dat het meer gefaciliteerd kan worden via een edge infrastructuur.
IN4: Wat is context awareness?
MH: Dat heeft meer te maken met dat de sensoren en het hele netwerk meer informatie levert over wat er nou gebeurt, de connectiviteit, context, en alles wat er omheen gebeurt, wat dus eigenlijk bijzaken zijn, en edge computing kan dat extra faciliteren. En wat ik eigenlijk wel heb gevonden is dat het ook voor een stuk zit gekoppeld aan hoeveel data je kan processen.
IN4: Dat is er inderdaad niet eentje die we apart zien.

MH: Dat is goed, komt me bekent voor van de andere interviewees. En dan heb je nog mobility support. Bijvoorbeeld als je ergens aan het rond rijden bent, dat je constant geconnect bent aan verschilende nodes.
IN4: dat kan natuurlijk cruciaal zijn bij IoT. En zeker bij cases waar je iets doet met een combinatie van GPS en informatie, etc.
MH: Ja, het is cruciaal.
IN4: Wat wij doen is materiaal, materieel beheer. Materieel beheer wordt al een hoop gedaan door middel van GPS in een end-to-end soltuion. Maar het volgen van de hamer, de spijker, de spijker gaat trouwens wel heel ver, maar de hamer en de boor, en waar is de boor nou, dat willen ze wel heel graag meten. Zeker in de bouw zijn dat soort dingen relevant, zeker belangrijk in de IoT.
MH: En connectiviteit, de stabiliteit daarvan?
IN4: Dat is een groot probleem. Maar, voor IoT is dat natuurlijk een stuk minder belangrijk dan voor spraak. Wij rollen twee dingen in het IT vlak uit, dat is natuurlijk VOIP en IoT. En M2M achtige diensten. En bij machine-to-machine wanneer een koffie apparaat een minuut later meld dat hij bijna leeg is, dan is dat ook prima. Maar, bij een trein bijvoorbeeld, kan het wel weer belangrijk zijn. Als het spoor pas zegt nadat je er overheen bent dat de trein kan gaan ontsporen, dan ben je te laat natuurlijk.
MH: Dus het verschilt wel echt per dienst.
IN4: Precies, dat is zeker zo. Het hangt er ook wel echt van af of je over cruciale data praat of niet. We hadden bijvoorbeeld een water meter in de server room. Was een heel modern gebouw, en de server ruimte staat onder NAP, en die liep wel eens onder water omdat het toch nog niet zo goed gebouwd was als ze dachten. En toen is daar een oplossing, door middel van LoRa geïntegreerd, die aangaf wanneer de ruimte onder water aan het lopen was. En die melding gaf hij wel heel snel. Dit was dan nog niet geconnecteerd aan de pompen, daar zijn ze nu mee bezig.
MH: En heb ook het idee dat een edge computing architectuur ook de connectiviteit kan verbeteren, omdat je misschien veel meer lokaal data processed.
IN4: Dat is natuurlijk ook een beetje het voorbeeld dat ik net gaf, alleen het nadeel ervan is ook wel weer dat het dan lokaal is.
MH: Ja, als zo'n edge node er uit ligt.
IN4: Dan ben je natuurlijk helemaal weg. Dus twijfeltje daar. En energy constraints?
MH: Veel devices werken op een batterijtje. En als je data dan naar een edge node stuurt in plaats van de cloud, kan dat minder energie kosten.
IN4: Zeker relevant, zeker nu accu's en batterijen nog niet super goed zijn.
MH: En als je dan kijkt naar deze 8 dingen, heb je dan het idee dat er nog iets bij zou moeten staan? Wat voor jullie bijvoorbeeld relevant zou kunnen staan
IN4: Ik weet niet of deze hierbij past, maar de software integratie is belangrijk. Bij IoT heb je allemaal overgangsmomenten van data. Dus, bij edge computing kan ik me voorstelen dat je het meer lokaal haalt, het processed en het dan op een goede manier doorgeeft. Waar wij veel problemen mee hebben is dat je allemaal dingen verschillende keren door geeft die het weer op andere manieren afhandelen. En dan wil je het in één dashboard, en dan heb je allemaal software pakketten nodig om één dashboard te maken. Dat is echt een probleem. Dus dat zou wel belangrijk zijn.
MH: Ik denk dat we daar nog wel een beetje op komen. Ik heb het nog niet helemaal op die manier verwoord, maar andere dingen die ik heb gedefinieerd zit m in de technical complexity.
IN4: standaarden he, dat is heel belangrijk.
MH: Precies.
IN4: Dat is hier momenteel een grote bende aan ITers.
MH: Zit er dan ook nog een verschil per IoT applicaties?
IN4: Ja.
MH: Dus dat zou ook een relevante criteria zijn om...
IN4: Keuzes te maken in wat je wel en niet zou doen.
MH: Precies. Oke, daar komen we straks nog op terug. Heb je verder nog het idee dat er iets mist?
IN4: Nee, ik denk dat je alles wel hebt.
MH: Ben je bekent met het concept serverless?
IN4: Nee, niet echt.
MH: Laten we dat dan maar even zitten voor nu.
IN4: Dat is goed.
MH: Dan kunnen we naar de volgende box gaan. Wat dus verder belangrijk is, is de switching cost. Je gaat dus van een huidig systeem naar een nieuw systeem. En daarvoor heb ik twee dingen geïdentificeerd. Allereerst dat je nieuwe edge infrastructuur competible kan zijn met je huidige infrastructuur. Stel je hebt je eigen database, dan wil je wel dat je edge infrastructuur daarmee competible is. En de tweede is de easiness of platform openness, het extreme geval zou hier opensource zijn.
IN4: Of iets met een API, of closed.
MH: Ja, en zie je daar veel verschil in per IoT applicaties? En is dat relevant?
IN4: Je ziet dat veel applicaties op open source zijn gedaan, maar dat de grote jongens wel een slag aan het maken. We hebben toevallig net de aandeelhoudersvergadering gehad. En wat we daar een beetje concludeerde was dat je de wet van de remmende voorsprong een beetje hebt. De kleinere partijen zijn er begonnen, en nu beginnen de grotere partijen in te stappen. Dus dat AWS, Google, Microsoft, IBM er druk mee bezig zijn. En dat zij in het laatste jaar echt wel stappen hebben gemaakt. Dus ik denk dat daar een shift is waar de experts worden opgeslokt door de grote jongens, en dat je dan dus dit soort dingen via een Microsoft kan bestellen.
MH: Microsoft is inderdaad ook bezig met Azure Edge.
IN4: Ja, dat zie je ook naar voren komen. Mijn persoonlijke visie is ook, dat Microsoft op de zakelijke markt erg sterk is. Maar het is dus aan de ene kant een open maar ook weer een gesloten systeem.
MH: Verschilt het ook nog per IoT applicatie?
IN4: Ik denk dat het vooral te maken heeft met de fase waar het zich in bevind en wat de kansen zijn die de grote partijen er achter zien. Maar, ik vind het wel lastig te zeggen.
MH: Oke.
IN4: Dus als je zegt platform criteria, en wat je net zei, van oud naar nieuw. Past mijn oude systeem wel bij de nieuwe applicatie.
MH: En als je het dus weer hebt over switching costs, naast platform characteristics, zouden er dan nog andere dingen die relevant kunnen zijn voor de klant?
IN4: Voor de klant is het relevant dat een applicatie, die heeft bijvoorbeeld een voorraad applicatie, of iets wat hij er mee doet. In

de catering bijvoorbeeld, dat het aan blijft sluiten bij wat hij al heeft. En daar zie je ook wel, bijvoorbeeld bij catering karren, dat de kosten te hoog zijn, en dat het verlies van een catering kar, niet groot genoeg is om alles maar te taggen.
MH: Ja, dus je initiele investeringskosten kunnen dus wel echt een probleem zijn voor de klant om het niet te doen.
IN4: Ja. En daarom denk ik dat het de grote bedrijven zijn die het verschil gaan maken. Die hebben bakken met geld, en zijn wat minder bang om te investeren. Wat ik een mooie case vindt, is VanderLande. Zij doen bagage verhandeling. En zij hebben een trail waar ze rondrijden zonder de banden die ze bij een airport hebben, maar ze rijden mat karretjes van de afhandeling naar het vliegtuig. En daar zit eigenlijk bijna niks tussen. Het is niet zoals bij Schiphol, waar een hoop tussen zit met allemaal banden. Maar ze zijn nu heel druk aan het investeren om dat allemaal met losse karretjes te doen. En dat vind ik een mooie IoT case, waar ze het tot koffer niveau gaan taggen. En wat je daar ziet is, dat Vanderlande is overgenomen door een Amerikaans bedrijf volgens mij, en daar zit heel veel private equity achter, die hen een hoop geld geeft om te investeren.
MH: Goed, dan kunnen we naar de derde toe gaan denk ik. En dan gaan we van het customer perspective naar de leveranciers, de mensen die het uit zouden rollen.
IN4: Helder.
MH: Dus, één van de requirements zou kunnen zijn dat je een grote customer base hebt.
IN4: Ja.
MH: Als je het over een target applicatie hebt, dan ga je daar dus competencies voor opbouwen. Dus er moet een grote customer base zijn. En er zijn drie dingen waar je dat mee kan identificeren. De onderste is eigenlijk de meest relevante, ik moet dit nog om draaien. Als aller eerste ga je kijken, wat is er nu, is het groot genoeg, kunnen we er short term revenu mee halen. En dan als tweede kijk je, sommige use-cases zijn nog niet zo groot, maar wellicht dat het in de toekomst heel groot wordt. Als je bijvoorbeeld kijkt naar zelf rijdende autos. Dan is dat nu nog bijna niet, maar in de toekomst enorme potentie. En dan als laatste ga je kijken hoeveel data je nou eigenlijk naar die edge kan pushen en wat je nog op de cloud wil. Want de cloud blijft natuurlijk ook z'n voordelen hebben.
IN4: Ja precies.
MH: Zijn dit nou ook criteria waar jullie ook naar zouden kijken?
IN4: Ik vind het wel een logische volgorde zoals je het op noemde.
MH: Of zijn er nog andere dingen die voor jullie relevant zijn?
IN4: Eigenlijk niet, ik denk dat je hier wel heel erg goed hebt van, heb je al een probleem wat je kan oplossen. En je moet heel goed nadenken over de levenscyclus volgens mij. Dus ik zou hier nog wel zeggen dat je een combinatie kan maken tussen edge en cloud natuurlijk. Of dat is altijd eigenlijk wel zo. En ik denk dat het wel relevant is dat je voor sommige oplossingen, die heel groot zijn, dat je zegt van ik doe meer in de edge en minder in de cloud. Verder, waar je ook aan moet denken is, wanneer je materiaal hebt dat rond beweegt. Stel het beweegt zich buiten het edge netwerk, dan heb je wel echt een probleem.
MH: Ja precies.
IN4: Verder merken we ook dat veel bedrijven gewoon eens moeten starten en proberen. Er wordt veel over gesproken, maar er gebeurt nog niet zoveel.
MH: Interessant.
IN4: Terugkomend op die twee, dit maakt het ook moeilijk. Ik denk dat de grote jongens ook de innovatie remmen. Dat heb je eigenlijk altijd wel in zo'n markt.
MH: Die hebben momenteel een goede business case.
IN4: Precies, KPN, Vodafone, Microsoft, die remmen ook wel een hoop dingen omdat ze log zijn.
MH: Die kunnen natuurlijk minder snel wenden.
IN4: Veel mensen vertrekken daarom ook juist bij die grote partijen, omdat alles zo sloom gaat. Alles moet weer een jaar door business case processen heen, en daar zijn ze op den duur een beetje klaar mee.
MH: Oke. Dan bij de volgende gaat het echt puur over het gebied waar je de edge moet uitrollen. Als je het dus over een groot gebied moet uitrollen, wordt het erg duur. Maar, wanneer je het in een kleiner gebied doet, zou het nog te doen kunnen zijn. Stel je will het in port Rotterdam doen, dan is het nog te overzien. Maar wil je het door heel Nederland doen, dan wordt het enorm groot. En daar zouden ook wel weer extra kosten aan kunnen zitten t.o.v. cloud computing.
IN4: Ja, dat is zeker zo. Op den duur kan het ongelofelijk duur worden.
MH: Zijn er nog andere dingen die daar impact op hebben?
IN4: Ja, het heeft ook wel te maken met de complexiteit en logaritmes achter de metingen. Dus, welke problemen los je op. En dat kan je natuurlijk wel allemaal naar de cloud halen, maar waar los je dat probleem dan op.
MH: Zijn er dan ook gevallen waar het goedkoper kan zijn om het allemaal lokaal op te lossen?
IN4: Ja, dat denk ik wel ja. Maar het gaat dus niet alleen om geografisch, maar vooral om het probleem dat je oplost.
MH: Goeie. Wat ik me dus ook kan voorstellen is, dit gaat dan weer alleen over die geografische range, dat er een treshhold is waar edge heel duur wordt. In het begin kan het heel goedkoop zijn, stel je hebt slechts een paar blackberriepies, maar als het dan een stuk groter wordt, dan zou het een stuk duurder kunnen worden.
IN4: Dat is zeker zo. Het blijft natuurlijk ook altijd wel een keuze, haal ik het nou lokaal of niet. En het is een soort handje druk waar het ineens heel duur kan worden. En in jouw keuze is het dan ook heel belangrijk wat nou de maturity van het product is. Dus bij IoT moet je heel goed nadenken, in welk stadium ben ik, en in welk stadium ga ik welke keuzes maken, dat maakt het ook complex.
MH: Maturity komen we straks ook nog op, dus goed dat je dat al noemt. Dan stel ik voor dat we naar de vijfde gaan. Hier moet je even wat minder kijken naar de meest linker factoren, die zijn misschien een beetje specifiek, maar waar het vooral op gaat is dat, wanneer je op een IoT applicatie gaat targeten, dat er een soort ecosysteem aan spelers is die de IoT applicatie supporten en uitrollen. En daar kan je dus aan een aantal factoren denken. Als eerste is dat er een diverse range aan bedrijven is in de IoT applicatie, dus niet 1 of 2 bedrijven, maar meerdere, die ook allemaal verschillen van elkaar en elkaar kunnen aanvullen. Aan de andere kant heb je de productiviteit van die bedrijven. Dus groeien ze, en maken ze winst. En dan moet het als laatste ook nog een robuust netwerk zijn. Dus, gaan de niet bankroet, en hoe interconnected zijn ze. Wat is de kans dat ze deze IoT applicatie blijven supporten en dat de applicatie dus here-to-stay is. Daarom kan het belangrijk zijn om daar de health van het ecosysteem te kijken die het levert. Hoe kijk jij hier naar?
IN4: Dat doe je als entrepreneur dus heel weinig, maar is zeker relevant. Dan ga je gewoon aan de bak, en kijk je wat er gebeurt. Maar het is wel heel relevant. Wat wij hebben gedaan, is een beetje slapend deze markt in gaan en dit nooit gedaan. En waar we tegenaan lopen zijn deze dingen. Er zit niemand in die markt. We zoeken partners, maar die begrijpen ook niet wat het is. Wij kunnen als bedrijf XX het een tijdje in de lucht houden, maar dat gaat ook niet eeuwig duren. Dus het is zeker relevant. En ik denk

ook dat de grote jongens in de markt hier mee bezig zijn. En daarom zie je een Microsoft en een Google ook vooral in de grote acties stappen, en wat minder in de kleinere.
MH: Ja zeker.
IN4: En de ondernemers doen het wat minder, maar die zullen hier ook zeker tegenaan lopen. Een voorbeeld is Stelena, daar zit Tata Telecom achter. Die stapte groot in IoT in 2015/2016, maar die zitten er helemaal niet meer in. Dus die waren wat minder robuust, en Tata Telecom zat er achter he, enorm groot, maar die ging er dus uit. Dus, zeer relevant denk ik, deze.
MH: Denk je dat er nog factoren zijn die naast diversiteit, productiviteit en robuustheid zijn.
IN4: Misschien dat je niet meer dan dit wil hebben, maar wat relevant kan zijn is kennis, knowledge.
MH: Ja, daar komen we ook nog wel op terug straks, bij een andere factor.
IN4: Oke.
MH: Ik zie dat we niet zoveel tijd meer hebben, dus we moeten even een beetje gas geven om het allemaal op tijd te halen.
IN4: Dat is goed. We hebben tot kwart over he, dus we hebben nog wel even.
MH: Is goed. Dan gaan we naar de zesde, dat is financieel risico. Stel je gaat competenties ontwikkelen om op een IoT applicatie te kunnen targeten, als provider, om daar edge netwerken uit te rollen. Dan zit er altijd een risico aan vast. Aan de ene kant staat de robustness er tegen aan, waar we het al over hadden. Maar aan de andere kant dus ook die maturity waar we het net over hadden. Als dus een IoT applicatie nog niet zo mature is, dan is er heel veel onzekerheid, misschien ook een hoop minder kennis, staat er niet expliciet in, maar zou ook kunnen. En dan als laatste, als je het groter uitrolt, hoe groter je initiële investering is, en dat verhoogt ook het risico.
IN4: Dat is zeker waar. Waar wij ook tegenaan lopen is dat wanneer er een initiële investering is, er iemand is die dat op moet hoesten. En wij kunnen dat momenteel niet, dus dat maakt het lastig, dan moet ik het aan mn klant gebruiken.
MH: Ja, dat is dus ook een stukje, wie betaalt wat.
IN4: Ja, zeker. De financiering en het hele business model er achter.
MH: Hoe we die financiering rond krijgen behandelen we zo in het volgende stukje ook, dat gaat meer over financial complexity, terwijl dit over het risico gaat.
IN4: Ja, het risico is dus ook dat iedereen altijd verwacht dat techneuten alles kunnen, maar je loopt wel het risico dat het altijd twee keer zo lang duurt en twee keer zoveel kost. En als het meer dan twee keer zoveel wordt, dan moet je wel echt achter je oren krabben of je dat risico kan nemen.
MH: Ja precies.
IN4: Wat ik dus ook denk is dat het om je hele ecosysteem health gaat, en niet alleen over de robustness.
MH: Ja, precies, is wellicht ook belangrijk.
IN4: Daarnaast wat ook belangrijk is hoe je met je partners kan samen werken. Wie levert wat, en sluit dat goed op elkaar aan. En als je dus naar het risico kijkt moet je ook kijken naar, kan je een goede partner vinden om mee samen te werken? Dit kan je financieel risico ook verlagen.
MH: Precies.
IN4: Wat ik ook nog bedenk dat het termijn van je investering belangrijk is. Dus als je het snel terug verdient zijn de risico's lager dan wanneer je echt voor de lange termijn gaat.
MH: Dat kan ik me voorstellen. Oke. Wat we nu dus hebben behandeld gaat over de business model viability. Kunnen we er genoeg geld uit halen, is het aantrekkelijk voor de klant. Maar aan de andere kant kunnen we ook naar de feasibility kijken. We weten nu dat we het willen doen, en dan moeten we nu kijken, kan het eigenlijk wel. En dan kan je dus naar drie grote factoren kijken. Financial complexity, Technical complexity en organizational complexity. En financial complexity is hier dus anders dan financial risk. Omdat het bij risk dus echt gaat over wat is het risico dat ik mn geld niet terug verdien, en bij de complexiteit kijk ik naar, kan ik de investeringskosten wel bij elkaar krijgen? Zoals je eerder, je hebt een aantal klanten, en als je alles voor moet schieten, dan is het lastig. Wat dus één van de dingen is, is wat is je initiële investering, dat is heel relevant. Maar aan de andere kant ook, met wat voor IoT partners werk ik samen, en wat voor resources hebben zij…
IN4: Ik vind dat je hier wel een beetje de klant mist hoor, als je nieuwe business hebt moet je altijd de klant betrekken, maar ik ben Economisch geschoold, dus dit is voor mij belangrijk. Je moet de klant betrekken in, wat investeer jij eigenlijk, wat is jouw business case, en hoe ziet jouw ROI er uit. En dan, kom je tot een interessanter model. Want dan kan je de initiële investeringen met elkaar delen. En dat is met IoT wel waar ik tegenaan loop. Wij doen dit bijvoorbeeld wel, je kan bij ons niet off-the-shelf kopen, maar wij verwachten dat MKBers ook mee investeren.
MH: Snap ik, en wat zijn dan factoren die zo'n medewerkingsverband makkelijker maken?
IN4: Wat ook nog goed is om te melden is dat IoT niet een product is, maar in je business zit. En daar zit bij IoT volgens mij wel een probleem zou je zeggen, of een kans. Omdat je dus in de core van je klanten komt, moet je je klanten heel goed begrijpen, en daar met elkaar over in gesprek gaan. Je moet dus heel goed definiëren wie jij bent en wie ik ben, en wie wat nou precies doet.
MH: Dus je moet ook inzichtelijk kunnen maken hoe we allebei werken, een stukje transparantie dus.
IN4: Ja, dat zit er zeker in. In je core product moet je natuurlijk zelf investeren, maar als je een specifieke business case aan gaat, dan kan je dat wel co-investeren.
MH: Begrijp ik.
IN4: Dus je moet echt vanuit de klant case terug filteren, dat is wat je moet doen. Een voorbeeld is de melkrobot. De melkrobotman gaat niet zonder de boer en zonder de bank iets doen, ze gaan met elkaar kijken hoe ze dat gaan doen.
MH: Ja, meer het klantperspectief, de customer, zou nog relevant kunnen zijn.
IN4: En verder zou economisch gezien de equity nog relevant kunnen zijn. Dat kan een stukje van de complexiteit van financiering weg kunnen halen.
MH: Begrijpelijk.
IN4: Wat je dus ook wel eens ziet, is dat er bedrijven zijn die zelf niet de competencies hebben om een IoT oplossing te bieden, of een edge oplossing, maar die wel de resources hebben. Dus dan gaan zij samenwerken met een edge partner, en leveren zij het geld aan de partner die minder geld heeft. Dat maakt dus complexere financiering wel weer mogelijk.
MH: Helder. Dat zijn nog wel factoren die ik inderdaad kan overwegen. Laten we dan maar naar technical complexity gaan. Als je het geografisch gezien groter maakt, zou het moeilijker kunnen worden.
IN4: Zeker waar.
MH: En dat eronder hebben we net al een beetje besproken. Dus standaarden he, zijn heel belangrijk.
IN4: Ja, ja, ja.
MH: En als je heterogene devices en services hebt, kan het nog wel een stuk moeilijker worden.

IN4: Ja, zeker, dit zijn wel echt relevante dingen.
MH: En zijn er nog andere dingen die hier zouden kunnen spelen?
IN4: Nee, ik denk dat je ze hier wel goed samenvat. Maar, ik denk dat de volgorde wel anders is.
MH: Ja, dat klopt, dat moet ik nog even aanpassen.
IN4: Standaarden is natuurlijk het belangrijkste. En geografisch hangt er natuurlijk vanaf. In sommige gevallen kan dit erg moeilijk worden, maar soms hoeft het niet een heel groot probleem te zijn.
MH: Precies. Oke, top, dan kunnen we naar de organizational complexity gaan. En dan halen we het allemaal precies binnen de tijd, dus dat is top. Dus, wat maakt het organizatorisch complex. Allereerst, met hoeveel partners moet ik samenwerken, dit kan een enorme stakeholder management worden. En dan aan de andere kant, wat is dus de kennis van die IoT bedrijven. Als ze weinig kennis over IT hebben, over de cloud, etc. dat maakt de opzet wellicht nog een stuk complexer.
IN4: Dat is zeker waar.
MH: En misschien dat jij nog wel mee factoren weet.
IN4: Zeker, wat dus ook belangrijk is, is de interne coherentie. En een stukje nieuwe business versus bestaande business. En ook de HR-achtige dingen die er achter zitten. Dus, willen mensen wel mee met de nieuwe techniek.
MH: Precies, de interne organisatie.
IN4: Ja, dus mensen en kennis, interne organisatie, oud vs. Nieuw, en mensen die er op zitten.
MH: Kan ik me voorstellen. Verder nog iets?
IN4: Nee, ik denk dat je het hiermee in grote lijnen wel hebt.
MH: Top, dan ga ik even mijn excel sheet er bij pakken en kunnen we naar het laatste stukje. Het ranken van de variabelen.
IN4: Is goed.

A.7.5 Interview 5 – Edge and cloud platform provider & (IoT) application provider

Interviewee 5 = IN5
Michiel Huisman (Interviewer) = MH

MH: Good, so did you have a chance to take a look at the documents?
IN5: I looked through the documents quickly last week.
MH: Do you have the document with the conceptual model on your screen right now?
IN5: Yes, I do
MH: Okey, perfect. So in the document are two pages. At the first one is the full conceptual model, which might look a bit chaotic at first sight. And the second page contains the 10 boxes I want to go through in the interview. Which should make it a bit more structured, and not containing as much data in one go. So, generally speaking, the model I am trying to build should help in two ways. On the one hand you have a couple of IoT specifications as input. So, an IoT application for instance has service requirements, there is a market segment, et cetera, et cetera. At the other hand you have a choice of technology, which could be cloud or edge. And eventually there should be a match, or no match, which leads to the potential of an IoT application for edge computing. So what this framework should help in, is identifying which IoT applications might be suitable for edge computing, and which ones might not be suitable. And what I found in literature, is that there is a lot of research about the technical factors, what are requirements, what are problems, how can we solve those problems. But there was no research about the organization and financial side. My research tries to integrate all three domains, and through that analyze which applications might have potential. So, are there already some things which aren't very clear to you, which you want me to elaborate. Or do you want me to start-off, and ask the questions from there on?
IN5: I have one question already. When you speak about applications, you already have a software solution for a problem, that is not a use-case, that is the next step. You already created a potential solution.
MH: What do you mean?
IN5: You said, you want to look which applications are suitable for edge computing, but that would mean you already have a use-case, and from that you already created a potential solution.
MH: So, the IoT application is already there, or there is a potential IoT application. And what I found in literature, is that edge computing mainly answers the lack of cloud computing for some IoT applications. And the application is already there. Let's for instance say autonomous driving, which has certain characteristics. But, what we don't know is, should we implement edge computing for autonomous driving, should companies be targeting at that, or rather at other potential use-cases.
IN5: Uhu.
MH: So that's kind-off the difference there. So, let's go to the boxes now. SO it is divided in 10 boxes. For the first nine boxes I am going to ask you three kinds of questions. First, looking at the variables you see, do you generally speaking think that it could be a reason to chose for edge computing instead of cloud computing. So at for instance the first box, we have different service requirements, so could these requirements have impact for the user to choose for an edge computing solution instead of a cloud computing solution. The second question would be, are there variables missing, that could have impact. And then the third one is related to the use-case I selected, which is predictive maintenance. And I will ask how the variables interact with this application. Which are important, how could they drive or stagger the potential, et cetera.
IN5: Okey.
MH: Sounds good?
IN5: Sounds good. Just to make sure I am at the correct page. We have box one, service requirements.
MH: Yes, this is exactly where we start.
IN5: Perfect.
MH: So, indeed, one of the first things we can look at is from the customer side. So, what is the added value for the customer to go for an edge computing infrastructure instead of the cloud. And the first thing we found is the service requirements. I identified from literature 8 requirements which could have an impact. SO it is from latency requirements, to the energy constraints of IoT devices. So, do you think all of these are important, or are there ones which are not relevant>
IN5: I feel that not all of them are as important.
MH: Okey.
IN5: I would say that energy constraints and mobility support are not of that great importance. Because I think that energy constraints depends on the industry you are in. And mobility support is also strongly dependent on the industry you are in. I would say that latency, raw amount of data, security and stability / reliability are the main drivers of this box.
MH: Good to know. So, would you say all of them, could have impact. Or would you say that even some of them should be excluded. For instance the variables of energy constraints or mobility support you just mentioned.
IN5: Give me a second to think. So energy constraints, do you mean the energy consumption of the edge device?
MH: So actually, what I found in literature, for the devices that do the offloading at the edge instead of the cloud. It takes you less energy to offload your tasks to the edge than at the cloud. And there was some experiment which said it could make a difference of 40% per query. But I just extracted it from 2 articles, so I am not sure if it is right.
IN5: I would take it out. Yes, bringing your data processing to the edge, there is different a different energy requirement than to the cloud. But, when you bring something to the edge, because of the second box, raw amount of data. You have a lot of data you want to process, and you have another device which you use to gather it and process it. So that also consumes energy. You are not just brining it somewhere for no reason. I would generally speaking say it is not a reason to go for an edge application.
MH: And what if those kinds of devices, which are offloading their data, what if they have no constant power supply, but they rather have a battery or something similar. Would it then be relevant, or still be the same case.
IN5: Still the same case. I think that the energy consumption will not change.
MH: Clear. And would there be some other factors you don't see yet?
IN5: Could you elaborate upon context awareness a bit?
MH: Yeah, so context awareness is about the contextual information you can extract, about your network, about the context of where the sensor is located, etc. And it is kind off attached to the amount of data you can process. So because of edge you can process more data, and thus include data which you would usually not process, but it is very connected to the amount of data.
IN5: So, I didn't know what to make out of this earlier, but in that case I would say it is important.
MH: So, good to know.

IN5: To give you a little heads-up, I am in the field of factory automation, so I can probably not help you to much in the field of autonomous driving. But, I think that there the context awareness is a bigger topic.
MH: In the industry sector?
IN5: Yes.
MH: That's fine, because the use case I selected is for predictive maintenance. And I think your industry experience of yours might be very valuable on that behalf.
IN5: Good.
MH: Let's see, so especially the energy constraints is not relevant. And the mobility support is also not as relevant, but the other will be right?
IN5: Exactly. With latency, raw amount of data, security, and connectivity as the main drivers.
MH: Yeah. And do you think edge computing can establish additional connectivity, compared to a cloud infrastructure, or would it be more of a hustle in general?
IN5: What do you mean with connectivity?
MH: That the stability of the connectivity would be enhanced compared to a cloud infrastructure.
IN5: Definitely.
MH: Perfect. Do you think there are other factors that might be relevant?
IN5: Yes, please give me a couple of seconds to think.
MH: Yes of course, take your time.
IN5: So you also mentioned that the whole scene of edge computing is not so discovered in the business fields, but just in the technical fields right.
MH: Correct.
IN5: And, maybe if you bring this in a bit like, innovation requirements.
MH: Innovation requirements?
IN5: Yeah, openness and innovation cycles. Because, we think that in the field of edge computing, next to latency of course and raw amount of data of course, what else can you bring to the table. And, I think that, through edge computing, and contextual awareness, we have the sensors, and everything else is connected, we are a lot faster with creating innovations and new applications for the sectors that we have. It is not like we have to connect everything to the cloud, so we can compare it to another site in China. But at the edge itself, at the site itself, it can drive innovation. We can look at the bottlenecks.
MH: And that might be another reason to go for an edge infrastructure than for a cloud infrastructure?
IN5: Exactly. Let's say we have connected the pre-processing of the data locally. I think that increases innovation cycles.
MH: That's a good one, I didn't hear about it yet.
IN5: And especially in the field where I work at the moment, this is one that is considered one of the advantages of edge computing in general. You enable many AI applications compared to the cloud. That's a computing addition, which is one of the bigger topics nowadays. It might have to do a bit with the raw amount of data. But it is basically to push 10TB of data to the cloud and use it for quality assessment. It is just not the way to go. This is something you have to do locally. I do not know if you want to put it under raw amount of data, or local data processing, but the edge enables AI applications.
MH: I definitely think it is not entirely covered in the raw amount of data, so I might want to make a distinction there. Between what's there right now, the raw amount of data, and what you just mentioned, the AI application, innovation cycles. It good be very good.
IN5: Because when I read the raw amount of data, I don't want to give critics, but what's also important, is that you realize that otherwise you would push all that costly data to the cloud. But, on the other side, it think that it also enables things that you could not do with a cloud system. So I would say that you can do more sophisticated and smart applications, you have more processing power.
MH: So would you usually do edge computing more at the complicated applications?
IN5: Yes, I would say so.
MH: Very good. Any other factors I might have forgotten there?
IN5: It is probably not a factor against the cloud, but it probably should be as open, concerning API's and standards, as the cloud. This would be in real life industrial use-cases. Here you have several systems working together. And you need standards in real life. Usually this is covered by the major cloud providers, and it should also be covered for the edge. But I am not sure if it is a requirement which should be covered for the edge, against cloud.
MH: I definitely think it is a prerequisite. And later, when we are going to talk about the technical complexity. We are going to talk a bit about the standards, which are very important. For instance, some IoT applications might be more standardized than others, and this makes it more easy, and it might be a reason for a provider to go for it or not. So I am happy you mention this, because I also identified it, and we will cover it later. So, there is a yellow box underneath it, it is about the additional functionalities of the edge. Are you familiar with this concept? Serverless?
IN5: I have heard about it, but maybe you can give me a recap.
MH: Of course, so serverless is very related with the function as a service. Where actually the machines, for instance, don't have any software their selves anymore. All they do is function calls, to for instance an edge system. And, they don't have any knowledge about the underlying infrastructure. All they know is that they have some functions, which they call at certain moments, and the infrastructure and the edge system could take care of the rest. You could either do this on the edge or on the cloud. But, there is an additional value for doing it at the edge, because you don't have problems with latency anymore. And thereby you could enable new things like for instance, operating machines on the edge instead of on the machines their selves. And that is one of the values which serverless could additionally bring if you use an edge infrastructure. Because you can't operate your machines on the cloud, because of latency, the amount of data, etc. But, on the other hand, the concept of serverless is still quite immature, so there is a lot of talking about it, but not so much implementation. So it is more on the future side, so I am not sure if it should be there for now, but it could certainly be relevant in the future.
IN5: It is something on the horizon.
MH: If you would say, you don't have as much expertise on serverless, I would suggest we skip that one and continue.
IN5: Sounds good.
MH: Then we do that. I think we now covered the first one, which was also the most difficult one to start with, because it had the most factors. And I would suggest we go to the second box. Which is talking about the switching costs for users. So, for instance, I currently have an infrastructure, and I want to go to an edge infrastructure, what are the switching cost I am making. One of the

things could be the possibility of system integration with the previous system. So I e.g. have an cloud infrastructure, and I want an edge infrastructure, then it should be compatible with each other. And on the other hand there is the openness of the IoT applications. Are there libraries, standards, etc. which I can continue developing on, which I can also use in the edge infrastructure. And this might lower the switching cost. What do you think of these factors, are they relevant?
IN5: Switching costs are definitely relevant. If you have a use-case, or an application, but let's say predictive maintenance, that saves an X amount of money, every year. And that X amount of money is bigger than the switching costs, it is a no-brainer, right. So switching costs are always there, to create something new. And it just depends on the business case you create with it, the added value. I mean, you are definitely right, but let's not only think in monetary dimensions. Definitely, the platform openness, and the whole standardization is key right. And especially in my industry field, there is very big innovation cycles, where the machines run there for 15 years, without any mistakes or problems. And they don't want to innovate, because when you stop the machine, the whole production line might stop. So it is very dangerous. As they say, never change a running system right. So the integration, and the cost of integration of it is key. So I wouldn't say that switching costs is the cost you have to procure in your equipment costs, but it is more the opportunity costs, what could go wrong?
MH: SO that's also a bit missing. What could go wrong? And what are the unknowns of what could go wrong?
IN5: Yes, this is probably what our clients look at. Because they have big businesses, which goes about the volume they produce, and the high quality. So, they are very cautious with integrating just a new toy somewhere in the production line, which might mess up the quality or the run-time. So I would say the switching costs or the opportunity costs are a big topic. Customers are very hesitant at the moment.
MH: Sounds good. By the way, I just remembered that I forgot to ask you 1 more thing at the first box. So I hope you don't mind going back for a bit.
IN5: Of course, no problem.
MH: The one thing I forgot to ask you. Which of these requirements would be reasons to go for an edge computing infrastructure for predictive maintenance? Which ones would be relevant?
IN5: Raw amount of data, for sure. I have to name one right?
MH: You can also mention more. So raw amount of data would be the most important one, but could there also be other reasons to go there?
IN5: Depending on the industry, security could be important. But, I think that what all industries combine, is definitely raw amount of data. I wouldn't say that latency is so important. Of course depending on the machines, there could be some importance, but in general it is not so important. So the raw amount of data, to make a good prediction, to plan the maintenance ahead, would be very important. And then time is usually not as critical, but it is important to make the right decision.
MH: And something like the stability of the connectivity, is that also relevant for predictive maintenance, or wouldn't it be a big problem if the system would be out for a short while?
IN5: I think it would depend on the industry. If you have a cutting, where people are working side-by-side with the machine. The reliability is key right.
MH: Yes.
IN5: So, if you take the example of the train. Then a couple of minutes down-time and loss of data. Leading not being able to measure the wheels, or axis of the train. It would be very unlikely that it will break, but the impact might be huge, so it could be a problem. There is only one thing I would imagine, which I have to notify you of. That is that the sensor is connected by cable to the edge device, because then it would make a bigger difference. Because with a cable I would assume a 100% connectivity.
MH: I can imagine. Then we can go to the second box again, where I will ask you kind off the same question again. So, do you see any problems with the system integration and the openness of the platform. So how open are these systems, and how easy is it to integrate it with the systems. Generally speaking of course.
IN5: I think that system integration can be hard. On the first hand, it is very use-case dependent. So, for example, if you measure vibrations right. You have XYZ axis, and you have a delta to where the machine was heading earlier, and it depends on how you measure it, e.g. millimeter, centimeter, meter, and there is no standards. This leads to a big hurdle to integrate predictive maintenance and roll it out on a bigger scale. It is always very use-case dependent, and that is a problem of course.
MH: That could also be a problem to the provider of course, because scaling the solution, and implementing similar solutions at other clients might be very hard.
IN5: Exactly. And they have great algorithms, and great solutions. But, it is very hard to export it to the next customer, even if they implemented it in a similar business.
MH: Perfect. I suggest we go to the next box then. Here we take the view from the provider, which could of course be you guys. And one of the important things would be I guess, and also when we are talking about developing some solution and trying to copy it to other clients, it is important that you have a certain customer base. And with a customer base I mean that you can measure it by three kinds of measures. I suggest we start at the bottom. First of all, what is important, is the current installed base of the IoT application. So how widely implemented is the IoT applications already. So what is your current market. And the second thing is, what is the potential of the IoT market. So if we are talking about autonomous vehicles again. Currently it is almost nothing, but the maximum potential can be use. And then on the other hand, we have to ask ourselves, so what is the percentage of data that we can push to the edge. Is it only going to be minor parts, or is it going to be major parts or even almost full systems. How do you feel about these factors in general?
IN5: I think that the current installed base of the IoT application in general of course it is key. If there is no structure yet, it is very hard to convince any customer to use it. Also, the investment will always be too high. Is that where you are trying to go with the question?
MH: It is more like, when you are going to implement an edge infrastructure. You are going to be targeting on some applications, and for those applications you will develop some competencies. And for that, to also scale your solution, you need some kind of customer base. And that is your current customer base. Does that clarify it?
IN5: Not so much, you have an IoT application, let's say predictive maintenance.
MH: So, how big is the application right now. So, is predictive maintenance then in the premature phases, or is it already implemented in many places. Do you understand?
IN5: Yes, predictive maintenance is very premature. That's because the goal would be that all your machines and equipment would have some kind of predictive maintenance running, but the reality is that, every customer is working on one predictive maintenance application for one of their machines. So it is very specific at the moment. There is no scalability at this moment. Does that make sense to you?

MH: Yes it totally makes sense to me.
IN5: On the other hand I think that the size of the potential market is gigantic. It is manifold of what we have now. Because, at the moment, many of the customers are at the prove of concept phase. They have one use-case that could be solved through predictive maintenance, which could save them some cost, but it is not so relevant to their business, so they can play around a bit with it. So they can use it as one of their test beds. So everyone is currently training the datasets and trying out what could go wrong, what could go right, how hard it is, how much insights you can create from the data you collect. But, I think the maximum IoT market is a lot bigger. Predictive maintenance could be a game changer.
MH: And we would still be talking about predictive maintenance, so it is still very immature, could that be a reason for you to not start in that area yet? So for instance focus on other areas, and wait till predictive maintenance has matured more? Or would you still do so.
IN5: That's difficult to answer. We actually offer predictive maintenance applications, and we really think there is big potential, but that is not everything. Just like I said before, we think AI is a big customer. And we think predictive maintenance has at it's hearth Artificial Intelligence. But in the end it depends on the customer. Some of them just want quality assurance, where edge computing is not so good at the moment. So that's more the statistical measures. But, predictive maintenance has that wauw factor to it, so that is why everyone is working on it. Hard to say, hard to say.
MH: Okey, I understand. Would there also be other factors you would look at in the customer base, except these three factors?
IN5: Maybe you could give me a little explanation with what you mean with customer base / revenue source.
MH: So, it's mainly from the definitions where I formally extracted from. It is from a business model framework. I mainly refer to the customer base and these customers would eventually be your revenue source, so you deliver a service for them and they provide a revenue to them.
IN5: Ah of course.
MH: Maybe I can give an example of another interviewee. He said that for instance service contracts, or anything related to that, could be a huge additional revenue source, which could add to the edge offering. So maybe you could sell additional service contracts, or something related to that.
IN5: Ah, yeah of course, of course. Now I get your point. Yes, besides selling edge ready hardware, and I software and connectivity, etc. there is definitely an opportunity to create new business models. This is definitely a key to why edge will be very interesting for especially OEMs
MH: And do you think there is a difference for different IoT applications, where some applications might offer way more potential for let's say extra service contracts than others?
IN5: Yes definitely.
MH: Okey, good.
IN5: That will be completely different, yeah.
MH: Sounds good. Then I suggest we go to the fourth box. Here we are talking about the relative cost. So for instance when you are going to implement an edge computing infrastructure, and I am still talking from the provider perspective. Rolling out an infrastructure for the edge can be more costly than for the cloud, but it depends. And what I found is that it could depend on your geographical coverage that you need. So for instance, when you would set-up your edge infrastructure in a factory, or a factory park, it is only very limited in geographical range. But if we would talk about autonomous vehicles again, we would have to talk about setting up an architecture for the whole country, and then it might get very expensive. And I think that could drive the edge vs. cloud choice.
IN5: It is probably a unsatisfying answer to you, but it probably depends on the sector or branches or domain you are in. Because I don't think you can compare a factory to let's say autonomous driving in a whole country. Because for instance if you have three factories in the Netherlands and one in China, I don't think it matters if you make two of them in the Netherlands edge ready and one of them in China. The equipment will be the same. I think it mainly matters about how complex the system is that you want to make edge ready. That will be the cost driver?
MH: So that will make it expensive?
IN5: Yes, exactly. So the complexity of the system you want to bring to the edge. Of course now you can argue that for autonomous driving the complexity of the system is very high. But, I wouldn't say that geographical coverage is the right factor.
MH: Yeah. It might be a too limited definition, and it might be more about the scale of your application, which might lead to huge difficulties in general. Is that what you want to say?
IN5: Yes. Let's say you produce bottles. Something goes wrong, it's bad, but it is not super harmful. In the realm of autonomous driving, life is at stake, so the roll-out will be more expensive. Because you will have redundant systems, safety software, more security, more safety. The requirements will be bigger. I would not frame it under geographical coverage, but again, under the complexity of the system you want to bring into the edge and the biggest harm that could happen in the system. For example at a nuclear power plant, where people could be at harm, it is way worse than simply the loss of production.
MH: Exactly. Can I then also extract from that, that it would make edge computing way more expensive than for instance a cloud computing infrastructure, for the same kind of solution, or would it for the cloud also be way more expensive?
IN5: I think for some of these use-cases it is not a decision between edge or cloud.
MH: Okey.
IN5: For example, cloud computing will not give you the opportunity to have autonomous driving. So either, when you want autonomous driving, you need to use edge technology. And if you don't want it, you just stick with traffic management through the cloud. So in that sense it is not a versus question I would say. In general a cloud solution would always be cheaper for sure.
MH: And how do you think the factors, we are not talking about geographical coverage anymore, but more about the scale and the requirements like you just said. How do you think it leads to the relative cost for predictive maintenance, regarding your edge architecture. Will the cost still be manageable, or will the cost in general be very high?
IN5: Can you give an example?
MH: So for instance, if you would be thinking about rolling out your edge infrastructure for a predictive maintenance solution, and we are talking about the complexity. This could be huge for autonomous driving, and this could be a reason not to do it. But, I am not sure what the relative cost would be for rolling out a predictive maintenance edge infrastructure. Does that make it more clear?
IN5: Yes it does. I think for predictive maintenance, it would not be such a high relative cost. Because you collect a big bunch of sensor data right.
MH: Yes.

IN5: And that hardware won't be too expensive. For predictive maintenance the most money will go to the algorithm which will gives you an indication if you need maintenance or not. And I think that is a lot of work, which will cost a lot for one use-case. But, I think the roll-out is adaptable and manageable. So it would be fairly cheap. So I don't think the hardware of the infrastructure would be the problem for it. The main problems would be in the software, the algorithms, at least for predictive maintenance. Again, for autonomous driving, you would need quite sophisticated software, but also a big redundant infrastructure of hardware, so there it would be the other way around I would say.
MH: Yes, I could imagine. And also because it has a huge scale, you will need enormous management and orchestration systems, which are hard and expensive to implement I guess.
IN5: Yes.
MH: Okey, clear. Let's go to the 5th box then. So, another thing, when a service provider is looking at which IoT applications they should target, an important thing is the whole ecosystem of the IoT application. So the companies whom are involved in delivering that IoT application. So autonomous driving would be an easy example, here it would be Waymo, Uber, Daimler, BMW, etc. All companies that are involved in that. And what is important is three factors, the productivity, robustness and diversity. The specific factors at the left might be a bit to perspective, so you can forget them for now, but they can help in explaining what the more general factors mean. So the first one is important, because there should not be one player who has the power, but a variety of players which are contributing and have different contributions. On the other hand, the ecosystem should be productive as in that the companies are profitable, and they are growing. So for instance they have a good return of investment. And, on the other hand, it is also important that the whole ecosystem is robust. So that means that the companies should not go bankrupt any moment, but what is also important, is that the companies will stay targeting the IoT application. Because, it could be that the companies their selves are productive, and there is a huge array of companies involved in it, but it is only a small part of their branch, and so they might stop with focusing on the IoT application, and focus only on their core system then. And those three measures make up your IoT ecosystem's health. And that might be important for selecting where you want to focus on implementing your edge infrastructures or now. How do you feel about that?
IN5: You are very right. Especially with regard to what you call diversity, which we call the depth of an ecosystem. The more variety of partners you have in an ecosystem, of providers, players, consortia's or whatsoever, create value to an ecosystem. I think that is definitely key, because in the end you can see it with Apple vs. Android, or the other big ecosystem wars, that have been fought around standards. I mean, that is key, of course. It is where the battle takes place. So, yes, the diversity of the ecosystem is very important for the ecosystem health.
MH: Yes. Would there also be other factors that might be relevant?
IN5: Yes, robustness. You mentioned companies going bankrupt. Of course for edge computing you want trusted partners, a company that will still be around in 15 years would be perfect of course, but it is not so important for that one company which has the service contract, if what they offer is absolutely standardized. Again in industry, the industry sector is very standardized. So, if one company goes bankrupt, then another integration provider, or another company which is creating for instance industrial PCs, it can take over. As long as everything is standardized, it should be fine. So, I think robustness is very important, but not on the level of one company, or the trustworthiness or creditworthiness of that one partner, but it is more on the standardization or dependency on one player in that ecosystem. Because, if everyone speaks the same language, it doesn't matter of one of them stops speaking. Do you understand what I mean?
MH: Yes I do. So it is not about the robustness of one firm, but about the whole ecosystem and how it interacts together.
IN5: Exactly. Because, the ecosystem is more than just the sum of its parts. And this is exactly what we can see. Because, the robustness is important, but it does not come from one or two players, but it comes from the IoT and how the players can interact in the ecosystem.
MH: I can imagine. And, if you are looking at those three factors for predictive maintenance in general, the ecosystem around it. Is it diverse, productive and robust?
IN5: For predictive maintenance, productivity is the key. Because, on the left boxes it says return on assets, and total asset growth, or let's say OII, if you know what that is.
MH: Yes.
IN5: This is of course why you have predictive maintenance. So, predictive maintenance is something to increase your productivity. So I would say it is very important. Does that answer your question?
MH: In rough lines yes. So I see we are running a bit out of time. Which means we have to hurry up for a bit if we want to make it in time. Because I definitely need to go through the 10th part, because I will do the ranking there. So let's go to the sixth part. Still from the provider perspective. So you have a certain financial risk, when you are developing competencies in a certain area. So on the one hand, if you ecosystem is not healthy, you might have a bigger financial risk. On the other hand, if your IoT application is not mature yet, you have a lot of unknowns, which might increase your financial risk. And then lastly, the bigger scale you have to implement your architecture, the higher your initial investment, which also leads to a higher financial risk. How do you feel about these factors?
IN5: All of what you say is correct. All of that leads to higher financial risk, and I think this is what is holding up current big industry players into going into the edge. They don't see the value, or they think the risk is too high for that value gain. And maybe, they don't see the big picture yet.
MH: Might there also be other drivers for risk, for the industry players?
IN5: I would again say that they create predictive maintenance for their production lines at the moment. But, it is all in a prove of concept environment. And what is holding them back, for going into their productive lines. And, again then, the opportunity costs can be high. What happens if that thing fails, and let's say, predictive maintenance has a false positive. And it shuts down wrongly. This could cost a lot. So it is the opportunity costs. Which are related to the lack of standards, and because it is still not there yet.
MH: I guess this is really related to the prematurity of predictive maintenance.
IN5: Exactly.
MH: And we already discussed a bit about the geographical coverage, and the ecosystem itself is kind off robust. So it is mainly about the maturity right, for predictive maintenance.
IN5: Exactly. That is definitely true.
MH: Clear.
IN5: That matches with question five, productivity.
MH: Yes. Let's go to the next one, seven, on the right top it is. So, before we talked a bit about viability, so do we want to do it? Is there indeed enough value for the network of companies, and the customers of course. And the other thing we have to look at is,

can we do it? And we can look at three main things. Box 7, 8 and 9. Which is the technical complexity, the organizational complexity and financial complexity. And if we look at the financial complexity. It is different from the financial risk. This one is about, do you have the resource, and can you get the resources. So, for the provider there might be two problems. On the one hand, the needed initial investment might be too high. So you are not able to get the resources for your department, or can't convince the managers to give to resources. On the other hand, your financial complexity might decrease if you have some kind of co-investment infrastructure with your customers. For that they of course need some resource, but they also need to want to provide it for you. How do you feel about these factors?
IN5: Again I think, especially in the realm of predictive maintenance, the solutions are not scalable. And therefore they are too expensive, because every solution has to be tailored. And therefore they don't see the scalable benefit. And therefore the initial investment is too high.
MH: Sounds good.
IN5: Sources of IoT partners….
MH: Yes, exactly, the second one, the co-investment, where you would co-own and co-invest with your clients. Is that something that is usual?
IN5: Co-owning the infrastructure, or what do you mean?
MH: So, there can be two models. One is that company XX would for instance implement the edge architecture and then owns it. But, on the other hand it can also be co-owned by the client. Or maybe even fully owned by the client. How does that usually go in your industry? For predictive maintenance.
IN5: So, what we are aiming for is that the client owns the hardware, but he pays per use for the predictive maintenance on the edge. Or pays per report. And all these digital business models definitely creates the smart and best for them, they only pay for what they use. Especially regarding the CAPEX vs. OPEX. It is what the companies want. But, at the moment, even for that, because the development is still very expensive, were we need very expensive data scientists, and the data collection takes quite some while. So what we see is that the breakeven will be far in the future. And only tailored to one specific use-case. So, I would say that the initial investment for something which is not scalable, with pay for use, is too high.
MH: Sounds good. And do you think there might be other factors impacting the financial complexity?
IN5: Yes, I think that they are not sure if they need that. The edge computing. Up to even today, many of let's say the car manufacturers are rarely using the cloud for their production right. Of course they use it for some parts, but not for the manufacturing. They think that maybe it is not something you have to tap into. Like I said earlier, predictive maintenance is something cool, but especially the quality assuring, statistical calculations will give you 99.99% of the quality in the production, and a newer network is good if it enhance it. Therefore, it is important to look at if it adds value for the industry. For a train for instance, it could be very good to have predictive maintenance. But for a machine that costs me 30K to substitute, I don't need a 20K algorithm to tell me three weeks before. I just buy two of them and stock, and change it. You know what I mean? It depends on the value that you gain. And some of the industries believe they don't see the benefit of it. And they think they can set it out.
MH: Sounds reasonable. Let's quickly do factor 8 and 9, and then we can go to the last part. So the technical complexity, I mainly found that there are three factors. And again, let's restate the geographical coverage more into the scale of the implementation. Furthermore, another important one, which can complexify the whole system, is the heterogeneity of the devices and the services. So for instance if you have all kinds of services and devices, with all kinds of requirements, it might get very complex. And lastly, very important, is the standardized. If everything is fairly standardized it might be easy. But otherwise it might get very hard.
IN5: I definitely think that the standardization is the main driver. Because the heterogeneity of the devices should not matter if they deliver and send data on the same standards and the same frequencies, the same quality, it is structured data. And then the heterogenicity does not matter if the standard is there. So I would say it is the main driver. So for predictive maintenance, there still is some kind of blue ocean. There is only a few players and a few ecosystems. And the standards battles have not been won yet. So there is still a lot of pushing and pulling. And only if this is done, the heterogeneity of devices will not matter anymore.
MH: Clear. And also you're not the first one that it is mainly about the standards, so it sounds familiar that in that case the heterogeneity wouldn't matter. Would there be other things that could increase the complexity?
IN5: Yes, especially when we consider the predictive maintenance, it is the missing knowledge in the workforce. We talk about completely new ways where you containerize your software, it is new. You can't expect your current workforce to change and adapt right away. So that definitely feeds on your technical complexity. Because the assumption that you hire someone with a lot of experience and post doc experience, is not true. It is hard to hire those.
MH: That's true. I think it very well suits at the 9th box tho. Where it might even be covered for a bit in the prior experience in market segment. So what is their current experience in IT etc. And it might be worth mentioning in a standalone system what their workforce capabilities are. So it is more an organizational complexity right?
IN5: Yes.
MH: And I think it might be a good bridge to the 9th one. So, what could complexify it organizationally, is the amount of partners you have to work with. SO is it one company you have to work with, or is it going to be a lot of stakeholder management? Because then it could become really hard.
IN5: in the terms of edge ecosystems, I don't think that the amount of partners matters too much. Because there are usually only 1 or 2 providers with the best ranking. So there might be a big network of partners. But every set of partners, in the creation of hardware and software, have their own niche. And, in the ecosystem even though there might be many external partners providing hardware, with the use-case you have, you only go to these one or two. So, in the end, because it is very specified, it is not easy business, it is very differentiated, and usually in an ecosystem, only the ones that create a niche win. So, I don't think that it will be a problem for long.
MH: Okey. Then I would suggest we go to the 10th part, which is about the ranking.

A.7.6 Interview 6 – Consultant

Interviewee 6 = IN6
Michiel Huisman (Interviewer) = MH

MH: did you have the time to look at the model already?
IN6: Yes, I did briefly look at it. One remark, it is fairly difficult to read, because of the size. So that would be the first comment I have.
MH: That's true. Do you have the model also in front of you right now?
IN6: Yes, I have it printed, in the hope it will be better readable, but it is still small.
MH: Perfect. Well, I agree it is indeed a bit small, and I plan to change that for sure. But eventually I expect the model to change here and there, so I will do the layout after that. I'm aware that I have to make the text somewhat larger to make it more readable. So, let me explain briefly what the model is about, it is also a bit what we talked about last time. The aim is to identify the potential of an IoT application for edge computing. And like we discussed previous time, when we use the business model literature, we can look at two things in order to do that. On one hand, the business model viability, do we want to do it. So is there enough customer and network value. And on the other hand we have the business model feasibility, which is about can we actually do it. So, like you said, when we look at the model, it can be a bit of an information overload. So what I did, on the second page, I cut the model in 10 pieces. Do you see those 10 boxes?
IN6: Yes.
MH: So what I for now wanted to do with you is go through those 10 boxes, and ask you a few questions. For the first nine boxes I will ask you three main questions. First I will first give you an explanation, then afterwards, I will ask you, do you think these factors are relevant? And then the second question will be, are these factors relevant? And then lastly, I will ask you how the factors apply to the chosen use-case, which is predictive maintenance. So, are these factors relevant? Do they stagger the use of edge for predictive maintenance or boost it, etc. And for the last box, those are the boxes resulting from the earlier 9 boxes, I will ask you to rank them. But, we will dive into that later. So, before we dive into box 1, are there already some questions at this moment?
IN6: No, this sounds reasonable.
MH: Perfect, then I suggest we start at the first box. So, that is the factors impacting the relative/perceived quality of service, you could also say it is kind off like the value creating elements. So an IoT application has certain service requirements, we can see it at the left top of the box. And there can be a match or no match with the chosen architecture. And depending on that match, we can go for edge or no edge. So, what I did, was draft from literature, 8 service requirements. That's from latency requirements to the energy constraints of IoT devices. Those 8 requirements can help you guide whether to go for the edge or not, for customer perspective. So, do you think those 8 factors, could all be relevant in the choice to go for edge vs. cloud, or may some not be relevant?
IN6: Yes, they are. But, there seems one thing that seems to be a bit underscored is the connectivity. As you mention it there, the IoT connectivity reliability. But if there is no connectivity, there is no IoT there. And actually all of the concerns listed there, they all have their own connectivity aspects. So, considering latency, energy, amount of data, etc. etc. all of those should have two phases. One is the edge itself, it's whatever you deploy on the edge, which in our current model contains the whole architecture on the edge. So, that is one aspect. And the other should pertain only for the connectivity. That's what I would do because, in IoT you have limited control over connectivity. Because it is sort off an external aspect to the core solution, and there is no choice essentially. You cannot built a complete infrastructure in most case. So, then in those cases, all these concerns should be addressed through the connectivity aspect.
MH: That's actually quite different from what I drafted from literature. So, in that sense it is something I should look into. Because, what I found is that, an edge architecture could enhance the connectivity and the reliability of the connectivity. Because, you are arranging everything locally, so you can mask if connection with the cloud is lost…..
IN6: that's true, you can buffer etc. But, whatever you deploy on the edge, remember this is bridging your actual sensors, devices, databases, etc. with the cloud. And this can compensate for shortcomings of the connectivity, but, if you look at latency, raw amount of data, privacy, etc. the connectivity that you apply to your solution is usually external and you have to validate if it actually confirm if it applies to your edge environment and your cloud environment.
MH: So you would say it is not a service requirement, but loose from it. So, how about the other factors, do you think these could be valid in your choice of edge versus cloud.
IN6: They are, and also I would actually add maybe another factor which seems to be missing. This would be the actual computing capability. And here I would consider it in all directions that it is into the scalability direction right, vertical, horizontal etc. Because, this will definitely be an aspect in the future of the edge. Because, things are changing, and this can actually change the core architecture, or like reference architecture of any IoT solution.
MH: Do you think that for instance that an edge solution would be less scalable than a cloud offering?
IN6: Not necessarily. Because, when you look up latency for example, currently we are in the stage that IoT consists mainly of choice. The main challenges change over time right. And connectivity is one of the important aspects that changes drastically the OT specifics. So, if you convert OT into IoT solutions, probably the largest challenge is the connectivity, and the main challenge to connectivity is the latency. And of course the volume of data. And considering what the 5th generation was supposed to be, in terms of the cellular networks, which was the mash networks, was completely reverted by the vendors into latency and velocity of data. Which is actually not what it was originally, but it was a side effect of it. So then, there will still be a lot of back and forth before this can be considered a commodity. So obviously edge can compensate this edge already, but the main way to be compensated is through scaling the computing power.
MH: Okey, interesting, I will definitely take a look at it. Let's see, some remarks I also got, regarding the context awareness, that it is actually more or less related to the raw amount of data. So if you would have an edge and cloud combined solution, you could process way more data, because you don't have to send everything to the cloud anymore……
IN6: Yes, the general tendency is actually, if you look up the large cloud environment, they are actually very similar to edge ones. Just look at Facebook or Google, they use the same lightweight process as the cloud. So, you see the symmetry there, and that's what's going to happen. I think that the future is in the portable runtime.
MH: Okey. And for instance, would you also say edge could enhance the privacy and thus diminish the problems on this behalf. And the same with security. And how do you see these relations

IN6: So with IoT you have to keep the balance, because the main challenge with regards the privacy and security is different than typical IT systems. That's because in IoT we often have contextless data. And some people use meta-data is the word, I don't like it, I think it is content, so it explains better what we talk about. But, what happens is that the system by itself, and what we are trying to do in our solutions, is data driven security. Which is basically, applying proper measures to the risks associated with the data. For instance, if you look time serious data, it has no impact on the privacy or security, if it is not put into the context. The thing though is, the context less data can be send into the open. Who cares what is the thermostat sensor in my home at a particular time. If you just collect the temperature, you have nothing. But if you know where it is located, and you know the owner of the house, this is the context. Then, it is a completely different situation.
MH: Yes
IN6: Give me a second, I get called, let me check if it is an emergency. Sorry, I'm back, had to check it, but it is no emergency.
MH: Aah, good.
IN6: So, for now the parts I see the best fitting purpose is this data driven security, but that may change. But, a problem to be addressed is to look at the context, so how are we protecting the context, and what this data would mean. And for instance with the use of AI, something that seems meaningless can suddenly become meaningful. But still, it has got to be reasonable. Because, the cost of securing data and edge can be pretty high.
MH: I can imagine. And you already mentioned another factor, but do you think there are more factors that are missing?
IN6: In the future?
MH: I mean from the service requirements. I listed the 8th, you already mentioned a 9th one.
IN6: I think otherwise they are okey. So, you have to context awareness, of which I hope it means the same thing I am talking about.
MH: It does.
IN6: Perfect.
MH: Okey. And have you heard about the concept of serverless?
IN6: Yes, I have.
MH: I could explain for a bit what I found maybe. So, serverless is very related to the concept as function as a Service, where actually your machines itself……..
IN6: I understand the concept, so it's fine. But, what I want to say is, that it is not new. For instance if you look at JBM, it is a good example, it is like a simple example of this kind of technology right.
MH: Okey, but do you think that by for instance having an edge architecture, you could make better use of this concept of serverless, and thus adding value, instead of having just a cloud architecture. Or, do you see no difference there?
IN6: I do see a difference. Because, what we are looking at is where the future lies. To freely export the code to the cloud, the edge and on prem. And we are already pretty near that, but the only thing is that, we don't have an IoT platform that would do it freely. I know only one company that is working on it, and that is close. And maybe Microsoft has it in the R&D stages as well, but this is basically where we are heading. I think overall that, especially in industrial solutions, we will be looking into this direction. And customer probably less. But, on the other hand, if you look at something like android, it is actually going into this direction.
MH: And, could this added value of serverless one of the reasons to go for an edge infrastructure instead of cloud?
IN6: It will definitely accelerate the progress. The edge is still, I think for quite a while, the edge will be driven by the physical capabilities. So, this is kind off secondary, but it will become a feature. The only thing though is that this requires a solid backend architecture, and this is the concept of platform of platforms that I am promoting within EY. Which is basically, providing a layer of unification between any edge so to speak. And part of this concept is actually the reinforcement of the API and the reinforcement of edge capabilities. And I think it would be valuable to have this in order to boost the edge.
MH: Okey, good. So, for now the last question of box one. Which of these factors would play an role to go for an edge infrastructure for predictive maintenance? Which factors would be most important?
IN6: I think all of them should be considered in any IoT solution, there is not really a way around it. So, at least it should be addressed in some kind of architectural framework or architectural concerns for the edge. So, I would say all of them. And in terms of predictive maintenance, I guess here actually the computing capability becomes a factor. Why? In our examples of applying the predictive maintenance, one of the elements that is of potentially large business value, is what you do with the information. So, it is not only that you order new parts, and schedule proper maintenance cycles in anticipation of breakage. But, also how you execute it. So, meaning that download, or reduce the load on parts that are expected to fail. Or, you support the team on-site in actual fixing of the device. Or, you make the device self-fixing. And this is actually taking a lot of computing power. For instance through AR or sophisticated algorithms for reacting to the state of the device, where it can balance it load for example in a better way, in order to reduce the wear. This would be best done on the edge. So that would be the missing part on the edge, the capability to run it on the edge as well.
MH: Okey. Let's go to the second box then. This is also from the consumer's perspective. So, the consumer already has an architecture. For instance he has a cloud infrastructure, or proprietary datacenters. And you want to switch to the edge. There is some switching costs related to it. One of them is possibility of integration. Let's say I have a current cloud system in place. I need edge for my IoT application. Then I want them to be integrated together right, that would reduce the switching costs. And on the other hand it is the easiness of platform openness, so are there libraries, standards, etc. on which I can develop. And the most extreme form would of course be an opensource platform. Also, what's not in here yet, but what I need to include, is mainly the initial investment for the customer itself. That's of course also a switching cost he has to make. So, how do you think about these factors? Might these be relevant in the decision to go to an edge?
IN6: What you just said popped out to me, that is the maintenance and operation costs. Because, when you look at distributed infrastructure, it is of course harder to maintain and operate. So, not only is there an additional cost of deployment. But, as you may remember, the requirements on which you apply the edge is different than when you it on a data center. Because, your mini-data centers which you have on site needs cooling, physical protection, energy, etc. right. So cost of deployment is one thing, and cost to maintain is another one for sure.
MH: I can imagine. And how do you think the other factors are relevant?
IN6: Yes they are, but what I would do here, is actually apply all the science around data centers here. So your data centers might be more exposed, and their requirements might be higher, but they are actually the same. Because eventually you just have your computing power at the edge. And so, there will be situations, and there are, so for instance in aviation. My interest lies in aviation that's why, because I am a pilot as well. So, in aviation, you will practically have the concerns of a high availability data center that is actually moving right.

MH: Yes.
IN6: Because that is how the aircraft instrumentation works, and one of the problems is highlighting this fact. So, which the progression of edge capabilities, this is the concern. So, your air plane is actually a flying datacenter.
MH: I can imagine.
IN6: To make a shortcut for you, if you essentially put all the datacenter concerns in a scope here, that is what will be a factor in the cost as well.
MH: That's true, but it will be more for the provider I guess, we will come at that later.
IN6: Okey.
MH: And if we look at predictive maintenance, which of these things would be problematic when a customer wants an edge infrastructure for predictive maintenance?
IN6: It is exactly what I just mentioned. If the predictive maintenance moves ahead, and is very well embedded, for instance in aviation. For instance when it looks-up the engine etc. Just look-up the A380, it has some 10.000 sensors. It's almost like a flying factory right. And in an engine might already be like 1.500 sensors. So, all of the concerns I just mentioned, are actually present right there, and this is important. So obviously, this is a good example because maintenance in aviation is key. If you want a good example where cost of maintenance is paramount, this is aviation. So, looking at this example is absolutely highlighting what we were talking about.
MH: Okey.
IN6: I would also change the name of switching, because to me it is confusing a bit, because I look at it from the network perspective. So, I would say maybe migration costs.
MH: Migration costs. That might be a more focused definition. The switching cost definition is from literature of platforms. It might be a bit more vague, and migration costs might be more focused. I will look at this.
IN6: And to give you just some example how again the computing power place in this is that important. Actually, we run the maintenance program for Air-France, and this is an IoT project. And, because of the large number of sensors. Not all data can be send through the satellite. Because it is too much data to send back, and the speed of data transfer is comparable to 90s or 80s data. So, what they do is, they buffer all the data from the slides on the aircraft. And whenever it comes into the range of WiFi or land network. Only then the data gets transferred from the aircraft to the main system. What it implies is that you not only need higher reliability computing power, which is the data center on the edge. But, also the data storage as well as a proper logic to manage all of this in a sensible way, and sort of reactively address connectivity issues.
MH: Okey, clear, good. I suggest we go to the third factor then. So, now we are switching from perspective. First, we looked from a customer perspective, now we will go towards the provider perspective. Which good be a Google, Microsoft, Siemens, which of course also have some edge solution. So, when you are targeting an IoT application, you need a suitable customer base, which will eventually also be your customer base. Because, you could be delivering a service. Or, you would only supply the network, but then still you are developing competencies and you want to copy the process and competencies to other clients as well. Lust like company XX is doing with their consulting practices. So, you need a substantial customer base. And, you can actually look at three kinds of variable, which I identified. So, the first one is the actual installed base of the IoT application, so how big is it currently. Is there a huge range of IoT devices that might make use of the edge infrastructure? Then the second one, what is the potential? So for instance if we look at autonomous vehicles, currently it is very small, but in the future it might become very big. And then lastly, what is the percentage of data we want to push to the edge, because, of course there are still some benefits at the cloud. So those are the factors I identified. How do you feel about them? Are they all relevant?
IN6: Okey, so if I correctly understand this box… the revenue sources and customer base are connected in a different way in IoT. They are not directly connected.
MH: Okey?
IN6: If you look on your Iphone for instance. It collects so much data, of which you are not even aware, and of which you are not benefitting, only Appel benefits. So, the same goes for a lot of free application, they are extremely sophisticated in terms of the service they provide, and they do it for free. Because, the data you provide in return is actually way more valuable. So, I don't know how you want to include this here.
MH: I agree that the IoT service itself might be free. But, the architecture they are using, which is currently for instance. Which can be a cloud infrastructure at this moment. Someone is making money out of it. If you talk about Microsoft azure. Then the IoT application uses that and pays Microsoft, they make money. And if we would make an Azure edge, it would be the same. But, in order for them to make enough money, you need enough devices to connect. Which in turn leads to a certain size of the edge.
IN6: That's completely correct. But, the example I was saying is that the entity is not providing the device, they provide the software. So, your cost is the development of the software, and not the development of the hardware. And the actual reality now is that we actually find more sensors than needed in most of the cases. Look at the industrial environment or the smart building environment, what usually happens is that, when we look at the as-ifs, there is no need to deploy many sensors. So typical scenario's that anywhere between 1 and 40% of the sensors are actually used or actively used. Only that percentage delivers useable information in the sense of current state. So, at least 60% of the sensors are not used. I wouldn't say they are useless, but they are not used. They may be used in the future, but currently they are not. And secondly, in a typical project, if we deploy additional sensors, it is three orders in magnitude smaller than the sensors that are already there. So if there are 3 sensors deployed already, we may deploy one more sensor. So, if you look at the edge itself, because sensors are cheap, and they are actually useful for vendors, usually the vendors provide the sensors, but they don't provide the data from them. Let's say you have a system, it already has hundreds of sensors in itself, that you don't you usually don't have access to. The data of the sensors is acceptable to the provider of the device, let's say Siemens, but not to you as the loaner of the device. Or a car is a very good example, let's say BMW. They only pass on 1% of the data. The remaining 99% is actually only readable by BMW. So you cannot really troubleshoot BMW in a generic garage. The same goes for your consumer device. Are you able to use all the sensors in your Iphone? Probably not right. Probably it's somewhat better with android, because it is a bit more open. But I am quite sure that for instance Huawei or Samsung can get more data from the device than the person who owns it. So, this is the situation, and if you then look up the customer base sources, and how you pop into those elements, those revenue sources, it is more complicated than just looking at data, size of the market, etc. It is more how you actually leverage the available infrastructure. So, that's why owning the platform is a big deal. That's why owning android, owning IoS, etc. is worth so much money.
MH: So, if you would have to say, which factor in short, should I add here in order to make it more relevant. In order to better describe which IoT applications I should target?

IN6: Platform ownership for sure, owning the platform. Platform openness, another thing, because you can own, but allow others to use it. Like android examples. And the ability to apply your own code with or without blessing from the owner.
MH: So to recap. It would be more about the value of platform ownership for that IoT application.
IN6: That's right.
MH: So what does it bring me to own a platform there.
IN6: The openness of the platform is another factor which his important. You can have an old platform, that is a commercial platform, that is open.
MH: But, if you are the platform owner, you can decide yourself to make it open yourself right.
IN6: Exactly. So, what I suspect is that someone might be developing a platform that is open, in order to grab the market from an Apple of Google.
MH: Okey. Well, what's your feeling about the customer base / size of the market for predictive maintenance?
IN6: So, I would say that revenue source might be a complex topic.
MH: Maybe we should talk more about the customer base and the value of the customers right.
IN6: I would say it is less of a customer base, and more about a data source spectrum.
MH: Yes, that's true. It is a more targeted definition. Because it is not about the customer, but about the device connected to it.
IN6: Exactly, because on that, they can build their application. And I would add analytical capabilities here.
MH: Analytical capabilities?
IN6: Yes, because they completely change how you monetize the data. So it is not only about the data you have, but also about what you can do with it. So with the use of AI you can e.g. retrieve way more value from the data as compared to working without AI.
MH: But how is that related to the edge? Can that enhance the comparable value of edge?
IN6: yes. For example if you have the phone that can recognize faces and correct the image that has value by itself. The computing power of a typical power is efficient to recognize objects by looking at them right.
MH: Okey. Let's continue for now. To the fourth one, because otherwise we will eventually run out of time. So, the fourth one, here it is stated quite a bit simplified. And I identified already another factor that should be there. So, it is about the relative cost of roll-out for the provider. So if I were to roll-out an edge infrastructure for instance, it may be way more expensive than a cloud architecture. So one of the things that could influence this is the scale / geographical coverage of roll-out. For instance if I were to roll-out an edge architecture for autonomous driving. Then I have to get coverage over the whole country. So at this enormous scale it might be very expensive. Whereas if I were to do it in a factory, or just a harbor, it might be more manageable. The other side is very much related to the complexity related to it, but I haven't formally defined this yet, because I got it from another interview. SO, how do you feel about these factors impacting the relative cost of edge computing compared to cloud.
IN6: The factor you have here is relevant for sure. But one major factors, that is not impacting the cloud as much, but impacts the edge, is the environmental issues. It is the protection against the environment. So, for instance in aircrafts, anything moving. Or in industrial environments, like dust protection, temperature protection, sunlight, water, etc. right. All of this is less of a concern, because this is a commodity on the cloud, whereas on the edge it has to be reconsidered.
MH: So, it would also have to do with the location where your edge is located right.
IN6: absolutely, but at any location it plays a role..
MH: Okey, other factors?
IN6: So, you don't have a box for maintenance. Only for roll-out, but the maintenance, operation, etc. can be major. Because you have a different infrastructure, your maintenance is different and way more complex than your typical IT system.
MH: Does that also differ per IoT application that you are targeting?
IN6: Precisely.
MH: Sounds clear, I agree. So, which of these factors, also including the one you just mentioned, could be a big problem for driving up the cost for an edge architecture for predictive maintenance? Or do you see no problems here?
IN6: I would actually put it, I don't know. This framework would becoming hard to use if you do this though. But all those factors we are putting in, in factor one, will be impacting the cost. So what I would do is, look-up the cost vector in different dimensions. Like, for every concern that you have for the decision making in terms of the deployment, cost would be one of the aspects. I would address all of the concerns of the decision point, which is the feasibility kind of thing, and then another vector from that to cost. And I would apply all the concerns against the cost as well.
MH: Can imagine that. But, this might be a bit to far for now. Because, I am doing the first step here, and if we want mathematical vectors, it is going to be more difficult, it could be next steps.
IN6: Maybe you could do it if you arrange it in another way.
MH: Okey, I will take a look at it. So, if you are looking at predictive maintenance, what would be the biggest problem driving up the relative cost?
IN6: So, for roll-out it would be integration actually, that's another one you are missing here actually.
MH: Okey, so the difficulty of integration.
IN6: Well, integration as a challenge.
MH: I would say that suits better at feasibility, we come there later. It is related to standards I would say.
IN6: Okey.
MH: So, let's go to the fifth one, we will stay in the provider's perspective. When you are going to target an IoT application, also related to what is your customer base. It is important that there is a whole healthy ecosystem surrounding that IoT application. And I am talking about companies providing the IoT application. So for instance if we are talking about autonomous driving we are talking about Uber, Waymoo, Daimler, etc. And what is important is that the ecosystem is healthy. And you can measure it by means of 3 main variables. Lease don't look at the most left ones, those are to specific, but it helps in explaining the other variables. First, there should be a diverse range of players. SO there should be multiple players, they should complement each other, etc. On the other hand, the players should be productive. They should make some profit, the ecosystem should be growing, etc. And then lastly is the robustness. So first of all, do the players have sufficient liquidity, of course they should not go bankrupt or anything. But, also are they likely to stay in the ecosystem, or might they put off this branch out of their company. So it is also about the centrality of the business to them. And, if those requirements are met, you have an healthy IoT system.
IN6: I see something important missing I think. I don't know how you would call it, but I would call it exposure. What it is, is when you look at a self-driving car right, all of the elements of a self-driving car can actually kill a person. So, it is not diversity, productivity or robustness, but something else. But more the risk or exposure that you are raising right. If your machine breaks,

and it is an aircraft or a car, and it breaks and you kill 300 people, then you have to account for that. And so, there should be measures that actually look-up the exposure of the system you are looking at.
MH: Exposure could be interesting, but I am not sure if it differs for edge versus cloud. Also, it is related to financial risk I would say instead of ecosystem health.
IN6: It is not just financial, I would put it in both. Let's say, there may be a lot of small factors that actually introduce a risk that was not present before. And, this risk is validated not by the value of the equipment, but the value of the environment that the equipment is in. So that's why I think it is a part of the ecosystem health, because I would want to trace, I would want to have a measure in a self-driving car, if the amount of sensors will have broken in the course of the action, it probably will allow it to drive still, but make a wrong decision in distinguishing between a bicycle and a person.
MH: But, do you think that if an application has higher exposure, like you just mentioned, do you think that would drive the decision towards the edge or stagger it?
IN6: I think it would drive. Look at the Boeings right. They have a sensors that is failing, but they have a system behind the sensor that does not react properly, and they have a pilot that is not trained properly to react it. So it is a chain of events. In that case they are lucky they can put blame on the pilot ultimately. You have to directly measure if the system itself is robust.
MH: Yes, but that is the system itself, not the ecosystem of companies.
IN6: But, if the system as a whole creates a situation where you are not safe, because of an error that is influencing several elements of the whole system, the result could be an outcome that puts person's life at risk.
MH: I guess it is an important thing to look at in general, for the IoT application, but not for the edge infrastructure.
IN6: Yes, but if you look at the environment and at how the IoT application works, it is important. So, I would put something that has more implicit value than the point that you mentioned here. So something like exposure, or human risk, or life risk.
MH: I will look at it. For now, let's go to the sixth one then. The financial risk. So there can actually be a couple of things driving your financial risk if you are going to roll-out an edge architecture, for the provider of course again. So for one, if the ecosystem is not robust, the companies working in that direction might retract from it, or go bankrupt, of course it might bring risk if you are betting big on there.
IN6: I would actually simplify it, and say that everything in the ecosystem health measures can be contributing to that.
MH: I have definitely thought about it. So there are also other things. If the application is not mature, we have many unknowns and it might be a more risky bet on that behalf, especially if you are betting big. And then of course it is about the scale and the geographical coverage as well. Let's say you are going to target autonomous vehicles which is quite immature.
IN6: That's right, but I would do it a bit differently, I would look at the ecosystem health as a component. And then look at the investment as a factor that feeds back into the improvement of ecosystem health. Because there are many things that can make the initial investment lower. So how the IoT usually works, because of the complexity, and also because practically any IoT solution has an AI aspect to it, so you don't actually know what is maturity stage, so to speak. Because, depending on the use-case, it may behave in a non-predictable way right. And, like the apple platform is a good example as well right, because you don't know what the people will be using your phones for right. So I might be getting a very unique set of data from the Iphone. So, this is where the system, and its use is not really predictable right.
MH: Okey. Let's go to the seventh one, because we don't have too much time yet. So let's leave this one for what it is for now. So, next to the financial risk, you also have the financial complexity. So, am I able to get the funding around? One of the important things is of course the initial investment. If I need to invest a whole bunch of money, it is very hard to get it from my department, or maybe my company in general does not have the financial resources. And on the other hand, maybe you can form some partnerships where you have a co-ownership or co-investment infrastructure, which might make the funding financially less complex.
IN6: What you say is true, but what I am missing here, and I don't know how you could integrate it in here, but this is basically how intelligent or how creative you are with the solution. I will give you an example; and this is only brain power, nothing else. It is basically innovation and a new way of thinking. So for instance, parking space management, you can buy a standard solution. To give an example of one of our clients, so XX managed the parking system by a parking solution of XX, which involved Gates, Video repeats, etc. etc. And such systems costs 10M dollar. Whereas, you can achieve exactly the same functions or functionalities using QR codes and company phones that employees already have. So you see the difference in initial investment right? You print the QR codes, put them on parking spaces and put them on the entry gate, and put an installation on your phone. And functionally speaking you have exactly the same outcome.
MH: I can imagine that it impacts the needed initial investment, but I guess this applies the same for the cloud. And aside from that, it is very hard to put those intangible factors in the model. I would think it is relevant to look at in general, but for this model I am not sure. Because, for the needed initial investment, you have to get it down right, but how far you can bring it down, by means of brain power, is very intangible.
IN6: I think this brain power can be a big factor here. Because, in the world of IoT, it is really the way you think about it. For example, what your platform allows, or is there a platform available already. And then your investment already drops down by an order of magnitude. And the examples that I gave you, and the decision on the platform or the knowledge, is the brain power, that is what I would put as factors impacting the financial complexity. The actual brain power and how it is applied in the solutioning.
MH: Okey. Let's go to the 8th factor, the technical complexity. So I identified three main topics. Which can make it technically very complex, and actually the second and the third one are very related, so I have to change that later. But, I think one major problem could be the lack of standards. If you have many standards and you can built upon those, it gets a whole bunch easier. If you don't have that, it might get very hard, and maybe it is not the application you should target at this moment, because it can get very complex. The other side is the scale of the implementation, if you look at massive scales, you have huge management and overhead and orchestration issues you might have to take care of. A good example is autonomous vehicles.
IN6: Definitely true. Also integration would be a big factor here. And the geographical should include the environmental what we just talked about as well. Because it also is related to technical complexity. And it should also include the connectivity.
MH: And if that were to be the case, would the major factors then be covered? Because, of course I don't need the full list, but the major ones should be there.
IN6: Yes, I guess so.
MH: Yes, because it does not have to be comprehensive, or encompassing everything. Just as long as it describes the main factors, it is good.
IN6: I think it does.

MH: Good. Let's go to the 9th one, the last one we do before the ranking. It is more about organizational complexity. So, for instance I am a provider. I am going to roll-out the edge architecture. One factor that could affect it is the amount of external partners, or parties with whom I have to work together. Let's say I have to work together with one or two partners, it should be easy. If it is going to be 10, you know, it is going to be a huge web of stakeholder management, and it might get very complex. And on the other hand it is also a bit about, what is their experience in the It. Have they already done some projects in it. Do they already have some cloud infrastructure, it might get it a whole bunch easier. Otherwise they might have to get whole new competencies, which makes it way more complex.
IN6: I agree, but one thing. You use the qualifier of external, and this I would not do it. So, I would actually say the number of stakeholders, that's it. Because in IoT solutions, whoever was just an external partner, can become a stakeholder because he has access to the data, because he can make money out of it. To give you an example. If you allow your cell operator to work with your data, then they instead of provider of a simple service, which is basically not even a partner, it is a vendor, they become a stakeholder. Because, they have business on your data. So, I would change it to stakeholders. And the other thing that occurs very often here is the cultural challenges.
MH: Okey.
IN6: So when you for instance expand your enterprise architecture to IoT, it is becoming way more complex than only the enterprise architecture which is marrying business with IT, and now we have to marriage it with OT as well. And it is a very different world. And the cultures of those worlds might be very different. If we have the operator of a system, and let's say a PLC programmer, or also a driver of a heavily instrumented vehicle, then, it is a completely different culture, because people's life depend on their action. Not many programmers think about other's people's lives being affected when they put in life's of code. So it is about how the culture has to be accounted in your organizational complexity.
MH: I will take a look at it. Good. Then I suggest we go to the ranking, the 10th part.

A.7.7 Interview 7 – Consultant

Interviewee 7 = IN7
Michiel Huisman (Interviewer) = MH

MH: Then I will put the recorder on now.
IN7: Okey.
MH: So, did you have the time to take a look at the documents I send to you?
IN7: I did, I just read through a bit.
MH: Perfect, 10-15 minutes is fine, just to get a bit a feeling for it. So, do you have the document with the conceptual in front of you now?
IN7: I do, but do you want to share your screen, so that we have the same documents we are looking at?
MH: Ah yes, that's a good idea. Did I share it now?
IN7: Not yet, sometimes it takes a minute. I see it now.
MH: So, I can imagine when you first see the model, it's quite a lot of variables. But the first page, which we are now looking at, is to get a sense about what the complete model is about. So, as input we have an IoT use-case, which has specifications. So, an IoT use-case has service requirements, a market segment, etc. On the other hand, we have a choice of technology, which is edge computing vs cloud computing. And based on the fit of this technology architecture, and the IoT use-case, we go through the model, and we end-up with some indication about what may be the potential of the IoT application for edge computing. So that's the general idea.
IN7: And would you say that your architecture only applies to IoT applications that have potential for the edge, or may it also apply to other applications?
MH: I think it may also apply to other applications, but I specifically chose the scope of IoT in order to make it more focused and manageable. So, I can't argue it works for other applications, but generically speaking it should.
IN7: Okey.
MH: Let's see, so in order to make it a bit more manageable, what I did on the second page, is cut it up in 10 boxes. And the first nine boxes all contain the specific IoT case variables, here on the left side. And on the right side, it leads to a generic variable. And then the tenth box lists the nine variables. So, what I actually want to do for this interview, is go through these 10 boxes one by one. For the first nine boxes it will be mainly three kinds of questions. The first ones will be; do you think these variables are indeed relevant. The second kinds of questions will be about; do you think there are other variables that I did not include but that are of relevance? And then thirdly, I will ask you about how these variables interact for the chosen application, which is predictive maintenance in industry application. So, what may be important, what is not important, what staggers development and what drives development, etc. And then for the tenth box, I want to rank the relative importance of these nine factors, by means of the best-worst method. But, we will come to that later. Is that clear?
IN7: Yes, so I was looking to this quite a bit. So, where would the computations happen? I don't understand the flow how you get to an answer, because I don't see some IF this THEN. So I am not understanding how you get to an end result.
MH: That's true, there is no computation. Especially at this stage of research it is quite hard to get a hard answer. So, what I actually aim to do is rank the relative importance of these generic variables, in order to give an indication in the end answer. So, if you know that the contextual factors, which drive or stagger the generic variables, do not sufficiently meet the requirements, and the generic factor is very important, then eventually, there might not be a high-potential application. So, it is going to be more like an indication, and a way of structuring your thoughts, than a hard answer in the end.
IN7: Okey.
MH: Also, looking at the current stage of research, there was not a model I could built upon. So it is more about drafting hypothesis, and giving some kind of indication about the answer, that would already contribute in scientific literature.
IN7: Clear.
MH: Good, are there any other questions you have already?
IN7: Just about the individual ten things, but I guess we will come at that.
MH: Yes. So, the first box is mainly about the relative / perceived quality of service. Or you could also see it as the value creating elements. And what you see here, at the left top of the box, is nine kinds of service requirements an application can have, which can drive the choice for an edge infrastructure instead of a cloud infrastructure. So, it is from latency requirements till energy constraints of IoT devices.
IN7: SO how would the energy requirements of devices their selves have any influence on the choice of edge.
MH: What I found is that the choice for an edge architecture could reduce the energy consumption by the device by as much as 40%. So, if you would have a sensor which runs on a battery, which is energy constrained, you could facilitate this by means of an edge infrastructure, and let it consume less energy. That is what I found in literature, but I am interested in your experience as well of course.
IN7: I don't know, I never considered this. Usually you don't do any computations on the IoT itself, but maybe by having the edge server on side, you could make the IoT device even more passive, it is definitely possible.
MH: Yes, but also, if you would send the data to the edge server instead of the cloud server, it would consume less energy on the device itself. Or at least, that is what I found in one or two articles.
IN7: If that's true, it is possibly enough to have an edge server.
MH: Really?
IN7: That would reduce the maintenance cost so much, changing batteries, tens of thousands on the side, reducing that cost, just imagine how much man hours that is. So if that is true, and you could justify that, it would be the most important thing, and you don't have to go further.
MH: Oh wauw, well if you stress it is that important, but you have never heard about it, I might check this again. It is not stated as one of the main benefits, but in some articles they describe it will reduce the energy consumptions.
IN7: So, if it will cut down the workforce on maintenance, it will be huge. I think the main thing would be the security. Because, what I heard is that security is the main reason not to go to the cloud.
MH: So you indeed think that an edge architecture could enhance the security?
IN7: Yes.
MH: And how about the other factors. Do you think all of them might be relevant in someone's consideration to go to the edge?

IN7: What do you see as the difference between privacy and security?
MH: So privacy is mainly related to… If I have privacy sensitive data, and I want to filter the privacy sensitive data before I send it to the cloud. And security is mainly related to malicious intentions of other parties.
IN7: I see them as the same thing.
MH: You see them as the same thing?
IN7: Yes.
MH: It could be an idea to mention them in the same box, because there is definitely some relation.
IN7: Because if you are worried about, a camera taking a picture, that doesn't matter if it is going to be in the cloud or in an edge server. But, if you are worried about the data that is going to be recorded, that is security right?
MH: Yes, so you secure your privacy sensitive data.
IN7: That's right.
MH: I can imagine, good remark, I will take a look at that.
IN7: Yes, the other ones are…. So context awareness, how would that change if you would go in the cloud or in the edge?
MH: Actually, what some other interviewee said, is that it is very related to the raw amount of data that you might be able to process. Because you have an edge architecture, you might be able to process more data, and thus include the contextual data, and thereby include the concept of context awareness.
IN7: maybe, or the other way around. Because you limit it, you may have less context. If you put it to the cloud, you could have more context, because you can compare sites.
MH: So, would you say that context awareness could play a role?
IN7: I think it could, but I don't think you can weight it the one way or the other.
MH: So, it is not a hard measure.
IN7: Right.
MH: Good. So, how about the mobility support?
IN7: Help me understand what you mean by that.
MH: It is mainly related to, if you have some kind of mobile device. Let's say an autonomous vehicle, which has to offload it's data. It can be supported by means of the edge, because you can have an edge computing node with the device that needs the computation power, which can still be reached when the cloud cannot be reached.
IN7: Okey. Could you say again what it is about, it is still not clear to me.
MH: So, the mobility support is about devices moving around. So it is mobile devices. And this can be supported by an edge architecture.
IN7: You mean outside a plant?
MH: Yes, or inside a plant.
IN7: Oke, because outside a plant you cannot do edge computing, unless you have some lightweight something. I don't really know entirely what support means there. How do you support this?
MH: Well, it would for instance be that, you have an edge infrastructure inside a port, and when the ships come inside there, you can perfectly track and trace them, what stuff is inside, where they are, but as soon as you get out of that harbor or the port, you lose the connectivity, so you don't have all the information anymore. So in that case the mobility of the ship is only supported in that range, but not outside. However …..
IN7: are you familiar with azure stack, and how they do that? So with azure stack there is a server on the ship, and then it is constantly working offline. And then when it gets to the port, it connects to another server, and it goes online and the data can sink.
MH: Exactly. So in that sense it supports mobility.
IN7: Still, I don't know…
MH: Okey, then let's leave it at that, I will take another look at it.
IN7: Sure.
MH: Would you have the feeling that there might be other variables in those service requirements that are not included, but might be important?
IN7: For the relative quality of service…
MH: Yeah or the value creating elements for the customer.
IN7: Can we get a high level view of the 10 of them, before I go into what is missing for this one? So we have quality of service… we have switching costs… what is switching costs?
MH: so, the first two are from the customer perspective, and the other ones are from the provider perspective. So we have the customer base, relative cost, ecosystem health, financial risk, financial complexity, technical complexity and organizational complexity, which are all from the provider perspective. And the first two, the relative QoS and the switching cost are impacting the value for the customer.
IN7: So, latency and I think the one you are missing is computation speed and storage. So, you have latency, which is just your speed to get to the server. But you also have the speed of the server, where the cloud is going to be way faster. And then you have the storage of the cloud, where you have infinite storage.
MH: That's a good one. But it would eventually also include you decision to only have an edge architecture or have a collaborative edge-cloud architecture I would say.
IN7: Uhu.
MH: Okey, so any other stuff I might be missing?
IN7: Maybe, If you are doing on site advanced analytics if you lose connectivity with the cloud, something like that, if you go offline, you may still be able to do some analytics at the edge server, but you can't do that on the cloud. But, I don't know how you can call that, because it is two thoughts in one.
MH: It also has to do with the connectivity right?
IN7: Ah, you do have connectivity.
MH: It is also related to the ship example, you just mentioned. You could see the data center on the ship as an edge node, which can still do the computation until it connects with the network again.
IN7: Yes.
MH: Okey good. Then let's look at the box at the bottom. Are you familiar with the concept of serverless.
IN7: Tell me what you mean by it and we will see.

MH: Because, if you are not familiar with it, I would suggest we would skip it because it would take some time to explain.
IN7: We can skip it, that's fine
MH: Perfect. So, if you would look at these service requirements at the top again, which of these service requirements would apply for predictive maintenance? What would be important when you would be doing predictive maintenance in general? Would it be latency, the raw amount of data, or a couple of those?
IN7: I think they would all be important.
MH: All of them?
IN7: Yes, what wouldn't be important? Latency is probably the least, because you do predictive maintenance for the future, so it doesn't really matter how long it takes. Amount of data, could be a problem. Privacy, Yes. Security, yes. Context awareness, definitely. Mobility support, I'm not sure about that one. Connectivity is not that important because you can do that in advance. And energy constraints could be huge.
MH: Perfect.
IN7: The energy constraints of IoT device is for what you would actually do preventive maintenance right, changing batteries.
MH: Yes. And if you could make sure the battery life-time would be longer, it would be something.
IN7: Yes.
MH: By the way, if you are interested, I can send you the article which has indicated this
IN7: That would be interesting.
MH: Okey, I will send it afterwards. So, I think we can tick-off the first box now. And I suggest we go to the second one, which is mainly about switching costs for users. And with users I main the companies which have some IoT application. And what I found from literature is that there are two kinds of switching costs. On the one hand it is the possibility of system integration with what they currently have. So maybe they have a cloud infrastructure or they have some data, and they may want to integrate it with what they currently have. And on the other hand it would be the easiness of platform openness. SO it would be related to standards, libraries, on which they could continue to develop. And that would also decrease their switching cost towards an edge infrastructure. So how do you feel about these factors?
IN7: So you are switching from what?
MH: It could either be from the cloud, or their proprietary data centers or from nothing of course.
IN7: I'm trying to understand the scenario. So, if they already have a cloud, what is the investment to switch towards an edge? And if they have an edge, what is the investment for switching to a cloud?
MH: It is about switching towards the edge from whatever users currently have.
IN7: Okey, you should change the header in order to make that more clear.
MH: Okey.
IN7: Possibility of system integration with previous offering, so with that you mean, how difficult is it to integrate, or how easy can you leverage what they have been using before?
MH: Mainly how difficult it would be to integrate it, so the first thing you mentioned.
IN7: And easiness for platform openness… I don't know what that means.
MH: Yes, platform openness is mainly related to… that you are developing on for instance open standards, open libraries, all those kinds of things, which would enhance the platform value and thus enhance how easily it gets adopted by users. Does that make it a bit more clear?
IN7: ….
MH: What some other interviewees indicated is that it is also a bit related to the top one. Because, if your platform is more open, it is easier to integrate it with the previous offering.
IN7: I think there are two things you could look at. The ease of switching towards an edge platform. There is three actually. The labor cost of switching, and there is the financial cost of switching..
MH: So what would it cost me to switch to there.
IN7: So first you want to know how difficult is it to switch, then you want to know how much work it will take, and lastly you will look at how much that is going to cost you. Because those two you have there are the same to me.
MH: Sounds familiar, those two are maybe related. So okey, you say there are three things. SO, if you would be looking at rolling out edge infrastructures for predictive maintenance. If you look at the three things you just mentioned, what would be the biggest hurdle. Or do you not see big hurdles?
IN7: I think the first one would be the biggest one, so how difficult will it be to switch towards the edge.
MH: Okey, is it usually difficult for predictive maintenance to switch towards the edge? From your experience.
IN7: It depends.
MH: Haha of course.
IN7: It shouldn't be, I mean if they are in azure cloud and will switch to azure stack, it isn't difficult. But, if you are going to switch between platforms, it will become way more difficult.
MH: Good. Let's go to the third one. So, now we are switching from the customer perspective towards the provider perspective. And, a provider could for instance be a Microsoft with their Azure offering, or it could be, let's say a Siemens, which also aims to roll-out edge systems, and when they are looking at what kind of market do we want to target, there is a couple of things that determine the market size for the IoT application they may target. And actually we should start from the bottom of those three variables. So, first there is some kind of current installed base of the IoT application, so how big is right now the IoT application that might benefit from my solution? The other one is the size of the potential IoT market. If we look at autonomous vehicles, currently it is not very big, but let's say maybe in 10 years, the market size of autonomous vehicles may be enormous. And on the other hand we have to look at what is the percentage of data we want to push towards the edge vs. the cloud. Because, I think in many instances it will still be some kind of edge-cloud collaboration.
IN7: So, we are looking at factors impacting the customer base and revenue source?
MH: Yes, so you have a customer base, and as you are delivering a service, your customer base will of course also be your revenue source, because they will be the ones paying you.
IN7: I keep going back to the factories, but in factories it would be customers vs. one customers? You mean the whole factory, but not the individual people that are using the data?
MH: Well, what it mainly is, is if I am a provider, and I am going to target an IoT application, I will start building competencies and make sure that when we are talking about factories again, I will built competencies to implement edge architectures at those sites. Or if I want to do it in harbors, I am going to build competencies to do that. And, I want to copy the same model a couple of times.

It is the same of course to what company XX does. They have some solution to a problem, and they try to use that solution in many other cases. So it would be important to look at, what markets you want to target, and for what markets you will develop capabilities. Because it is important that there is a substantial customer base and eventually revenue source of what you will target.
IN7: I thought the survey would be for customers to determine if they were going to be in edge or cloud.
MH: No, it is about the complete business model actually. So, it is partly from the customer perspective, that is the first part, so there has to be enough customer value. But, on the other hand the network of companies, or the single company that is going to roll-out the edge architecture, should have enough benefit from it. And only if those two things are met, we have a viable business model.
IN7: Okey, so that's what we are doing, that's fine.
MH: Sorry, maybe I should have said that a bit more clearly.
IN7: So, the current installed base of IoT applications, so you want to know how many different customers company XX has, that uses IoT applications?
MH: No, the first thing is, do you think it would be relevant for a service provider to look at this before targeting a certain IoT application?
IN7: I don't understand it or what we are getting at.
MH: Could you explain what part you understand?
IN7: I just don't understand, you said that a service provider is entering the market, and they want to target a market. So who is creating the service, and why do they want to know the number of IoT applications. Why would they create it in the first place if they didn't know that.
MH: So, let's say Siemens is thinking about targeting predictive maintenance applications in factories for their edge platform right. So, before they are going to enter that market, the first thing they have to analyze is what the size of the market is, what the potential of the market is, and how much data can actually be pushed towards to the edge, in order to estimate, when we are going to target this market and built competencies in order to roll-out the edge for these kinds of applications, then first they should know, is there a good customer base for that? Because, otherwise they may be better of targeting other IoT services, or other IoT applications.
IN7: Okey.
MH: Does that make it a bit more clear?
IN7: Could you go back up to the first sheet? I want to understand how these go together. Because, we had one and two, which were in my mind talking about completely different thing, and now number three is a completely different topic to me.
MH: Maybe we should go a bit from the back, and maybe I should have explained this a bit more clearly from the start. So, in order to determine the potential of an IoT application, you are going to look at two things…
IN7: So for who?
MH: It is for the service provider, so what is the potential for them? Let's say Microsoft wants to look at an IoT application for edge computing, and they want to estimate the potential, it is for them. Then, you have to look at two main things, which is the viability of the business model, and the feasibility of the business model. So, the feasibility would be, can we actually do it. And the viability is about, do we actually want to do it. And how can we determine if we want to do it? It is by means of two things; the customer value, which the first two boxes were about. And then, is there enough network value, or value for the network of companies that will roll-out the infrastructure. So you have the customer perspective and provider perspective. So, if you look at the customer value, you look at the customer value, the switching cost, etc. And if you look at, is there enough network value, you will look at things like; is there a big enough customer base what you may target on, do we have a healthy ecosystem, what is the relative cost of roll-out…..
IN7: So when you say, do we have a healthy ecosystem, you don't mean the customer?
MH: Well I am going to target an IoT application, and what I want to know is, is that ecosystem of the IoT application actually healthy. And what is healthy in that sense? It means it is diverse, productive and robust, and that says is that it delivers extra valuable opportunities for people within that ecosystem. And eventually for me as a service provider, it would give me extra benefit if I would target an IoT application which has a healthy ecosystem.
IN7: So the ecosystem does not mean the installed base of the customer, but everything that exists in the market.
MH: Yes, so if you say here the installed base it says something about the size, which is one thing…..
IN7: No, I don't mean size, I mean the infrastructure of the customers.
MH: No it is not about the infrastructure if that was your question. Is it a bit more clear already?
IN7: Yea, but you would interview a whole bunch of customers to just get the first part? Because you are not just talking to one person to complete this. You have to talk to a whole bunch of customers, and the come up with the facts, and then you do another assessment of the network and anything that exists in the market.
MH: What do you mean? I don't really understand your question.
IN7: When I first started in this model, I though you would do it for each customer, but now I see that it is not for each customer, only the first part is for the customer, but I am not sure who is going to answer the rest?
MH: Well, the rest of the questions is going to be answered by the service provider which would roll-out the edge architecture, could be Microsoft, Google, Siemens, Liberty Global etc.
IN7: So with ecosystem you mean with, what is the ecosystem that your company provides?
MH: No, I mean what is the ecosystem of the companies which are focused on rolling out the IoT application. So when we would talk about autonomous driving, there could be an ecosystem of companies working together to develop and roll-out the application.
IN7: So you would ask someone in that market about other ecosystems that they are not part of? Just because they are available?
MH: No, when you want to enter a market, one determinant, next to the size of the market is mainly about, what is the healthiness of the market, or the companies inside that market, for which you will develop you competencies to roll-out.
IN7: So, we would be the ones which will answer that for them right. They wouldn't know the answer, the competitors or what they offer. They would want an independent advisory company which tells them, because the customers don't know.
MH: So, I am not asking the customers, but I am asking the providers. So, it is not something the customer would look at ….
IN7: But, with customer I mean Microsoft, Dell, Siemens, etc. That's EY's customer, and call them a service provider, but they don't know much about their competitors, they come to us to ask it. So if you are asking service providers about the ecosystem, etc. they don't know the answers, they will ask us to help them with that.

MH: But I am not asking Microsoft about their competitors, but I am asking them about, in the market that you are targeting, what kind of companies would be your customers. So I am asking about the ecosystem of their customers, than the ecosystem of their competitors.
IN7: Okey.
MH: Does that make it more clear?
IN7: Yes, it's clear now.
MH: Okey, good.
IN7: I just want to make sure that I understand how this exactly works so I can answer your questions correctly.
MH: That's good, it also keeps me sharp, so that's a good thing. Also it helps me in rephrasing some of the stuff later on. So, do you think we could continue?
IN7: Sure.
MH: Okey, perfect. So for instance if a Microsoft would be targeting an IoT application or a market for a certain IoT application, they would look at what is the customer base there right.
IN7: Uhu.
MH: And you can look at that by means of these three variables, what is your feeling about these three variables, would they be of importance when determining to target a market, or not?
IN7: Let me see for a moment. Yes, I think all three of them would be relevant.
MH: And would there be other factors that might be relevant?
IN7: Not that I can think of.
MH: Okey. And if we were to look at predictive maintenance, what is your feeling, is predictive maintenance already widely rolled-out, or is it still a bit in its premature phases, and what is the potential?
IN7: There is definitely a lot of potential, but it is still in its infancy.
MH: So would it be a future market?
IN7: Yes.
MH: Okey. I guess the percentage of data you would push on the edge vs. the cloud is very hard to answer, because it is very case dependent.
IN7: Exactly. Current prescriptive maintenance, that is probably a better term than predictive, because you prescribe the maintenance right. So, prescriptive maintenance right now is based on schedules, they look at historical data and they will do the maintenance safely before it is anticipated to break down. But if you do advanced analytics, you don't want to look at the device only, but you also want to look at the context, like environment, what kind of work it is doing, so you will add the context data to that. So, all the other data, and then when you start pushing that to the cloud you can get better prescriptive analytics, but most companies aren't there yet so prescriptions are rather basic right now.
MH: Good to know. I think that would cover the third box. So, the fourth box is mainly about if you are going to roll-out that architecture, there is going to be a couple of factors that will impact the relative cost of edge vs. cloud. So one of the things is, well it says geographical coverage, but what I intent to say is the scale of the implementation. If you want to roll-out for instance edge computing on a country wide level, let's say for autonomous driving, it is going to be incredibly expensive. But, if you will do it on factory level, it might be manageable.
IN7: That's definitely true. But when I think about geographical coverage I am thinking about where these companies are, and there might still be worth to consider. Because, if a cloud server can't reach a location close by, you might have another reason for the edge.
MH: Exactly, so what would be other factors impacting the relative cost of edge vs. cloud?
IN7: Mhh, relative cost.
MH: What kind of factors, that are some kind of characteristic of an edge application, could make the edge significantly more expensive than the cloud?
IN7: I guess the cost for support and maintenance. So, is it going to require to have more IoT support to have an edge device, and what is going to be the price of having your servers and keeping them running.
MH: Sounds clear. And for predictive maintenance, what do you usually see, is it usually on a factory level? Or can I also see many applications on pipe-lines almost country wide, or how can I see that?
IN7: You can definitely use it anywhere.
MH: Sure. Okey, let's go to the fifth one then. The ecosystem health what we just talked a bit about as well. I will ask you to forget the factors all the way on the left for now, because they may be to specific, but it clarifies a bit what I intent to say with the more generic three factors. So, what I found in literature is, if your customers have a healthy ecosystem, so let's say I am Microsoft, and I am targeting autonomous vehicles, and the ecosystem of companies that make up an autonomous driving offering, there is an healthy ecosystem right there, that would enhance the value, because I know that the ecosystem is providing some good opportunities for the customers, and I can benefit from that. Because, It is more likely that the application will be there to stay. And I can say that by means of three things. First the diversity. So in the ecosystem is a whole range of companies that are diverse and complement each other. On the other hand it should be productive, which means they have a good return on assets, it is growing, they make some profit, etc. And lastly it is about the robustness, so how sensitive is the ecosystem to change. Are the companies likely to exit the ecosystem, and are the companies financially healthy, etc. So, what is your feeling about these factors regarding ecosystem health. Would it be important for companies thinking about entering a market, to look at these kinds of things?
IN7: Tell me again what you mean by productivity.
MH: So, productivity is mainly related to that they make some profit, so they have a sufficient return on assets, but on the other hand also that it is a growing ecosystem.
IN7: Okey, so they need to be diverse, financially stable and they need to be robust.
MH: Yes.
IN7: Sounds good, yes.
MH: Would there be anything else you would look at when looking at the ecosystem health?
IN7: I can't think of anything else, it looks good.
MH: Okey, and if you were to look at the ecosystem of companies which make up the customers rolling out predictive maintenance applications, would you say it is diverse, productive and robust?
IN7: Well, the companies I work with are not very diverse, but I would say they are robust and they are making money in general.

MH: So, you wouldn't see any problems in the ecosystem health?
IN7: Not that I am aware of.
MH: Okey, clear. Let's go to the sixth one then, so the financial risk. So, if I am going to roll-out and I am going to target on a certain application, I might have some risk. On the one hand it is of course to the robustness. So, it is a bit about the liquidity of the companies, about the creditworthiness, are they likely to stay in the ecosystem. On the other hand also the maturity of the application, let's say I will be targeting predictive maintenance right now, but it is still very premature, and it may be a hype, or its trajectory might significantly change, I might have invested in the wrong competencies. And on the other hand, if I am the service provider, and I will own the edge infrastructure myself, and I have to roll-out a big infrastructure, I will have a big initial investment which could lead to increased financial risk. SO how do you feel about this.
IN7: Let me thing a bit about it. So we have ecosystem robustness, needed initial investment… I don't know, I don't work in that part of the business, so…
MH: It's no problem, it's no problem. So for instance, if I would roll-out an edge architecture as a provider, and I would just provide the service to the customers, and the customer will only pay per use, so I own the architecture. And then if I have to own the infrastructure, which is a huge investment, I have a big risk right, because the company may stop using it.
IN7: Right.
MH: And then we have the maturity. So if it is an immature application, we have many uncertainties, and it could therefore involve risk if I will target that. And then lastly, if the companies are not likely to stay in the IoT ecosystem, I might also have a big financial risk, because I will not earn back my investments.
IN7: Okey, so if I go through this, amount of connections among partners. Are you saying that if there are more connections there is less risk?
MH: It is a bit related to what I said previously, those three factors are a bit too specific, and I want to exclude them later, but it is more about giving a kind of indication about what you would look at. And usually indeed, if they have many collaborations and partnerships, they are more likely to stay in that ecosystem and not switch or abandon it.
IN7: Okey. I think that's good.
MH: You think it is relevant, yes?
IN7: I don't really know, I don't work with financial things, but it sounds fine.
MH: In that case lets then not dive too deep in it. One more question, if you were to roll-out an edge infrastructure for predictive maintenance in factories, who would be the owner of the infrastructure. Would it be the customer or the provider?
IN7: It would be the customer.
MH: Okey, then the provider wouldn't have the risk of owning the infrastructure.
IN7: That's right, I couldn't think about an example where it is the other way around.
MH: Yes, it may be mainly in other industries. So, maturity we also kind of covered, it is in its infancy. And lastly, we also covered the robustness, the ecosystem seems robust.
IN7: Yes.
MH: Good, let's go to the next one. And let me take a step back before. SO what we did now is look at the viability of edge computing for the IoT application. SO that relates to, do we want to do it. Now we are going to look at the feasibility. Which is related to the question, can we actually do it? And then we look at the financial complexity, technical complexity and organizational complexity.
IN7: And those are the financial, technical and organizational complexity?
MH: That's right. So, let's just quickly look at the financial complexity, as you say you have more experience in other areas. So, this is different from financial risk, because the financial risk is only related to the risk I would be taking, but the complexity is related to am I able to get the financials around, so am I able to get the money. So it may be that the risk is not that big, and I have a good business case, but I am not able to get the money to roll it out.
IN7: Okey.
MH: So on the one hand it is related to what is the initial investment, what we just covered. But on the other hand it is also related to what are the resources of the customers. If they have sufficient resources, and I can access those resources, you could do some co-investment or co-ownership structures. Or even like you say what is usual in the industry is that the customer fully owns the infrastructure. And, if they have sufficient resources and I can access those, it would decrease the financial complexity.
IN7: Would it? I wouldn't say it makes it less complex. You have more resources, but that would be more you have to manage. I mean with the external resources. So, why is that less financially complex?
MH: It is mainly about am I able to get the funding for the project. So, will I get enough money to roll it out. And let's say I have some resources as a provider, but my department or this project does not get the resources to fully roll it out. Then if the customers also have sufficient resources, and they are willing to co-invest in the infrastructure, then it may make it financially less complex to get enough funding.
IN7: I don't think you are not using the right term for complex, because that sounds more complex. You may have more financial means, but it is not less complex. Complex is the more people you introduce and the more different factors, the more complex it is.
MH: That is true.
IN7: So, everything you said sound like you have more resources, and it makes it more financially viable, but it is also more complex.
MH: maybe I should rephrase it a bit into financial feasibility, so is it actually possible.
IN7: Right.
MH: Maybe that better describes the concept I aim to target here. So would there be other factors you would suggest I look at when targeting financial feasibility.
IN7: I mean technical complexity and organizational complexity would make it more expensive right. So if you fed number 8 and number 9 into number 7 it would be great.
MH: I haven't done that, might be worth looking at. Then, let's go to the technical complexity, you probably know quite a lot about that. So, a couple of things which can impact it. On the one hand it says geographical coverage again, but I mean the scale of the implementation. If you need a huge edge architecture, it might get very difficult, but for instance in a cloud it is way easier to scale up. And then the last two, are kind of related, so I may have to change that. But, if there is a lack of standards in the IoT application, it might get very complex to roll-out, and then for a provider it may be good to wait for a bit until those standards are there. And that is kind off related to the heterogeneity of devices and services, which might be very hard to integrate if you don't have any standards. So how do you think about these factors impacting the technical complexity.

IN7: Can you tell me a bit more about the heterogeneity of services and devices?
MH: So, it is mainly about, if there are all kinds of different devices, which have different run-times, different protocols, and they all have different demands, then it might be very technically complex to integrate all of that into one edge architecture. But, that would not be a problem if you have the standards in order to integrate those.
IN7: And by standards you mean communication protocols, messaging, etc.
MH: Yes, so for instance all your devices are operating on the same kinds of protocols, etc.
IN7: I mean those are big buckets. So, anything I can think of can fit into those.
MH: Could you mention some of thing you are thinking about? Which might be included in those things. It is still relevant for me to hear.
IN7: So technical complexity, so you are looking at the types of devices, you are looking at the information they require, you are looking at how that information is represented and how it is communicated, so you have different communication protocols for how that message is send from that device to the server, you have the infrastructure, so wireless or wired that transfers that message. That's pretty much it.
MH: Okey.
IN7: Does that make sense? That it fits what you are trying to say with your standards, etc.
MH: Definitely. Sounds very familiar. So, if we would look at the devices in predictive maintenance in the industry segment, is there a lot of standards to build upon generally speaking or can it get technically very complex, or is it really case dependent.
IN7: There are a lot of standards. The part where there isn't is the message itself. They are trying to make standards there now, but it is hard. So, you may have a webservice that is standardized, but the way the message is packed inside that webservice is not really standardized.
MH: Yes, clear. Let's go to the ninth one then. That's about the organizational complexity, or organizational feasibility you could almost call it. I found two kind of factors from literature. One is the number of external partners you have to work with. It is related with what you just said earlier, organizationally speaking it gets very difficult if you have many stakeholders to work with in order to roll it out. And on the other hand you have what is their prior experience regarding IT. So the experience of the customer with IT solutions such as cloud, edge, etc. So do they have the people, do they have the knowledge, do they have some basic systems in place which we can built upon. Because, if they don't have the experience, it might organizationally speaking get very complex.
IN7: So we are talking about service providers again?
MH: The top one is about how many companies does the service provider have to work with in order to roll-out this specific edge computing infrastructure for the IoT application. And the bottom one is about, what is the experience of the service provider's customer in the IT segment, and what do they already have on that behalf.
IN7: What do you mean? Prior IT experience in market?
MH: Yes, so those customers may have prior IT experience, so do they have people with knowledge about how this kind of stuff works, with whom you can talk when you roll it out. Because usually I can imagine that you are not doing the project completely loosely standing, but you also need input from the customer. Therefore, they also need some experience on that behalf right.
IN7: Okey understand. But, what I am thinking about is that you will ask service providers about their customers IT experience, it may be hard for them to estimate it. But in general I think it is good.
MH: Good. So maybe another question, if you look at organizational complexity, would there be other things that may be relevant?
IN7: I don't know, I haven't really thought about it from the perspective of a service provider, so I don't know what struggles they have.
MH: Okey, that's totally fine. Then I suggest we go to the tenth box.

A.7.8 Interview 8 – Edge and cloud platform provider & (IoT) application provider

Interviewee 8 = IN8
Michiel Huisman (Interviewer) = MH

MH: Have you had the chance to take a quick look at some of the documents I sent to you?
IN8: Yes I had the chance, but I could only take a quick look at it. So I don't know the details, I just took a quick look to get an overview.
MH: That's perfectly fine, I just expected a quick look, so that's good. So, do you have to document with the conceptual model in front of you now?
IN8: Yes, I have.
MH: So actually, the document contains two pages. The first page contains the full conceptual model. And the second page contains what I want to talk with you about for now, it is the conceptual model cut into 10 pieces in order to make it more manageable and better understandable, Because there is quite some variables, so it might look complex.
IN8: Yes.
MH: So at the first page, in the general model, we have an input, which is an IoT use-case. And, an IoT use-case has certain specifications such as; service requirements, some platform characteristics, a market segment, etc. etc. Then on the other hand, we have a choice of technology, which is from the top on. Which could be edge computing or cloud computing. And then in the end, if we go through the model, what should be there is an indication about the potential of the IoT applications for edge computing. And it is not going to be a hard measurement, but it is more going to be some kind of indication, like is there any potential. And, if we are speaking in broad terms, we can determine that potential by means of two kind of concepts. On the one hand we have the business model viability. Which tells us something about do we actually want to do it, is there enough customer value, but also if there is enough value for the network of companies which plan to roll-out the architecture. And on the other hand we can also look at the business model feasibility, so are we actually able to do it. And that is in the broad sense what the framework is about.
IN8: Okey
MH: So, before we go into the boxes on the second page, do you already have some questions?
IN8: Out of curiosity, how did you derive the model, is it based on existing ones, or is it completely new.
MH: If you look at the right side, those variables, that is from some existing models, actually one model which is the STOF business model. And if you look at the left side, that is mainly derived from bits of lose literature and informal talks, so it is a bit of a mix.
IN8: Okey.
MH: And also, mainly about the left part I will ask you questions about, because the right part is very much researched. Good?
IN8: And a second question is, basically, in the beginning of the model you raise if the choice of technology architecture is edge or cloud. Is there a clean distinction between if this is possible or where are the barriers so to say.
MH: No, not necessarily, and I am also not sure if it is going to be exactly like this. But at some parts, especially if you look from a service provider perspective, it may be good to compare an edge offering to a cloud offering. Because, eventually you will only roll-out an edge architecture if it will offer you more value than could in terms of profit, customers, etc. But in the distinction I am not that sure, it is not that clean-cut, so you are right about that.
AR: Okey, fine, so no further questions so far.
MH: Good. Then on the second page, I drafted ten boxes. And for the first nine ones, I want to ask you three kinds of questions. The first ones are going to be about: do you think that the variables that are drafted are indeed of relevance. Then the second kind of questions are going to be about: did I forget variables that might be interesting but that are not included. Because I mainly drafted it from literature, so some of the industry knowledge may not be in there yet. And then the third kind of questions I am going to ask you about is about how do you think the variables interact with the chosen use-case, which is predictive maintenance in industrial applications, in factories. And then, after we have done that for the first nine boxes, the new go to the tenth box. And what we have at the end of each of the nine boxes, is a generic variable, which are all listed in the ninth method. And I want to rank the relative importance of those at the end, but we will talk a bit more about that later.
IN8: Clear.
MH: So, I suggest we just start at the first box, and the first box is about the factors which can have an impact on the relative or perceived quality of service. So, if I were a customer, and I would have to choose whether or not to take an edge architecture or not, what are factors that may impact my decision? And what I first want to look at is the target group, which has service requirements. I identified 8 factors, from latency requirements to energy constraints of IoT device. How do you think about these variables, would these have influence for a customer to go for an edge computing architecture or not?
IN8: Yes, definitely. So, from point of view I think that especially privacy and security are at the moment very interesting challenges. So, from my experience we face several customers who say no we don't want to go to the cloud, because we have privacy sensitive data, and we need to fulfill the security requirements. Furthermore, latency and raw amount of data is a problem, but not so important. The same for context awareness and mobility support. One thing we do not completely consider from our point of view is the energy constraints of IoT devices. Because in this moment in the industry area, energy is always the second or third thing to optimize.
MH: Okey. Maybe I can even elaborate a bit about it. So, what I found about the energy constraints of IoT devices, is that, in some cases, actually if you use an edge architecture instead of a cloud solution, the energy which is consumed per query can be significantly decreased on the IoT device itself.
IN8: Yes.
MH: So, if it runs on a battery it might maybe enhance the life-time, but I only found it in two papers.
IN8: We actually analyzed this and said, what is the difference between the energy consumption transferring to an edge node or a fog node to the cloud, but that is another thing. But from our point of view, because we don't have mobile devices at the moment, which require battery at the moment, it is not a requirements. Because, they have a steady power supply, and therefore we do not consider it. But I totally agree that, when it comes to mobility and energy consumption, you can definitely gain benefit out of the use of edge computing.
MH: Interesting. Also good to know that for you it is not interesting, but it may still be relevant. And would there be any other requirements that might be important, but are not included in those 8 factors?
IN8: One thing which we always look at is the accessibility. For example, because when you put it in an edge computing cluster or

so to say, yes it is accessible when you are on-site, nonetheless it has some technical implications when you what you control something out of your bed, so to say, it is more easy with an edge solution than a cloud computing solution. That is something we always tell to our customers.
MH: Accessibility. Okey.
IN8: Or reachability let's call it like this, that is what I would actually mention.
MH: So why is it easier on the cloud than the edge.
IN8: The cloud is centrally managed, so you don't have to overcome a lot of network requirements. Probably you found yourself in the edge infrastructure, in our case we are talking about a factory. And this network infrastructure requirements in such a factory, are such a big research theme by itself. And you adapt a completely new system towards it. When you think about a typical cloud solution you have an IP and a domain name, and that is it. And they go from proxy to proxy and whatever and things like that, so it is completely complicated.
MH: Okey, maybe it could eventually mainly impact the technical complexity itself.
IN8: Totally, yes.
MH: Good, that's also one of the generic factors we will come at later, but that is definitely a good remark. So, would there also be other requirements next to that one?
IN8: Perhaps, but I cannot think at any of those at the moment.
MH: Perfect, let's leave it at that then. Are you familiar with the concept of serverless?
IN8: Yes.
MH: So, what I found is that in some cases, the concept of serverless could be better utilized on edge infrastructures instead of on cloud infrastructures, and therefore it could enhance some of the technological functionalities, and in some cases even enhance the ease of use. Do you see, for customers, that this might be a reason to go for an edge infrastructure instead of a cloud infrastructure?
IN8: Okey, I have two opinions. First of all, our customers don't ask for that at the moment. So from a slow business perspectives I don't see any requirements. From a technical perspective I however think this is a benefit. Nonetheless we don't see the requirements from the customer side so far.
MH: Okey. Would it be something that is of value for company xx in this case, would it for you be a reason to the edge even further?
IN8: Not at the moment to be honest, because we have several other characteristics which are more interesting than serverless at the moment. But, I think it is a moment of time. I think cloud is approaching that technology because it requires that functionality, in order to outsource the functionality without having overhead. And I think it is just a matter of time before it gets integrated into the edge.
MH: What you say is very similar to what I have heard. There might be some potential, but currently maybe not. Maybe wait for it a bit, till it is more mature.
IN8: Yes.
MH: Sounds reasonable. Then, if we look at those requirements, we had at the top again. If you look for predictive maintenance applications, which of these requirements would be important?
IN8: First of all, predictive maintenance is a quite big thing, so it depends on what you want to do predictive maintenance on. We are talking about several predictive maintenance, and then there are some use-cases where latency is a problem, because you have to react immediately. On the other hand there are some use-cases where you need to get some answer out on whether the thing will fail or not.
MH: Latency is very dependent.
IN8: Yes. Then raw amount of data is no problem so far. So actually for most of the things, the amount of data is still manageable to be honest. It is just a matter of variables that you have to get out in order to realize those predictive maintenance scenarios. Privacy and security in predictive maintenance is really a big, big thing, so that is one of the most important things. Context awareness I wouldn't say so. Also mobility support is not so important. Connectivity stability is very important. And like I said, energy constraints is not important for predictive maintenance. Because they have the power. So only when you already have the benefit of the predictive maintenance, then you will look at how you can optimize the power use of the IoT devices.
MH: Exactly, I can totally imagine.
IN8: But as I said, this is for us the case, because we have a steady power supply.
MH: Of course, especially if you are talking about doing predictive maintenance in a factory, then energy constraints would not be a problem.
IN8: Right.
MH: Good. Let's go to the second box then.
IN8: Yes.
MH: It is still from the customer perspective, and it is mainly about the switching cost. So, currently customers have a certain infrastructure for their application, and they are going to shift towards an edge infrastructure. And then there might be some switching cost involved with that. On the one hand it is the possibility of system integration with what they currently have. So if it is possible to integrate their current system with the new system, then what they currently have is not useless. And on the other hand we have the platform openness, which his in some way related to the top one, but it relates to the use of open standards, open libraries, etc. Actually the most extreme form would be that you have opensource software on which everyone can freely develop upon each other. So that can eventually impact the switching cost for a user.
IN8: First of all, I am not quite sure if switching cost is the right term here, because it depends on where do you switch from what to what.
MH: Yes.
IN8: Is it from cloud to edge, or is it from nothing to edge. That's why I am asking, because we have several customers where the cloud is available for them right now, but there are also some customers which have not touched it. So you have switching costs from nothing to edge. But, there are also some customers which have their existing Azure IoT stack, and their existing infrastructure, and their goal is to use the already existing IT infrastructure, together with the new concept.
MH: Exactly, so, for them the possibility of integration with what they currently have would be very important.
IN8: Yes.
MH: And for those other customers, so let's say they are still switching, because currently they have no infrastructure, but they are switching towards the edge. What would happen for them?

IN8: For the switching cost yes, first of all it's as you said the integration with previous systems. So in industry when it comes to ERP systems, those are often asked for, so the integration. And second of all, I totally agree with the easiness or in general the openness of the platform, so to rely on an infrastructure which offers that. And third of all, Especially I would also add, the long-time support so to say. Because in cloud technology, or when you are coming from the Internet world, I think everything was very short-living. There are weekly updates, there are new technologies turning up every half a year. But, in an industry scenario where company xx currently is, we have customers which rely on, okey we buy something from company xx now, and they will provide the service for the next 20 years for it. So this is a completely different mindset to be honest, which I also didn't know before I started at company xx. That is, that they are trying to establish something long-living, and there you have to give the support for. And if you compare it to a website, I am not even sure what will happen with Facebook for the next 10 or 20 years.
MH: Definitely true. If you are talking about Facebook, I am also curious how that will evolve, lot of stuff going on there.
IN8: And you see in case a website like Facebook will not be available in 20 years, no one will care, but if something from company xx, from a technical perspective is not working, it is a big deal. Because they have established trust from their customers, that they will provide this long-time support, so this is for technologies that are moving really fast.
MH: Good. Also another thing, usually, when you run the project, and you will deliver an edge infrastructure, who would be the owner of the infrastructure? Would that be the customer, or company xx, and that then the customer pays per use.
IN8: Actually it will not be company xx, it will either be the end-customer or the machine builder. And they are offering this edge infrastructure as a service. But not company xx, company xx is just providing the technology.
MH: Okey good. Because, in my earlier assumptions, I thought that it would always be the provider that owns it, but I have heard it a couple of times that it can be different in industry applications.
IN8: Yea.
MH: So, lastly, how do you think this interacts for predictive maintenance. Is it usually difficult to integrate with what they currently have. Or is can it even be on some stand-alone systems, what is what you usually find?
IN8: I think they don't care as long as the value is good. As long as you provide them with a working predictive maintenance scenario, they don't really care about the switching cost to be honest. It is just a manner of how much money can I safe with a predictive maintenance scenario, and how much money do I spend. So, they have no problem spending a couple of millions if the predictive maintenance use-case is very big. So from this point of view, I think there are actually no barriers. As long as the use-case provides the promised value.
MH: Perfect. And then lastly we would assume that, in order to roll-out that use-case, we do need an edge architecture, right.
IN8: In case you promise the value with the edge infrastructure, and you need that infrastructure to deliver that value, you got it.
MH: Exactly, clear. SO let's go to the third factor now. Here we switch from the customer perspective towards the provider perspective, which would be you guys of course. And when you are analyzing the IoT applications, which you may target, one of the important things what I found is that you would look at the customer base. So what you do is, you target some kind of IoT applications, and you will built some competencies for that, you will built some reputation for that, but before you do so, you want to make sure there is a substantial customer base. And you can actually look at three kinds of things. First of all, you can look at that the current IoT application is already quite big. Where you could deliver some extra benefit with the edge infrastructure. The other one relates to the potential of the market. So for instance when you are talking about autonomous vehicles, it is currently still quite small, but eventually it may become a huge application, so that may also be something you want to look at. And at the other hand, how much data do you want to push towards the edge vs the cloud. Because that also determines the market for how the edge will be used. How do you feel about those factors, is that relevant for you?
IN8: I am following the order you put up. So first of all, we as company xx have pretty big installed base of automation technology, and this is actually our market entry. So, I would not call that IoT technology, but in the end they all have a network adaptor, and they all have sensors, etc. and it is just a small step to turn them into IoT device. And then, coming to the second step, so if we have a big installed base, then yes we need a big potential market which we can target. But what I cannot answer is the % of data on the edge vs. cloud. My personal opinion is that you process the data at the place where it makes sense. So there are also examples where edge computing is the place to do it, but there are also some use-cases to do it on the cloud. So I think these two worlds will always come together, because you do the things where it makes the most sense. So, this is actually nothing we are targeting concretely yet.
MH: I can understand. Is there any other measures you would look at when looking at the customer base?
IN8: Yes, I am thinking about how to phrase it. Let's call it technology openness.
MH: Okey?
IN8: And what I mean with that is, there are some customers that are doing their business for 40 years on, they are doing a good business, but they are not open for innovation.
MH: Ah, so it is also a bit about the culture.
IN8: Yes. Let's phrase it as culture of innovation openness. Or call it readiness for edge. It is something we consider, because there might be some very old companies which do really good business in their area, but they are not open for these things. And then there are typically other companies which are looking at what do I gain and what do you give to me.
MH: Okey, good one actually. I think I have a generic variable where it may even make more sense, but we will come at that later. I definitely can imagine that it is an important factor.
IN8: Yea
MH: If you look at predictive maintenance, if we are talking a bit about how big it currently is. Is predictive maintenance already rolled-out at quite some use-cases, or is it still in it's infancy, or how do you see that?
IN8: Very good question. Actually everyone is talking about it, but I have a feeling that not many people are doing it. I have seen some small and very easy applications, but predictive maintenance in a big scale, I think no-one is doing it so far. And looking at your facts here, yes there is a big installed base, there are plenty of scenarios where you may apply it, but there is a missing infrastructure. How do I get these scenarios in place, and how can I utilize them on a big scale?
MH: Aah, scaling it up, I understand. So let's go to the next one. That one is about the relative cost of roll-out for the edge vs. the cloud. So what makes the edge way more expensive than the cloud. I first drafted this for if the provider would own it, but it would still hold if it would be the customer who owns it. So one of the important things that could impact the relative cost is the scale of the implementation. Here I drafted geographical coverage, but I mean the scale of the implementation. If you have a small implementation, you can do it with just a few edge nodes and it would not be that expensive. But if you want to do it on country wide level, for instance for autonomous vehicles, it would be very difficult because you have to make all the nodes together, but also you need many, many, many nodes throughout the country which could make it very expensive. How do you feel about that?

IN8: Who is in charge for that relative cost?
MH: Do you mean who is going to pay for it?
IN8: Yes.
MH: So, it depends on how the ownership structure is, so for now let's just talk about how you guys usually do it, so it would be the customer which pays for it. Because, you have to roll-out the edge infrastructure right. And what I found is that it is going to get exponentially more expensive you have a huge scale. So if you do it in a factory it may be fine, but if it will be country wide, it may be very expensive. Especially compared to the cloud, because in cloud computing the computing resources are still centralized.
IN8: Though question, to be honest, I would not be able to answer it right now.
MH: Okey, then , if we are talking about the relative cost, would there be other factors of which you know that make it a more costly for edge deployment?
IN8: Yes first of all I would think about for edge computing you have to put your own device there in the first place. When you start really early, in order to roll-out an edge infrastructure, and this somehow relates to the geographical coverage, you have to bring some computational power to where it is needed. And if it is already there, you have to make sure that it works in the infrastructure. If you don't have it, you have to buy it there. For cloud computing it is easier. There you just have to put it in your shopping basket so to say. But, I wouldn't say it is geographical coverage, but it is different.
MH: Maybe it is also a bit about the absence or presence of current computing power on site. Is that right?
IN8: First of all, for the cost of roll-out you have to bring in some devices into your area, and as you said, in the cloud you don't care where it is, you just buy it.
MH: Exactly.
IN8: And also from an operator perspective, I think also when you are going back to the long-time support and availability. Because, in the cloud you just scale it up, but scaling up edge infrastructure is very hard, because you need more devices, etc. So scalability is a bit expensive in the edge, and that is also related to the cost of the roll-out. Because, at the best case you already know to roll-out what you need, but that is not always the case.
MH: I can imagine that, clear. So, if we are talking about rolling-out edge computing infrastructure for predictive maintenance in the industrial applications, do you usually see there any problems driving up the relative cost? Making it extremely costly.
IN8: No.
MH: Okey, so relative cost should not be a big problem for predictive maintenance?
IN8: No. As I already said, as long as you have the value, the cost is not important.
MH: I understand, good. Let's go to the fifth one then. This one needs a bit explanation. It's also from the provider perspective, again, when you are targeting an IoT application, you will not only look at the customer base, so what is the size of the market, but you would also look at how the ecosystem of companies that make-up the application would look like. More specifically, I am talking about if the ecosystem of companies in the IoT application is healthy. So let me give the autonomout vehicle example again, we would be talking about if that is healthy. So for autonomous driving it could be the ecosystem of companies working together with for instance waymo, or with Daimler, of there are healthy ecosystems there. And you can analyze that by means of three main concepts. Firstly, the diversity, so is there a big variety of partners which differentiate, which may be able to contribute towards each other. On the other hand, it is about the productivity of the ecosystem. So, is there sufficient return on their assets, and also, is there a growing ecosystem? And then lastly, it is about the robustness. So, are the companies creditworthy, but more importantly, are they likely to stay in this ecosystem or might it just be some kind of side-branch which they may cut-off. And if an ecosystem is diverse, productive and robust, then you know that it is an healthy ecosystem and it is likely to stay there, which may be a good target market. How do you feel about those factors, are they relevant for you?
IN8: I totally agree to the variety, to the return on assets and the growth of assets. What I do not completely agree on is the liquidity ratio and the creditworthiness, because I am not really sure how you would measure this in an ecosystem per se. Of course everyone who participates in an ecosystem must have sufficient liquidity, but I am not sure how you would measure that correctly.
MH: You are right, these are just some of the measurements which may measure the robustness, but I am planning to exclude the left variables, because they may be to specific. Instead it should give a broader sense about the robustness of the ecosystem. And then these variables are not hard-determined, but they give some kind of hint about it.
IN8: Ah, okey. What I am missing a bit is, you mentioned it already for a bit, but it is the duration of partners participating in the ecosystem.
MH: Okey.
IN8: So to say, customer life-time value or something like that.
MH: I think that should be included in the robustness. So, if an ecosystem is robust, it is likely to not change a lot of time. So, the players are likely to stay participating in the ecosystem, so their lifetime would be longer.
IN8: Yes. But, also having in mind the new incomers over time. So you have a stead state of really established players in the ecosystem which are doing their business there. But, you also have a steady growth curve of new players, like fresh wind in the market again.
MH: That would definitely be a plus I guess.
IN8: Yes, definitely. For example, if you always have to buy Apples, it might get boring at some point.
MH: Okey, so if you would look at the productivity, robustness and diversity of the companies which may be interested in predictive maintenance, in the industry, is it diverse, is it productive, is it robust?
IN8: I am having some problems to bring predictive maintenance in there together with the ecosystem. Because, predictive maintenance in the end is an asset that is part of the ecosystem, but one partner offers it right, and the other one buys it. So, yes of course you have a variety, because you have at least two partners. One is offering a service, and the other one is buying it, and this is basically an asset. And yes, the number of assets is growing, but currently there is only one big scaled predictive maintenance example which works. I think the ecosystem is also satisfied somehow if you do not have a total asset growth, yes you have more instances of that running, which somehow relates to that growth, but it is somehow related to productivity, you can match it somehow. Regarding robustness, I don't know how to measure that right now.
MH: I can imagine. Then, for now let's just leave it at that.
IN8: Okey.
MH: I suggest we go to the sixth one then. Sometimes I have to continue for a bit, because otherwise we won't make it. So, the next factor which you can look at, is the financial risk you would be taking. So, one of the things you would look at is the ecosystem robustness, so if you were to target a certain IoT application, you want it to be there to stay. You want it to be robust, the companies which are going to form your customer base. Because if you would invest to develop competencies for a certain IoT

application, but the customers which you target, or the IoT application itself is not there to stay, it is a risky investment. On the other hand you have the maturity of the IoT application, which is related to the uncertainty of the trajectory of the IoT application. This uncertainty could again lead to risk. And then lastly, you have the initial investment costs. This is on the premise again that the provider owns the architecture, but if you have a big scale implementation, then you have a big initial investment. And this might especially be financially risky if the customer is only going to pay per use. How do you feel about that, may that be relevant?
IN8: Yes of course. I think that actually everything has some risk. But what I am missing here is some technical risk. So you will for instance invest in some technologies that will not make it. And that is a technological risk that will end up in a financial risk. You mentioned the maturity of the IoT application, but I think it is also about the maturity of the infrastructure that you are providing. Depending on what technologies you will have to rely and if they are going to make it, it is a risk you have to cover.
MH: So that means that you have different technologies you would use for rolling out edge infrastructures for different IoT applications?
IN8: Most probably. There are plenty of things coming to an end, when it comes to predictive maintenance. There are several approaches, and you perhaps have to rely on a technological bases. Let's say in the end you go for the AI algorithm one or two. And perhaps the first one will be death in the first year, but the other one will make it.
MH: Okey. Good. So not only maturity of the IoT application, but also of the infrastructure. So, if we would be talking about financial risk, for the provider for predictive maintenance. If we look at the size of the implementation and the initial investment. In predictive maintenance, it should not be a problem, because it is the customer who usually does the investment. Then we have the maturity of predictive maintenance. Do you see many uncertainties there, of big chances of overestimation, or something related, or how do you see that?
IN8: Difficult question to be honest. I think from a technological perspective it is do-able, but nonetheless as I said there is a scalability problem. I think you can go from machine-to-machine and establish a predictive maintenance solution. But what I am missing is some kind of white label solution. And then it comes to the maturity of predictive maintenance. Because, it is not difficult to roll-out predictive maintenance for a small set of machines working together. But, I think it is not do-able to roll it out on a factory level, or even across factories. So on that sense I think there is still a risk, because you have to do it step-by-step.
MH: Okey. And then ecosystem robustness, let's just leave it at that, because you indicated you find it hard to answer. So we can go to the seventh box. What we now kind off ticked off is the business model viability, which gives us an indication about if we want to do it. So is there enough value for both the provider and the customer. And then next we talk about the feasibility, which can be measured by means of technical complexity, financial complexity, and organizational complexity. Or how you could also call it is technical, organizational and financial feasibility. So, on the seventh box, we still somewhat have the premise that it would be the provider which owns the architecture. So, I saw two things which could impact the financial feasibility. On the one hand it is the initial investment, which his related to the kind of scale of implementation. So, if you have a huge initial investment that you need, it might be very hard to get the money for this project or department. Or maybe it could even be that the company does not have sufficient funds to support it. But, on the other hand, if you are going to target another IoT application, and those customers have sufficient resources, and they are willing to share those resources. Then you could have some co-investment and co-ownership structure, or maybe even, what you guys do very often, some full-ownership structures. And in that case you could use the customer's resources to make it more financially feasible. So, do you think those things are both relevant?
IN8: Yes. I totally agree. But I think the geographical coverage needed is manageable. What I think is that, as you said, that the initial investment is definitely a factor impacting the financial complexity. But, I think that the geographical coverage is just a small part of it.
MH: I should rephrase that factor for sure, it is more about the scale of the implementation. That is what I intent to say there. Would that better cover what you think drives the initial investment?
IN8: Yes, I think so.
MH: Would there be other things that may be relevant for the financial feasibility?
IN8: For me it is generally the complexity of the ecosystem. Because it is not just the resources of the IoT partners, but it is also about the complexity with the partners. Because, when you think about the ecosystem of our mobile phones. It is very normal to pay for the service if it is good, but you also have to get you monthly data contract. And from my point this is something where you also have to include the new financial complexity. Because you are not just buying the predictive maintenance scenario, but you also have to buy and maintain the infrastructure to establish it. Because, there is several different players now, coming together, all offering different parts of the solution so to say. And you have to pay separately for them. And this makes it financially quite complex, because some people are just paid for the infrastructure, and the others for the application that are running on the infrastructure.
MH: I can imagine that it could make that quite complex. So, I think for predictive maintenance we already covered the other factors in the previous ones.
IN8: Yes.
MH: So the initial investment should not be a big problem and if the value is big enough they are very happy to provide their resources.
IN8: Yes.
MH: then let's go to the eight one, so what I found, and again, it should not be geographical coverage, but the scale of the implementation. But what I found were three factors that could have impact. One is the scale of the implementation, so first of all you have huge management and overhead issues, also you have a huge number of edge nodes which have to work together. Then another one is the heterogeneity of devices and services, which is very much related to the latest one, the standards that you have. So, if you have a huge variety of devices and services, which different interfaces, protocols, requirements, it may be very hard to integrate with each other, especially if it gets very bit. And then on the other hand, if you have many standards, then it gets a whole bunch easier. How do you feel about those factors?
IN8: I totally agree with them, but for me it is a bit strange how you phrase them. With the heterogeneity of the devices you basically say okey there are plenty of devices which you have to support etc. And then standards in IoT, and then I read, I am missing standards. So somehow this adverb is confusing. Is it the missing standards or the heterogeneity of standards.
MH: It is about the absence or presence of standards. So if everything is built upon standards, it is very easy, but if nothing is based on standards, it gets very hard.
IN8: Yes. Then just a suggestion, write that there, so it gets easier to understand.
MH: Good suggestion.

IN8: I think what you can also do is, dig one step deeper and think about the heterogenicity of devices, which also comes to the heterogeneity of programming paradigms and languages, because you have some kind of clash of established programming languages coming from an old world with the cloud world so to say. But you could also phrase it into the skillset.
MH: You mean the skillset of the people working on it, or the libraries available?
IN8: Both.
MH: Okey, good one. Would there be other factors?
IN8: Yes, so to say, for us it is very important, but I think it comes to the ninth part, but it comes to the clash of IT and OT. We always say there is a fight between OT and IT. The OT has some technology, but have a completely different mindset. And I think that the OT guys are very safety, security and efficiency driven. But the IT guys, coming from a cloud point, if Facebook is not working for a while, some people may be bored at work, but nothing really strange will happen. But, if a factory stands still for an hour, it would kill them. It is a very different mind-set, but I would maybe put that at the organizational complexity.
MH: So, if we talk about the organismal part, then one part would be about the culture regarding innovation openness. And then the other one would be the mindset regarding what would happen if we have some down-time, and what would happen if we switch from one paradigm to another one.
IN8: Yes. And another thing is, when we look at organizational, is that it is often unclear who is making the decisions. What you see in industry often is that they have a clear distinction between IT and OT. And if you sell something which is directly in between of them, also the companies do not know who is in decision for that. Is it the one in charge for IT, which buys the cloud software, or is it the one who is buying the automation resources. For us this is a very big challenge, because we do not know what to ask, because they do not know who is deciding on it.
MH: So that may also be a bit about the clearness and transparency about who is responsible for what.
IN8: Yes, so where are the barriers, and who decides for that. And are there barriers, or is it completely going together.
MH: Okey. Before we completely dive into organizational, one last question for the technical complexity, and we kind of discussed it for a bit already, but I need to confirm. What makes it technically complex to roll-out edge computing for edge computing? Or do you not observe any real problems regarding these factors?
IN8: I think the challenges for predictive maintenance are mainly… First of all, there are plenty of devices which are very heterogeneous, meaning you have to adapt the application to all the devices. Then, there are some standards, but not so many or so widely used standards. And then the technical complexity is really dependent on the heterogenicity, which does not make is scalable.
MH: Actually it is also very interwoven, those three factors.
IN8: Could you repeat that? I didn't understand it.
MH: Those three variables may be very interwoven.
IN8: Yes.
MH: Because if you were to look at a larger scale, I guess the heterogenicity of the devices is going to be way bigger.
IN8: I totally agree.
MH: Good. Then let's go to the organizational. So, next to the factors you already mentioned, I mentioned two others. So one thing that could make it very organizationally complex is, if you have to work together with a huge amount of people, partners, customers, organizations, departments, etc. it can get organizationally speaking very hard. And on the other hand, it is more about, and it shouldn't be stating market segment, but what it the IT experience of the customer and what kind of systems and capabilities do they have in place. Because if they don't have any experience regarding that, they are very old fashioned for instance, then it may get very hard.
IN8: Yes.
MH: Do you think those two factors are both relevant as well?
IN8: In general yes, but unless you have a healthy ecosystem, I think it can be solved. With a healthy ecosystem it would be very much more easy to collaborate among many partners, but that is another implication of a healthy ecosystem I would say.
MH: I understand. Next to the things you already mentioned regarding the organizational complexity, would there still be any other factor you would like to add?
IN8: I don't know any right now.
MH: Okey, good. And if we would be looking at the organizational complexity, what would make it complex to roll-out predictive maintenance? Or don't you see any problems there.
IN8: Yes, I see problems, basically, as I said, it is unclear who is in charge of establishing such a scenario. Is it the one who is buying the machine, or is it the one currently buying the cloud services. Then, also from the organizational complexity, the security, who is in charge of that then? So, as with edge computing, you now have the connection from the field level to the cloud level somehow. And you are touching several departments, and therefore it is unclear who is responsible for the security. But that is independent of the use-case, so it is a general problem that is difficult.
MH: I can totally imagine. Then I suggest we go to the tenth box, which is about the ranking.

A.7.9 Interview 9 – Network provider & Network equipment provider

Interviewee 9 = IN9
Michiel Huisman (Interviewer) = MH

MH: Mooi dat je al even naar de documenten kunnen kijken, dat scheelt weer. Heb je toevallig ook dat document met het conceptuele model voor je?
IN9: Ja, dat heb ik voor me.
MH: Oke. Ik zal het even een klein beetje toelichten. Als je dus op de eerste pagina kijkt, dan zie je redelijk veel variabelen. Maar, dat is uiteindelijk het gehele model dat ik ontwerp. En, daar heb je eigenlijk aan de rechter kant hele generieke variabelen, die eigenlijk al vaak gebruikt zijn. En aan de linker kant heb je de meer contextuele variabelen, die echt betrekking hebben tot edge computing.
IN9: Ja.
MH: En wat eigenlijk het grotere doel van het model is, is dat je een IoT use-case als input hebt, en die heeft bepaalde specificaties zoals service requirements, platform characteristics, market segment, etc. En aan de andere kant, boven, heb je een keuze in technology. Om het makkelijk te maken heb ik er even edge computing vs. Cloud computing van gemaakt. En daar zit dan een match in of geen match in met edge computing, voor die IoT applicatie. En daar moet dan een soort indicatie uit rollen die aangeeft of er nou potentie in die IoT applicatie zit of niet, dat is een beetje het generieke idee.
IN9: Ja.
MH: En als je van achter in dat model kijkt, om dat potentieel te bepalen, dan kan je naar het business model kijken, dat is de aanpak die ik heb genomen. Als je dan kijkt naar de business model literatuur, dan zijn er twee hoofd concepten. Als eerste is er de business model viability, dus is er voldoende waarde voor de klant, maar ook voor de bedrijven die het uitrollen. Het moet natuurlijk een betere business case zijn dan wat ze nu hebben. En aan de andere kant moet het ook feasible, haalbaar zijn. En dan kan je dus kijken naar de financiële, technische en organisatorische complexiteit.
IN9: Ja.
MH: Dus dat is generiek het model. En wat ik heb gedaan op de tweede pagina, misschien heb je dat ook al wel gelezen, is dat ik het heb opgeknipt in 10 stukjes om het wat overzichtelijker te maken. En die 10 blokken wil ik eigenlijk langs gaan. Waar ik bij de eerste 9 blokken 2 type vragen wil stellen. Eerst ga ik natuurlijk een beetje uitleggen wat ik bedoel. En dan ga ik je vragen of de factoren inderdaad relevant zijn voor het bepalen van de variabele die op het einde van de box staat. En het tweede type vraag is, oke, deze variabelen heb ik dus neergezet, zijn er dan ook nog andere variabelen die relevant zijn? Dat doe ik dus voor de eerste 9 boxen. De 10^e box is dan een soort samenvatting van de eerste 9 boxen, dus wat er uit die eerste 9 komt staat onder elkaar in de 10^e box. En die variabelen wil ik ranken ten opzichte van elkaar om toch een soort gewicht te hangen aan het model
IN9: Oke hartstikke goed, voor de eerste negen heb ik al wat aantekeningen voor mezelf gemaakt. Die 10^e nog niet, dus dat ranken heb ik nog niet gedaan. Dus ik verwacht daar wat extra tijd voor nodig te hebben.
MH: Dat is prima. Dat ranken ga ik ook doen via de best-worst method, die het zo structureert dat het wat makkelijker voor je zou moeten zijn om het te ranken
IN9: Oke.
MH: Dat is ten minste het doel van de methode.
IN9: Nu natuurlijk nog kijken of het ook zo uitpakt.
MH: Precies.
IN9: Dan stel ik voor dat we naar box 1 gaan kijken.
MH: Voordat we naar box 1 gaan kijken, zijn er dan over het generieke model al vragen die je zou willen stellen?
IN9: Nee, over het algemeen was de bijlage redelijk duidelijk. Je benoemde net ook al dat je het vaak over edge vs. Cloud hebt. Voor het gemak ga ik er vanuit dat cloud ook wat meer traditionele hosting is. Is dat correct?
MH: Wat bedoel je precies met traditionele hosting?
IN9: Als ik kijk naar cloud, denk ik aan Microsoft Azure, of AWS, etc. Maar, er zijn ook best wat applicaties die draaien helemaal niet in de cloud. Bijvoorbeeld omdat ze niet cloud ready zijn, of vanwege andere redenen. Bijvoorbeeld ook security achtige redenen. Die schuif ik nu even onder het kopje cloud.
MH: Ja, correct.
IN9: Dan noemen we het gewoon private cloud.
MH: Precies.
IN9: Voor de rest had ik her en der nog wat vragen, maar dat komt wel terwijl we de boxen doorgaan.
MH: Helder, dan is dat goed. Dan kunnen we gewoon bij de eerste box beginnen. Dat is dus volledig vanuit customer perspective. En het eerste waar ik eigenlijk naar wil kijken zijn die service requirements. Een customer, dat is in dit geval dus een IoT applicatie, die kan bepaalde service requirements hebben, en dat kan dan de keuze uiteindelijk voor een edge of cloud architectuur mede bepalen. En ik heb daar 8 requirements uit de literatuur kunnen halen, van latency requirements tot de energy constraints van IoT devices. En denk jij dat die 8 variabelen allemaal invloed kunnen hebben op die keuze van een klant?
IN9: Die hebben sowieso allemaal een invloed, dat lijkt me duidelijk.
MH: Oke, dat is helder. En zijn er dan nog andere dingen die je daar nog meer in mee zou kunnen nemen, die je hier nog niet tussen ziet staan.
IN9: Ik weet niet of we dat in deze box erbij kunnen zetten, maar ik zal even zeggen wat in mijn hoofd omging. We hebben het al een beetje gehad over security requirements, dat wordt ook steeds belangrijker, dus wat ik soms in de praktijk zie is dat dingen soms niet naar de cloud gaan omdat het qua security niet kan. Maar aan de andere kant zie ik ook dat cloud providers en IoT ketens steeds beter zijn in het zichtbaar maken of verwerken van security requirements. Maar in de praktijk wil ik je toch wel mee geven dat om security redenen vaak iets niet in de edge kan, maar dat het dan op traditioneel hosting level geleverd moet worden. Dus dan gaat het over grote partijen ook in de Nederlandse markt. De zaken waar ik verder nog mee zat. Eén van de blokken die enorm belangrijk is, zijn APIs.
MH: APIs.
IN9: Die zie ik hier niet echt in terug, en ik denk dat dit wel een van de componenten is die wel onderzocht zou kunnen worden. Dat zou dan misschien een functionele requirement kunnen zijn.
MH: Ja, dat er voldoende APIs zijn om daar eigenlijk op voort te bouwen en het makkelijker te maken.

IN9: Precies, want je ziet vaak dat alles modulair is opgebouwd, en of je APIs kan enablen, ja of nee, heeft er alles mee te maken of je business case en ook je klant goed kan bedienen in dit geval.
MH: Ja, zeker. En dat kan denk ik per IoT applicatie ook wel verschillen in hoeverre die APIs al beschikbaar zijn voor de edge.
IN9: Precies. Volgensmij staan die er nog niet zozeer in.
MH: Ik denk dat je daar inderdaad wel een goede hebt, en dat die misschien nog wel beter bij het tweede blokje zou passen, bij de switching costs.
IN9: Ja, dat kan ook inderdaad.
MH: Precies, ik denk dat het daar wel goed bij zou staan. En het zou voor een stukje ook al onder platform openness kunnen staan, afhankelijk van hoe je dat definieert.
IN9: Klopt.
MH: Maar, ik denk dat het inderdaad wel goed kan zijn om het zelfs los te noemen
IN9: Oke, ik vind het in ieder geval lastig, want we komen zo ook bij wat andere, dus ik heb meer gekeken van wat mis ik nou, maar waar je dat precies kan plaatsen heb ik niet altijd een even goed beeld bij. Dus dat moet je ook zelf even kijken. Maar bij bedrijf xx is dit in ieder geval een hot item, maar je kan heb denk ik ook bij 2 plaatsen.
MH: Snap ik. Betreft die service requirements, zijn er verder nog dingen waar je tegenaan liep?
IN9: Ik had nog een paar andere dingen, een ervan was, die hoort hier denk ik ook niet in thuis, maar wat belangrijk is, is je netwerk virtualisatie, je network function virtualization. En de mate hoe dat is ingebet, en dat is er misschien ook een voor de tweede, gaat ook je succes bepalen voor IoT adoption.
MH: Ja. En zit daar ook nog een groot verschil tussen of je voor cloud of edge gaat?
IN9: Ja. Wat je ziet bij mijn bedrijf, is dat we enorm bezig zijn om allemaal netwerk functionaliteiten om die te gaan virtualiseren zodat we uiteindelijk daarmee ook makkelijker onze klanten kunnen bedienen. En dan gaan wij dus minder kosten maken omdat je dingen niet fysiek hebt, en je kan ook dingen makkelijker aan elkaar knopen.
MH: Ja precies. En als je voor een IoT applicatie die virtualisatie in een verder stadium hebt, zou je dan ook makkelijker naar zo'n edge toe kunnen?
IN9: Ja, dan kun je makkelijker switchen. En dat is ook meer een generieke opmerking die ik heb, en het werd al een beetje in je bijlage genoemd, maar dat is de beweging van verschillende clouds naar verschillende clouds. En om dat te enabelen heb je netwerk virtualisatie nodig, om dat goed te kunnen doen.
MH: Ja, en dat is natuurlijk al helemaal relevant met edge nodes waar je elke keer maar weer naar de dichtstbijzijnde moet switchen. Zeker als je bijwijzen van spreken aan het rondrijden bent.
IN9: Ja. Dat was er dus een. Deze is wat minder relevant, maar, ik weet ook niet of dat bij 1 hoort hoor, maar ik zat ook in mijn hoofd met wat is de relatie tussen IoT, blockchain, AI en data services. Want die is zeker ook wel relevant, en als je kijkt naar de klant, vanuit klant perspectief, dus je blokje 1 en 2.
MH: Ja klopt.
IN9: De klant wil gewoon een geconsolideerde service hebben, dus wat je in de markt ziet is dat klanten steeds minder puntoplossingen kopen, maar naar bedrijven gaan en vragen om één service offering. En dat zijn dan net zoals economieën bewegingen, maar op dit moment zie ik bij mijn klanten dat we het vooral met elkaar moeten doen en ik denk ook dat de mate van integratie met de andere technieken waaronder blockchain bijvoorbeeld, ook zeer relevant is. En dat zou dan wellicht ook als requirement mee genomen kunnen worden in blokje 1. Maar eigenlijk, samenvattend, want ik schiet nu met wat hagel, maar ik denk dat je een stukje mist met technical requirements in 1.
MH: Kan ik me voorstellen. Ook inderdaad die integratie met dat soort technieken valt misschien wel weer een stukje onder dat concept van openness.
IN9: Ja.
MH: Als je edge infrastructuur redelijk open is, dan zal het ook makkelijker te integreren zijn met dat soort technieken, maar je hebt inderdaad wel gelijk dat het de moeite waard is om het expliciet ook te benoemen en misschien zelfs los ervan te trekken.
IN9: Ja.
MH: Misschien dat openness wel een beetje te breed is wat dat betreft en ik het ook verder kan opknippen. Ik moet zeggen dat ik er ook zelf wel voor heb gekozen om andere technieken zoal Blockchain, AI, 5G er een stukje vanaf te snijden om het nog managable te maken, maar het is zeker gerelateerd.
IN9: Dat is natuurlijk goed voer voor de discussie, om dat te schrijven. En het zelfde geldt ook voor, en ik weet niet of je dat als variabele moet nemen, maar de speed of change.
MH: Wat bedoel je?
IN9: Hoe snel de wereld überhaupt verandert, en hoe snel onze technieken veranderen. Waarbij IoT wat mij betreft dat sneller kan handelen met de speed of change dan de cloud.
MH: Oke.
IN9: Dus wellicht ook iets om dat in je inleiding mee te nemen of iets dergelijks, maar dat is wel absoluut een van de elementen waardoor je zou kunnen kiezen, oke doe ik het in de edge en niet in de cloud. Omdat het in de edge veel makkelijker is om zaken aan te passen.
MH: Ja. Oke, dat zou inderdaad wel een belangrijke requirement kunnen zijn. Hoe snel verandert die IoT applicatie en moet de infrastructuur ook die flexibiliteit faciliteren. Kan me voor me zien dat het relevant is.
IN9: Oke, dat waren mijn punten hierbij. Oowja, nog twee, en ik heb niet overal zo'n uitgebreide uitleg bij hoor.
MH: 1 is ook wel de lastigste hoor, dus had al wel een beetje verwacht dat we daar lang mee bezig zouden zijn.
IN9: Ik zag deze dus ook al een beetje terug bij anderen, maar het gaat over performance requirements en performance metrics. Want we hebben het hier heel veel over techniek en op een gegeven moment komt financiën, maar uiteindelijk wil de klant gewoon dat zijn applicatie goed draait. En als je een ultra low latency omgeving neerzet, prima, maar dat garandeert de klant nog niet dat zijn applicatie goed draait. Er moet ook genoeg beschikbare capaciteit zijn op de edge, wat de edge dan ook is. Daar hebben we natuurlijk laatst ook al over gesproken.
MH: Precies.
IN9: Dus er zal ook iets ingericht moeten worden als een stukje capacity management, en dat er genoeg capaciteit is om dat aan te kunnen.
MH: Computing and storage power on the edge eigenlijk dus?
IN9: Ja precies.

MH: Zeker, ook wel interessant dat je dat zegt, want een andere interviewee gaf dat ook al aan. Dus dat zou zeker belangrijk kunnen zijn.
IN9: Dat is zeker belangrijk. Vooral omdat we met die speed of change ook verwachten dat het aanbod aan IoT tools extreem zal gaan toenemen. En op het moment dat het heel snel toeneemt en je kan het niet meer aan op je edge, dan krijg je echt een performance impact en dan kan het zelfs zijn dat de applicaties onderuit liggen.
MH: Dan wordt het heel ongezellig.
IN9: Daar wordt het inderdaad niet heel veel beter op. Maar, dat brengt me gelijk bij het laatste punt, en dat is dat ik zie bij de klanten dat men steeds minder down time wil. En in mijn optiek, als je de impact van downtime wil verminderen, dan kan de edge daarvoor een goede oplossing zijn. Dus als je kijkt naar de cloud, als de AWS cloud plat ligt, ligt echt alles plat. Maar, ben je een deel van je edge oplossing kwijt, dan ligt misschien een deel van je applicatie plat, maar niet alles.
MH: Ja precies. Misschien zit dat zelfs wel voor een stuk onder het stuk connectivity. Maar, ook voor een deel weer niet. Maar, met de edge zal je stabiliteit met je connectie beter zijn, en het zal altijd wel deels available zijn. Maar, als die cloud er uit ligt, dan ligt inderdaad alles er uit.
IN9: Ja, dat klopt.
MH: Oke, goede, ga ik zeker naar kijken. Ben jij bekent met het concept serverless?
IN9: Ja, daar ben ik wel mee bekent.
MH: Wat ik dus heb gevonden is dat met het concept van serverless, dat je dat in bepaalde toepassingen beter gebruik van kan maken op de edge dan op de cloud. En dat kan dan ook wellicht, dit heb ik inductief geredeneerd, een reden zou kunnen zijn, doordat je die functionaliteiten nu kan gebruiken, en op de cloud wat minder, dat het een van de redenen kan zijn om voor een edge infrastuctuur te gaan. Is dat ook iets wat je ziet, of eigenlijk niet zo.
IN9: We voeren hier eigenlijk al veel de discussie, wat is nou de edge. Is dat nou een klein data centertje op de hoek van elke straat, best dicht bij de bron opgesteld. Of is het een ding dat we op een paar locaties hebben. Dus dan heb je mid-scale datacenters binnen Nederland.
MH: Ja, wanneer is het edge.
IN9: Wij voeren dus heel die discussie nog, maar ik kan me wel voorstellen dat serverless een reden zou kunnen zijn om voor edge te gaan.
MH: Ik kan het nog wel wat extra toelichten, dat is voor jou ook wel interessant nog om te weten. Ik dacht namelijk eerst dat serverless echt een goede driver zou kunnen zijn voor edge, maar als je kijkt, gaat dat waarschijnlijk nog wel een paar jaar duren voor het van de grond zal komen. Het staat nog wel echt in het begin stadia, of dat heb ik me in ieder geval laten vertellen. En momenteel valt dat nog mee, hoeveel dat een driver is voor klanten. Maar, in de toekomst zou het een mooie rol kunnen spelen.
IN9: Precies. Dan is het natuurlijk voor jou de vraag of je het mee wil nemen in je model.
MH: Exact, daarom was ik ook benieuwd naar wat jij dacht
IN9: Ik zie het bij bedrijf xx in ieder geval nog niet te gebeuren.
MH: Precies, komt me bekent voor.
IN9: Maar, wij zijn dan toch wel een wat loggere organisatie dan misschien andere kleinere organisaties. Zeker als je het hebt over de snelheid van adoptie van nieuwe technologieën, die is niet extreem hoog.
MH: Kan ik me voorstellen. Dan stel ik voor dat we naar de tweede box toe gaan.
IN9: Ja.
MH: Dat zijn dan die switching costs waar we het ook net al een stukje over hadden. En de twee variabelen die ik dan heb geïdentificeerd is, een de easiness of platform openness, wat ook al wat relateert aan bepaalde dingen die je net benoemde. En de andere heeft vooral te maken met, een klant heeft misschien al een huidig systeem, een cloud oplossing, een eigen data center, private cloud laten we dat dan noemen. En dan gaan ze naar de edge toe. Maar, wat je dan niet wil is dat wat ze nu hebben totaal waardeloos is, je wil dat het geïntegreerd kan worden. En als dat kan zijn je switching costs natuurlijk een stuk lager. Dat zijn dan de dingen die ik vanuit de literatuur heb geïdentificeerd. Denk je dat dat relevant zijn?
IN9: Ik denk inderdaad dat ze beide relevant zijn. Dus het is inderdaad belangrijk dat die platformen op elkaar toegespitst zijn, want je ziet ook bij ons, wij doen heel veel migraties, en daar is dit echt een hot topic. En dan maakt het niet uit hoe het platform heet, cloud, edge, of een traditioneel hosting platform, maar het gaat altijd over hoe de klant verdeeld over de verschillende platformen bediend kan worden. Daar gaat het dan ook niet alleen over techniek, maar ook over processen. En dat is natuurlijk een van de dingen die we zo ook gaan aanhalen, maar wat mij betreft is dat nog wel een beetje onderbelicht in deze studie. Maar, wat je straks gaat krijgen is dat er veel partijen zijn die in een bepaald product zitten, en op het moment dat je wat gedonder krijgt omdat de performance wat lager is, dan vermoed ik dat iedereen naar elkaar zal gaan wijzen. Maar, integratie is dus zeker belangrijk, en niet alleen qua techniek, maar ook qua processen. En ik wil er ook nog aan toevoegen dat de complexiteit van een migratie zelf relevant is. Op het moment dat het redelijk complexe migraties zijn, dan zullen je switching costs veel hoger zijn, dan wanneer je dat met één vinkje kan doen inderdaad. En daar heb ik niet echt een beeld bij, wat die complexiteit gaat zijn. Ik denk dat dat ook per applicatie of per opstelling anders zal zijn.
MH: Nee precies. Ja, die migratie kosten en complexiteit is hier wellicht niet voldoende in meegenomen.
IN9: Maar, als ik nu kijk naar de praktijk, dan is het grofst van de kosten die wij maken om klanten te migreren naar een ander platform, het resultaat van de complexiteit. Dus wij raten de applicatie naar de complexiteit, en aan de hand van die complexiteit zit daar een bepaald prijskaartje aan.
MH: En die migratie kosten worden dan per direct doorgerekend naar de klant?
IN9: Niet perse direct naar de klant, dat hangt van de klant af. In sommige gevallen betalen we er zelf een stukje aan mee, maar soms wordt het ook direct doorgerekend.
MH: Oke. Zijn er dan nog andere factoren die de switching costs kunnen beïnvloeden?
IN9: Ik denk vooral dat de complexiteit en doorlooptijd relevant zijn. Dus ik zou opteren om naast deze toch wat meer technische componenten ook wat meer praktische dingen er aan toe te voegen. Vooral omdat mijn ervaring is dat dat het meeste drukt op de kosten.
MH: Helder. Dan denk ik dat we naar de derde kunnen
IN9: Ja.
MH: Dus, dan gaan we van de customer perspective naar de provider perspective. Dat zijn jullie dan bijvoorbeeld. En een van de dingen waar je naar kan kijken is, is er wel een groot genoege customer base in de IoT applicatie die je gaat targeten. Je had het net inderdaad namelijk al een beetje over migratie kosten, en stel je gaat zo'n edge infrastructuur uitrollen, dan ga je toch wel bepaalde applicaties selecteren waar je competenties voor gaat ontwikkelen om het makkelijker te maken. En je gaat dus het zelfde

concept op verschillende plekken of in verschillende applicaties uitrollen. EY is hier natuurlijk heel goed in…. Maar dan heb ik 3 factoren die ik heb geïdentificeerd om hier naar te kijken, en het beste is om vanaf onder te beginnen, ik moet dit nog opnieuw rangschikken. Eerst ga je dan kijken, wat is de current installed base of the IoT application, dus hoe groot is nu de IoT applicatie die baad zou kunnen hebben van zo'n edge computing infrastructuur. Twee is dan wat de potentie is van de IoT applicatie. Als je dan kijkt naar zelfrijdende auto's, dat staat echt nog in de babyschoenen, maar wie weet waar dat over 10 jaar staat. Het zou dus een enorme potentie kunnen hebben, is dat dan daardoor weer een markt die je wil targeten? En dan als laatste denk ik dat er toch vaak een interactie is tussen de edge en de cloud, en dan is het de vraag hoeveel % van de data je nou uiteindelijk naar de edge wil pushen, want uiteindelijk bepaald dat waarschijnlijk ook wel voor een stukje hoe groot je markt is.
IN9: Ik denk zelf inderdaad dat je vaak uitkomt op een hybride model. Je kan ook binnen applicatie landschappen hebben dat een deel op de cloud staat, een deel op de edge en soms zelfs een deel op de traditionele datacenters.
MH: Precies, dat denk ik inderdaad ook. Als we het dan hebben over die customer base, zijn dit dan ook alle drie dingen die relevant voor jou zouden zijn?
IN9: Volgens mij zijn dit inderdaad vrij theoretische benaderingen om je revenue te benaderen, dus ik kan daar moeilijk tegenin gaan.
MH: Precies, zou je er nog meer aan toe willen voegen?
IN9: Nee, dit telt samen wel op tot een customer base, of het is in ieder geval één van de manieren, dus dat is prima.
MH: Mooi. Oke, box 4 gaat dan over de relatieve kosten die een provider heeft als hij zo'n edge infrastructuur heeft die hij gaat uitrollen. Dat hangt dan deel natuurlijk ook wel af van hoe je contract is, maar dat zal vaak toch ook wel op de provider, jullie dus, aankomen. En ik kan me voorstellen dat dit een factor zou zijn die je overweegt wanneer je een edge infrastructuur gaat aanbieden of toch de cloud. En wat ik vond, is dat eigenlijk de grootste driver voor de kosten, de scale of implementation is. Er staat geographical coverage, maar ik bedoel de scale of implementation, dus hoe groot ga je dit uitrollen. Laten we zeggen, ga je dit in de port of Rotterdam doen, wat eigenlijk al redelijk groot is, of ga je het in een fabriek doen, of ga je het over het hele land doen voor bijvoorbeeld zelfrijdende auto's. En als het dan zo groot wordt, wordt het eigenlijk enorm complex, dat moet er misschien nog een beetje tussen, maar dus ook heel duur. Want je moet overal edge nodes neerzetten, en het moet allemaal samen werken, en dan worden die relatieve kosten gewoon erg duur.
IN9: Ja. Cloud is natuurlijk gewoon erg massaal. Edge is wat dat betref het tegenovergestelde, hangt er wel vanaf hoe je het implementeert. Dus, dit is zeker de factor die hierin het meest meeweegt. Hoe bedrijf xx dat bijvoorbeeld doet bij 5G, dan zijn de relatieve kosten gewoon of je een deel van Nederland gaat doen of heel Nederland. En waar je nu ook ziet dat bedrijf xx momenteel meer investeert dan is aangegeven in eerste instantie voor de roll-out, is dat voornamelijk door de oppervlakte die we moeten faciliteren. Ik had er nog wel bij staan, maar dat is dan misschien mijn gebrek aan kennis over hoe je edge moet implementeren, maar ik kan mij voorstellen dat misschien meerdere manieren van implementeren nodig zijn, afhankelijk van een applicatie landschap, dus je IoT applicatie landschap. En dan zou het aantal manieren, dus de number of various kinds of implementations, impact kunnen hebben op je relatieve kosten.
MH: Even kijken, de nummer van manieren waarop je dat kan implementeren. Bedoel je dat als er meer manieren zijn je meer keuze hebt en dat het daardoor goedkoper wordt, of juist duurder, omdat het moeilijker wordt, of hoe zie je dat?
IN9: Ik denk dat het dan voornamelijk duurder wordt. Zoals ik het zelf zie is, stel voor ik heb hier bij mij in de straat zo'n edge node staan en ik heb meerdere IoT applicaties in huis. Eentje kijkt bijvoorbeeld of ik wel genoeg brandstof in mijn auto heb, en de ander kijkt hoe het dan met mijn thermostaat gesteld is. Dan ben ik heel erg benieuwd of de manier van aansluiten van mijn auto en mijn thermostaat op de edge bij mij verderop in de straat, of dat in één keer kan gebeuren, of dat daar verschillende technieken achter zitten.
MH: Aaah oke, dat heeft dan ook wel een beetje te maken met de heterogeniteit van je devices en standaarden over hoe het communiceert.
IN9: Ja, met name die standaarden.
MH: Dat is dus ook belangrijk voor de kosten?
IN9: Ja, dat denk ik wel ja.
MH: Kan ik me voorstellen.
IN9: Standaarden is inderdaad exact wat ik bedoel.
MH: Nog andere dingen waar je over nadenkt als je het hebt over relatieve kosten?
IN9: Nee, vooral als je kijkt naar de geografische coverage, dan heb je 95% te pakken.
MH: Top, dan gaan we naar 5 toe. Dan praat je eigenlijk weer een stukje over die customer base. Dan heb je het over, dat noemen we dan ecosysteem health, dat is ook een theoretisch concept, en dan gaat het eigenlijk over het ecosysteem van de IoT applicatie. Dus, welke bedrijven werken bijvoorbeeld samen om zo'n IoT applicatie uit te rollen. Laten we zeggen we hebben het weer over zelfrijdende auto's, dan kan het zo zijn dat Daimler en BMW samen een partnership hebben om dat uit te rollen, en die hebben daar weer allemaal andere partners achter hangen. En dan ga je kijken, zijn die ecosystemen dan weer healthy. En als dat het geval is, dan kan dat extra waarde brengen, omdat het aangeeft dat zo'n ecosysteem elkaar meer kansen geeft en meer potentie. Dat is eigenlijk het 1+1 = 3 verhaaltje. En dat kan je meten aan de hand van 3 concepten. De diversity, productivity en robsutness. En wat daar links van staat, dat is misschien een beetje specifiek, dus daar moet je ook niet te letterlijk naar kijken, maar dat is meer om een indicatie te geven over hoe je die drie generieke concepten moet meten. En als je het dan hebt over diversity, dan kijk je naar, wat voor partners werken met elkaar, en hoe kunnen die elkaar aanvullen. De productiviteit heeft meer te maken met, maakt dat ecosysteem nou winst, wat is hun return on assets, is het ook een groeiend ecosysteem. En dan heeft de robustness vooral te maken met, oke die bedrijven die er zitten vormen nu wel een ecosysteem, maar hoe robuust is dat nou? En blijft dat ook over de tijd zo bestaan. Want als dat niet zo is, dan kan het dat een bedrijf zelf wel heel robuust is, maar niet in die IoT applicatie of dat ecosysteem participeren. En dan is het een instabiele markt die je misschien wat minder goed kan targeten. Hoe kijk jij daar tegenaan, is dat relevant?
IN9: Dat is sowieso heel relevant. Het heeft niet alleen te maken met een applicatie, maar ook met de doorontwikkeling daarvan, dus ik zag het en dacht gelijk van, ja dit is echt een goede topic. Dus volgens mij wordt het ook steeds belangrijker, dat ecosysteem. Wat je nu ziet is dat er een aantal bedrijven bezig zijn in IoT, maar nog niet alle bedrijven zijn actief opzoek naar partners in een IoT ecosysteem. Wat we vanuit bedrijf xx doen, dat kan je ook online vinden, we hebben bedrijf xx Ventures, en binnen dat fonds zijn we heel actief opzoek naar partners voor ons ecosysteem. En dat levert best wel veel op. Dus we participeren ook in die kleine bedrijven, of we nemen ze op een gegeven moment, of we funden ze. En, onze finance chef zit daar heel actief in. En misschien dat het ook voor jouw scriptie een goed voorbeeld is om te kijken hoe bedrijven daarmee omgaan. Ik denk wel dat als

je kijkt naar productiviteit, dat ik return on assets kan plaatsen. Maar Asset growth, kan een beeld schetsen, maar dat is niet 1 op 1 gerelateerd aan productiviteit.
MH: Oke, wat zouden dan andere dingen zijn als je kijkt naar productiviteit die relevant zouden kunnen zijn?
IN9: Is je return on assets enkel een financiële metric?
MH: Ja.
IN9: Zitten daar medewerkers ook in?
MH: Nee, het is echt een financiële metric.
IN9: Want productiviteit voor mij betekent dat een medewerker in plaats van 10 boutjes bijvoorbeeld per dag 12 maakt bij wijze van spreken. Dus iets kan groeien, maar dan kan je productiviteit nog steeds naar beneden gaan.
MH: Ja, dat klopt.
IN9: Ik snap wat je wil zeggen, maar ik vind die een beetje lastig om te plaatsten.
MH: Wat je ook moet weten is dat die factoren aan de linker kant, wat ik al noemde, dat zijn relatief specifieke factoren die meer zijn bedoeld om een indicatie te geven van, productiviteit, hoe meet je dat dan. En omdat dit framework ook wel echt in een begin stadium is, zal het meer zijn dat productiviteit kwalitatief meetbaar wordt gemaakt, want het is in dit stadium nog niet te doen om het helemaal hard te maken.
IN9: Ja, zeker. Ook als je kijkt naar de meeste IoT applicaties, die zijn echt nog in de begin fase van überhaupt omzet genereren. Dus hoe ga je die return op assets dan meten in een bepaald IoT landschap, ik denk dat er nog best wat IoT landschappen negatief draaien.
MH: Dat denk ik zeker.
IN9: Dus dat is wel een beetje lastig, maar als je het gewoon die asset growth neerzet om aan te tonen waar uiteindelijk het ecosysteem naartoe groeit, dat het een groeiende business is, dan is het prima, maar ik zou m niet een op een relateren aan productiviteit.
MH: Kan ik me voorstellen. Top. Verder nog dingen over dit blok?
IN9: Ja, één heel belangrijk ding die ik hier mis. Ik ben blij dat er diversiteit staat. Het belangrijkste voor mij is wel echt de kennis, altijd. En ik mis kennis een beetje.
MH: Ja, klopt staat hier niet tussen.
IN9: Dus inhoudelijke kennis over IoT. En volgens mij heb je dat verderop ook nog ergens staan. Bij puntje 9 heb je die ook nog staan.
MH: Ja precies, organizational complexity. Sowieso één van die twee dingen moet die wel expliciet tussen staan, dat ben ik met je eens.
IN9: ja, lijkt me heel belangrijk, omdat je ziet dat er steeds meer bedrijven zijn die denken van hé we moeten iets met die IoT, maar je zit dan met redelijk schaarse kennis.
MH: Ik denk ook inderdaad dat die bij 9 heel goed erbij past, dus daar zullen we het straks ook nog even over hebben.
IN9: Top, dan parkeren we die even. Verder had ik hier geen aanmerkingen op.
MH: Dan gaan we naar 6. Dat is eigenlijk je financiële risico dat je neemt als je op een bepaalde applicatie target. En ik had daar eigenlijk 3 generieke dingen geïdentificeerd. Eén is het ecosysteem robustness. Als dat hele ecosysteem niet robuust is, en je gaat met die bedrijven in zee, dan kan het nogal risicovol worden. Aan de andere kant de maturity van een IoT applicatie. Dus, staat het echt nog in de baby shoenen, en is er nog veel onzekerheid over, dus welke kant gaat het op, en wordt het uberhaupt wel groot. Of is het redelijk mature en zijn er al harde use-cases, dan heb je wat minder onzekerheden. En aan de andere kant toch ook, en zeker als je zelf die infrastructuur beheerd en ownership daarvan hebt, dan leidt de scale of implementation tot hoe groot je investering is. Want, ik kan me voorstellen dat het soms een pay-per-use business case is. En als je dan enorme initial investments hebt, dan is het risico dat je het niet terug verdient wellicht groter. Hoe kijk jij daar tegenaan?
IN9: Ik had hier verder geen opmerkingen over. Kan er eigenlijk geen speld tussen stoppen. Het enige wat ik dan vanuit de praktijk zou willen opmerken is dat je kan zeggen, van ik moet over een heel land of een heel werelddeel coverage doen. Maar, bij de implementatie kan je dan ook starten met applicatie die kleine dekking nodig hebben, zodat je het financiële risico verminderd.
MH: Ja, precies. Dus daar zit dan ook al een beetje aan van wat heb je al uitgerold, of iets in die trend. Dus als je eerst die kleine schaal applicaties al hebt uitgerold, dan heb je een deel van het land al gecovered, dan kan je daar op door bouwen voor de grote applicaties.
IN9: Precies, zo zou ik m aanpakken. Zo minimaliseer je de risico's.
MH: In dat geval gaan we dan naar 7 toe. We hadden het net dus over de viability, willen we het eigenlijk wel doen. En de volgende drie boxen gaan over de feasibility, kunnen we het eigenlijk wel doen. En dan kan je dus naar de financial, technical en organizational complexity, of feasibility, of hoe je het ook wil noemen, kijken. En als je het dan hebt over financial complexity, dat is dan anders dan het financial risk. Want eerst kijk je naar het risico dat je loopt. En daarna kijk je dan naar, kunnen we de funding eigenlijk wel rond krijgen. En dat heeft aan de ene kant te maken weer met die initial investment. Het kan bijvoorbeeld dat de initiële investering te groot is, en je voor dit project deze resources daar niet voor krijgt. Maar aan de andere kant, en dit noemde je net ook al een beetje, is dat je ook andere structuren kan verzinnen waar je dan een co-investment en co-ownership contract hebt. Waar dan de klant, die IoT applicatie dus, mee investeren in zo'n infrastructuur. En dan hangt het er natuurlijk vanaf, van wat zijn hun resources en zijn ze ook bereid om daar toegang toe te verschaffen.
IN9: Volgens mij is dat een goed fundament, je zou het aantal partners daar nog aan toe kunnen voegen. Dus niet alleen de monetaire resources, geld, maar ook het aantal partners. Omdat als het aantal partners toeneemt, dan neem de financiële complexiteit ook toe. En ik had er nog eentje staan, maar dat is meer ter discussie. Dat is namelijk number of movements between cloud en edge.
MH: Ja?
IN9: En daarmee bedoel ik het aantal bewegingen waarmee we applicaties het ene moment in de cloud draaien en op het andere moment in de edge. En dat is meer in de run. Is dit alleen bedoeld voor het begin van een project, of ook in de run van een project, de financiële complexiteit.
MH: Het zou ook zeker in de run kunnen zijn.
IN9: Want het aantal bewegingen dat dan naar de cloud toe moet of naar de edge, of andersom, dat bepaald wel hoe financieel complex het wordt. Het kan dus zo zijn dat een landschap, bestaande uit een aantal applicaties, zeg 2 applicaties, dat die continue wisselen tussen de cloud en de edge. Omdat, ik mij kan voorstellen, met name als het gaat over het verzamelen en analyseren van data, dat je dat in de cloud wil doen en niet op de edge, want anders moet je in de edge een groot data center hebben, dus dan kan het zo zijn dat die twee applicaties nu in de cloud staan, maar over een half uur in de edge.

MH: Ja precies, en dat het eigenlijk dynamisch de ene keer daar en de andere keer daar staat.
IN9: Ja, en dan krijg je het P*Q, en dan krijg je mogelijk ook andere leveringstijden, en dat maakt het financieel complex.
MH: Ben ik met je eens. En het maakt het natuurlijk ook complex met het inschatten van hoeveel resources heb ik nou eigenlijk nodig. Als het niet 1 applicatie is, maar 100 of 1000. En er zitten bepaalde cyclus in dat het allemaal op het zelfde moment is, en dan kan je natuurlijk piek en dal momenten krijgen, en dan wordt het al helemaal lastig.
IN9: Klopt. En die dingen moeten natuurlijk ook gebackuped worden, maar dat is meer een praktische overweging, en ik weet ook niet of je die mee wil en moet nemen.
MH: Wel relevant om even naar te kijken.
IN9: En verder had ik niks op dit punt.
MH: Top, dan gaan we naar 8. En daar had ik 3 factoren, waarbij de onderste eigenlijk een beetje aan elkaar gelinked zijn. Aan de ene kant, als je op grote schaal kijkt, wordt het lastiger. Omdat je dan meer edge nodes hebt die met elkaar moeten samenwerken, meer devices ook die er aan gekoppeld worden. Daardoor heb je ook meer management en orchestration issues. Sowieso het hele onderhoudt van dat grote netwerk van nodes die allemaal gedecentraliseerd zijn, dat kan technisch erg complex worden. En aan de andere kant, wat het ook complex kan maken, hoe heterogener de devices en services zijn die geconnect worden aan de edge nodes, hoe lastiger het ook wordt. Omdat je allemaal verschillende devices hebt met verschillende requirements, etc. etc. Maar, dat zij eigenlijk weer een beetje verholpen kunnen worden als je standaarden hebt waar alle devices aan voldoen. Als je dus standaard protocollen hebt, en run times, etc. dan wordt het technisch gezien gelijk een stuk makkelijker. Ook dat je niet allemaal verschillende interfaces hoeft te gebruiken. Maar als je dat dus niet hebt, dan kan het technisch gezien wellicht een complex project worden.
IN9: Ja, klopt.
MH: Hoe kijk jij tegen deze 3 factoren aan? Is dat alle drie relevant?
IN9: Ja, alle drie zijn ze zeker relevant. En ik herken ook je toelichting erbij. Maar, je moet niet alleen naar de technische aspecten kijken, maar ook naar de mensen aspecten. Mensen moeten ook weten hoe de techniek zich verhoudt. Precies wat jij ook beschrijft, zie ik ook bij ons gebeuren, als we dan een niet standaard stukje verkopen, en dan gaat het helemaal niet om grote proporties van onze installed base, maar dan is er altijd een moment in het contact dat we daar gezeik me krijgen. En bij die IoT dingen, dat zijn enorm veel devices, met enorm veel stroompjes, en dat wordt nog de grootste uitdaging.
MH: Zijn er nog andere dingen die je bij de technische complexiteit ook ziet?
IN9: Ik had iet opgeschreven, even denken wat ik er ook al weer bij had bedacht. Aantal modules used fort the end product.
MH: Zijn het de aantal nodes?
IN9: Nee, wat ik hiermee bedoel is eigenlijk, en ik denk dat het wel onder heterogeniteit valt, maar we gaan toe naar een meer modulair opgebouwde wereld met allemaal bouwblokjes die op elkaar gestapeld worden. En daarbij, als je een iets ander product wil maken, hoef je er alleen een ander bouwblok in te schuiven, of te vervangen door een ander bouwblok. Daar werken we naartoe. Maar ik kan me voorstellen dat het aantal modules dat wordt gebruik voor het eind product, voor de applicatie zelf, dat dat wel heel belangrijk is ook voor de technische complexiteit. Het is wat anders als je drie modules op elkaar stapelt, dan wanneer je er misschien wel 100 hebt. Dan neemt de complexiteit wel enorm toe, dat is wat ik daar bedoelde.
MH: Goeie, en dat valt misschien inderdaad ook wel onder de heterogeniteit. Ik heb het niet op die manier benoemd, maar is zeker relevant.
IN9: Ik had m hier staan als modularity of IoT applications.
MH: Goed.
IN9: Verder geen op- of aanmerkingen.
MH: Top. Dan gaan we naar 9. Organisatorische complexiteit. Twee dingen kon ik daar eigenlijk maar uit de literatuur, die ik heb bestudeerd natuurlijk, eruit halen. Eén is eigenlijk, met hoe meer mensen je moet samenwerken, partners, stakeholders, hoe je het ook wil noemen, hoe lastiger het wordt. Je krijgt enorme stakehodler management als je veel partners hebt. Maar aan de andere kant als je maar met een paar mensen hoeft te overleggen gaat dat een stuk makkelijker. En aan de andere kant, en dat relateert misschien ook al aan wat je eerder benoemde. Dat is eigenlijk van je klant dus, wat hun IT experience is. En jij benoemde het net als IoT experience, dat is iets breder, maar in hoe verre zijn zij al gedigitaliseerd. Hebben zij eigenlijk die mensen in huis, en die systemen in huis. Want als ze dat dus nog weinig hebben, dan wordt het ook lastig om met hun zo iets aan te pakken. Hoe kijk jij daar tegenaan?
IN9: Ja, mee eens. Maar, ik werk in het IT bedrijf van bedrijf xx en ik merk dat IT iets heel anders is dan IoT. Dus, ik kan niet zomaar medewerkers van mij neerzetten op een IoT afdeling. Op een gegeven moment na wat trainingen gedaan te hebben gaan ze het zeker begrijpen, maar het is wel echt belangrijk dat je lost IoT kennis hebt.
MH: Zie je dan ook wel eens bij bedrijven dat ze een of andere IoT applicatie willen uitrollen, maar er geen kennis van hebben?
IN9: Dat is zelfs al bij de IT applicaties. Legio voorval van.
MH: Nou, dat is nog wel een goede om los mee te nemen, IoT kennis. Nog andere dingen die het organisatorisch complex kunnen maken?
IN9: Ja, ik mis hier een stukje de mens kant. En zoals je het net uitlegde zit het al deels in stukje 2, maar people is wel echt een belangrijk blokje. We hebben het er net al over gehad, maar niet alleen kennis voor IoT, maar ook diversiteit, en hoe mensen om kunnen gaan met verandering.
MH: Misschien ook wel een stukje de cultuur van het bedrijf?
IN9: Cultuur zeker. En misschien zelfs ook, maar dit gaat misschien een beetje ver, maar ik denk dat de rollen binnen organisaties gaan veranderen. Ik zie dat er steeds minder management rollen zijn en steeds meer technische development rollen waardoor je organisatie complexiteit wel toeneemt.
MH: Oke, helder.
IN9: En ik denk dat met name, en ik heb het bij puntje 1 ook al benoemd, maar dat het belangrijk is hoe de ketens gedefinieerd zijn. En daarmee bedoel ik de end-to-end ketens. Een klant neemt een dienst af, en daar werken allemaal bedrijven of afdelingen aan, en dat zijn allemaal eilanden, en wat het belangrijkste is, is hoe dat end-to-end gemanaged wordt. Dus er moet in ieder geval iets van een beschrijving/design komen per IoT applicatie, over de processen en verantwoordelijkheden van zo'n project.
MH: Ja precies. Wat ook iemand anders aangaf is dat, als je kijkt in de industrie, dat je vaak hebt dat een bedrijf een OT en een IT department heeft die los van elkaar staan. En als je het dan hebt over edge computing dan weten ze eigenlijk niet meer waar dat onder valt, omdat het een stukje gaat over het efficiënter maken van je processen, maar het is weer een IT applicatie. En dan kan het heel lastig zijn wie er nou binnen de klant verantwoordelijk is voor de inkoop, uitvoering. Dus alleen de interne processen kunnen al heel lastig worden.

IN9: Ja dat klopt, als je kijkt welke afdelingen we bij bedrijf xx al hebben. Dan zou dat inkoop zijn, dus procurement, en dat zijn een aantal leverende afdelingen waaronder connectiviteit, waaronder de jongens die de servers beheren op de edge, dat zou een applicatie team kunnen zijn, dus specifiek opgesteld voor een bepaalde IoT applicatie, dus dat zijn allemaal partners die we alleen al binnen bedrijf xx hebben. En zo heeft elk bedrijf binnen die keten die een stukje levert van de totale dienst dat wel eigenlijk.
MH: Ja, precies. Zijn er nog andere dingen waar je over nadenkt?
IN9: Volgens mij zijn dit wel de meest relevante zaken.
MH: Super. Dan kunnen we naar de 10e box, het ranken. Dat is dus eigenlijk de uitkomst van de eerdere negen boxes.

A.7.10 Interview 10 – Edge and cloud platform provider

Interviewee 10 = IN10
Interviewee 11 = IN11
Michiel Huisman (Interviewer) = MH

MH: Ik heb de recorder nu aan gezet.
IN10: Helemaal goed.
MH: Ik heb dus een model gemaakt, met veel variabelen zoals je al ziet. En wat eigenlijk een beetje het idee is van dit model, en dat spitst zich ook een beetje toe op wat ik net al zei, als je kijkt naar edge computing, dan is er op business vlak nog relatief weinig onderzocht. En dat leidt met name tot een probleem voor service providers met het bepalen op welke IoT applicaties ze moeten targeten om zo'n edge infrastructuur uit te rollen.
IN10: En als je het hebt over een edge infrastructuur, wat is dan jouw definitie daarvan?
MH: Ja, eigenlijk heb ik een hele brede definitie. Het is het zelfde service model als je met een cloud kan bieden, SaaS, PaaS, IaaS, maar dan in een gedecentraliseerde architectuur, en bijna alles dat het op die manier kan aanbieden definieer ik als de edge.
IN10: Oke.
IN11: Wij als bedrijf xx zien het eigenlijk als een onderdeel van de cloud. Dus je hebt iets, en dat moet ergens draaien. En dat draait in de cloud bij ons op de hardware, en soms wil je het op de edge draaien, maar dan is het nog steeds managed by the cloud. Dus daarom zien wij het als 1 cloud. Als je dus ook kijkt naar de dingen die we hebben , bijvoorbeeld Azure Stack, dat is een stuk dat je on-premise kan installeren, en dat noemen wij ook edge, maar vaak zie je bij edge dat het zo groot is, maar dit is dan zo groot. En het is dus het zelfde concept, managed by cloud, en het ding kan geheel zelfstandig functioneren als het moet, disconnected, en als hij dan weer geconnect komt, dan communiceert hij weer. Alleen zit er heel veel power in. Aan de andere kant is dan weer raspberry pi, dat zien wij allemaal als de edge.
MH: Dat zie ik ook precies, zoals je het beschrijft, van raspberry pi, tot een mini-datacenter, dat is voor mij ook de edge.
IN10: En als je onze CEO ziet presenteren dan positioneert hij het heel duidelijk vanuit de intelligent cloud en de intelligent edge. Maar, wel managed vanuit 1 omgeving.
MH: Een tijd geleden heb ik er wel wat filmpjes over gezien inderdaad, vooral in het begin stadium. Maar stel je gaat dan analyseren voor welke IoT applicaties je dat gaat uitrollen, want de edge is natuurlijk altijd on-site geplaatst, daar heb ik een moeilijkheid geïdentificeerd. En dan kan je naar 2 dingen kijken, dat is de viability van het business model.
IN10: Het kan liggen aan mijn ogen, maar….
MH: Ik praat er nu even doorheen, en dan zoomen we zo in op de onderdelen. Dus, de viability, willen we het eigenlijk doen, is er genoeg klantwaarde, maar is er ook genoeg waarde voor de provider? Want het moet uiteindelijk wel iets toevoegen aan de cloud. En aan de andere kant, is het feasible, dus kunnen we het eigenlijk wel doen.
IN10: En dat feasible, kunnen we het eigenlijk wel doen, waar is dat afhankelijk van?
MH: 3 hoofdfactoren, Technologische complexiteit, financiële complexiteit en organisatorische complexiteit. Gaan we straks nog op in.
IN10: Oke.
MH: Dus wat het model eigenlijk heeft is een IoT use-case als input, en die heeft allemaal specificaties, zoals service requirements, platform karakteristieken, een markt segment, etc. etc. En aan de andere kant kan je kiezen voor een technologische infrastructuur, cloud vs. Edge. En dat gaat dan door dat hele model heen, en daar moet dan een indicatie uit komen over de potentie voor een IoT applicatie voor edge computing. En dan heb je dus een soort indicatie over of je een edge infrastructuur daar wil uitrollen of niet. Wat ik met jullie straks door wil gaan, zijn deze blokjes, ik heb er 10 blokjes van gemaakt. Ik heb het opgeknipt om het wat meer managable te maken.
IN11: Waarom doe je dit? Omdat je van te voren wil kiezen?
MH: Hoe bedoel je?
IN11: Waarom begin je niet gewoon in de cloud en kom je er daarna achter dat het in de edge draait?
MH: Het lijkt me dat je een soort target markt moet hebben als provider. Aangezien je daar competenties en awareness zal creëren. Zodat je uiteindelijk makkelijker je edge infrastructuru daar uit kan rollen. Nu ligt dat voor bedrijf xx misschien wat anders, maar wat ik van bedrijf xx heb gehoord, die zijn bezig met een edge infrastructuur in de industrie, en je wil toch dat dat allemaal soepel verloopt. Vooral de integratie daarnaartoe. En dat kan per IoT applicatie nog best wel een beetje verschillen, afhankelijk van factoren die daar in zitten.
IN11: Dan is er toch nog wel een erg groot verschil dat bedrijf xx echt vanuit de industriële automatisering komt. Die beginnen dus bij de PLCs, en dat is ongeveer waar wij stoppen. Daar zie je toch ook wel een verschil in inzicht, waar je moet oppassen in je definitie. Je ziet dat bedrijf xx vanuit de machine komt en richting de cloud gaat. En je ziet dat wij vanuit de cloud komen en dat we richting de machine gaan. Maar je zal dus nooit zien dat een machine rechtstreeks vanuit de cloud wordt aangestuurd. Een cloud zal alleen maar advies geven van, ik zou dit doen beste machine, maar de PLC lokaal blijft altijd nog besturing hebben. Dus, dat is een beetje een andere benadering, wat je natuurlijk typisch ziet, ook in andere gebieden, en dat is dat mensen hun business model gaan verschuiven.
MH: Dat klopt ook, en ik heb ook met bedrijf XX gepraat, en met bedrijf XX, etc. Dus het is ook juist de bedoeling om dat allemaal te beschrijven en alle inzichten te vergaren. Dus ik moet juist alle kanten zien. En wat ik dus in de literatuur vond, is dat de killer applicaties, dus waar gaan we op targeten, waar gaan we die edge systemen concreet neerzetten, dat dat redelijk lastig is. En daar heb ik dit onderzoek op toegespitst.
IN11: En heb je dan gekeken naar fabriekshallen, dus productiestraten, of ook naar drones, en dat soort applicaties.
MH: IoT applicaties in de brede zin, dus het kan drones zijn, auto's maar ook fabrieken. Het hangt er maar net vanaf. In principe moet alles in dat model kunnen zolang het maar een IoT use-case is.
IN10: Volgens mij hangt deze samen met wat je net zei, de value. De business value voor een klant of de klant daar weer achter, maar er moet iets van waarde in zitten waarom een klant het zou willen. En dat moet je zichtbaar maken aan de hand van een business-case.
MH: Precies, en het model moet op een paar manieren daar aan bijdragen. Eén manier is het selecteren van de applicaties, maar er zit ook een grote bijdrage van het model in het structureren van de gedachten waar ik over na moet denken wanneer ik zoiets ga uitrollen. En dat is zowel voor de provider, maar ook het perspectief van de klant zit er in. En dan kan je dus je gedachten op een rijtje zetten, en daar gestructureerd een beslissing in maken.

IN10: Als je het hebt over IoT applicaties, waar ik vaak met mijn partners over spreek, is meer IoT scenario's. Als ik denk aan applicaties, denk ik echt aan een stuk software met input-output, waar er iets gebeurt dat je toevallig op een IoT edge zet. Dat vind ik een onderdeel van een scenario. Dus ik weet niet of je hier specifiek inzoomd op een applicatie deel op de edge, of pak je de volle breedte en dus het scenario.
MH: Met een scenario bedoel je dus bijvoorbeeld autonomous driving.
IN10: Ja. Maar ook bijvoorbeeld; hoe richt je asset manangement in, of hoe richt je predictive maintenance in.
MH: Ja, dan gaat het inderdaad over scenario's, wat ik hier bedoel met applicaties.
IN10: Helder.
MH: Dus, wat ik heb gedaan, 9 stukken hier opgeknipt, en 10 is een samenvoeging van de 9 stukken. Ik wil deze redelijk snel door gaan. En deze 9 stukken relateren aan een generieke factor die zou kunnen helpen in het bepalen van de potentie van een applicatie. En in box 10 staan deze 9 factoren op een lijstje, en dan wil ik ranken welke meer en minder belangrijk zijn. Dat laatste deel zouden we eventueel ook nog achteraf kunnen doen, dan stuur ik een survey op. Goed, nu ga ik het model leesbaar maken. En als aller eerst waar je naar kan kijken is het customer perspective. Dus, is er waarde voor een customer om zoiets op een edge uit te voeren i.p.v. een cloud. En een customer heeft dus bepaalde service requirements, deze 8 dingen. En dat bepaald dus uiteindelijk je relative / perceived quality of service. En wat zijn dan dingen zijn waarom een klant voor een edge infrastructuur zou gaan i.p.v. een cloud infrastructuur? Nou, vanuit de literatuur kom ik dan op deze 8 factoren uit. Als jullie dan vanuit jullie ervaring kijken, heb je dan het idee dat deze 8 factoren allemaal relevant zijn voor de klant in deze afweging?
IN10: Ja.
IN11: Ja. Security vindt ik overigens altijd weer een hele leuke, wij hebben het tegenovergestelde namelijk.
MH: Hoe bedoel je?
IN11: Je ziet vaak dat mensen dingen juist vaak wel in de cloud doen, omdat de cloud veel veiliger is dan de edge.
MH: Het kan twee kanten op werken he, het kan ook een reden zijn om het niet te doen.
IN11: Ja, dat is wel een grappige. Verder zijn het wel bekende dingen. Dus latency, netwerk achtige dingen. De hoeveelheid data die je over de lijn heen stuurt. Dat zie je bij autonomous drones bijvoorbeeld, die houden alle data vast en sturen het in een keer door. Privacy requirements, security requirements, ja.
IN10: Context, bedoel je daar locatie mee? Want soms heb je geen keuze, we hebben bijvoorbeeld een klant, die heeft 140.000 compressoren in de markt staan, waar ze een IoT connectie mee hebben. En dat is op basis van de context, dan moet je daar wel edge gaan toepassen. Ik weet niet of je in die hoek zit.
MH: Ja precies, locatie, waar ben ik nou eigenlijk onderdeel van.
IN11: En mobility support, wat bedoel je precies daar mee?
MH: Ja, dat heeft een beetje te maken met dat Azure Stack bijvoorbeeld. Stel je hebt een schip, die gaat dan de haven uit, dan heb je geen connectiviteit meer, maar dan kan je die edge computing node gebruiken om….
IN11: Aah connected-disconnected bedoel je. En dan is de volgende de connectivity natuurlijk. En dan als laatste de energy constraints, dat is dus of je voldoende energie hebt op je device.
MH: Precies, en wat ik dus heb gevonden is dat het voor een IoT device minder energie kost om data naar een edge node toe te sturen, dan voor een cloud node te sturen.
IN11: Een mooi voorbeeld daarvan is LoRa. Dat is onwijs low-energy. En dat is juist, als je ergens op zit, waar je geen energie hebt, en een van de voorbeelden die ik begrepen heb is dat ze chips in bakstenen stoppen in aardbeving gebieden, en dan moet je je hele huis afbreken als je er nieuwe batterijen in moet stoppen. En daar heb je dus weer een heel ander scenario, waar je een kast neerzet waar je de stekker in stopt, en WiFi hebt, etc. En daar zie je inderdaad die twee verschillende dingen
MH: En als je dan naar die 8 requirements kijkt, zijn er dan nog dingen die je mist in je afweging?
IN11: Je hebt ook een tussen vorm, en dat is een hub-scenario. Dus, dan heb je dat sensoren rechtstreeks naar de cloud toe gaan. En je hebt dus dat er een hub tussen zit, dus dat je 1 hub hebt, dat is dan in jouw definitie ook een edge neem ik aan?
MH: Ja.
IN10: Dan heb je dus een gelaagd model.
MH: Ik zie de edge echt als de filosofie dat je de service van cloud dichter naar de user brengt, en hoe je dat precies uitrolt is meer een keuze.
IN11: Ja, die abstractie blijf je wat verder vanaf.
MH: Ja.
IN10: Ik zit te denken aan de scenario's en de klanten die we daar voor hebben. Connectivity heb je er bij staan dat is een belangrijke. Managability…
MH: Wat bedoel je daar mee.
IN10: Hoe je dat in zijn totaliteit managed. Het is leuk als je er een IoT device hangt, maar hoe ga je dat managen vanaf een bepaalde locatie. Stel je voor dat zo'n device stuk gaat. Ik ben met partners bezig hoe je global distribution van specifieke devices kunnen ondersteunen. Ik ben dus bezig met Sensortera, ik weet niet of je ze kent, maar die maken hufter-proof watermeet sensoren. Die bouwen ze zelf, en die zetten ze in de grond, en dan kunnen ze meten wat de optimale waterhoeveelheid is voor kassen en agriculturen. Die moeten dus ook gemanaged worden. Als je er 10.000 verspreidt, en je hebt er als klant 5.000 waar je verantwoordelijk voor bent, hoe ga je dat managen?
MH: Wordt dat dan moeilijker met een edge infrastructuur?
IN10: Nee het hoort er bij, meer hoe je zo'n omgeving beheerd.
MH: Oke, het is wel relevant, maar het moet misschien niet bij service requirements. Maar het is generiek gezien wel relevant.
IN10: Ja, het is wel belangrijk om rekening mee te houden. En het heeft ook te maken met het stuk van data ops. Dat betekent dat het mooi is dat je heel veel data krijgt, maar door de tijd heen moet je dat ook gaan managen. Want, als je elke dag bulken met input krijgt, hoe ga je dat opslaan, hoe ga je dat beheren, welke relevante data haal je er uit, hoe ga je dat door de tijd heen managen met bijvoorbeeld Azure Digital Twin, wat voor impact het heeft over de tijd. Dus het is niet zozeer een requirement, maar wel iets waar je over na moet denken.
IN11: Updates.
IN10: Die heeft er ook mee te maken ja.
IN11: Een bekent scenario dat ik ken zijn die kippen ovens. Van die dingen waar die kippen in gaan. En om de zoveel tijd krijgen die een nieuw menu, en vroeger moest daar iemand met een USB stick langs. En dat is een typisch IoT scenario, en waar past die hier in. Dus dat je updates doet aan een device kant. Want hoe rijker je client wordt, hoe meer security updates je moet doen.
MH: Zou dat dan een reden zijn voor een klant om voor de edge te gaan of juist voor de cloud.

IN11: Eerder juist niet de edge. Hoe dikker de edge, hoe meer software regels, hoe groter de kans op fouten, hoe meer updates je krijgt.
MH: Het zou dus juist tegen kunnen werken.
IN11: Ja.
MH: Helder.
IN10: Wij hebben ook een voorbeeld, dat heb je hier ook in ons customer experience center staan. High-tech, dat is een partij die levert alle weegschaaltjes van de Primera. En dat moet regelmatig voorzien worden van updates. En die moeten ook worden uitgerold wanneer er een nieuwe winkel bij komt. En ze zetten ook in no-time zo'n ding neer, ze kunnen m remote aan zetten. Dus dat hele managability stuk, met updates, dat is wel echt relevant. En als je het remote dus allemaal kan beheren en updaten, of je moet dat mannetje met die USB stick overal langs laten gaan, dat scheelt een hoop in de kosten.
IN11: En ook hoe kleiner je de edge maakt, hoe kleiner de updates, hoe dunner de lijn kan zijn. Dus als je zo'n edge als Stack wil updaten, dan heb je een grote netwerk kabel. Terwijl als jij een LoRa dingetje hebt dat zo groot is als je nagel, dan is het een kwestie van een paar seconden. Ik weet niet of het....
MH: Het zit hier niet in verwerkt, maar ik ga er naar kijken of en hoe ik dat zou verwerken. Laten we ondertussen even door gaan. Zijn jullie bekent met het concept serverless?
IN10: Ja.
IN11: Ja.
MH: Hebben jullie het idee dat serverless nog extra waarde kan toevoegen in een edge computing structuur i.p.v. een cloud computing structuur.
IN11: Als je kijkt naar bedrijf xx, de hele architectuur is gebaseerd op containers, dus dat zit al daar op.
IN10: de-facto standaard.
IN11: Dat is ook waarom wij dingen kunnen kiezen. Je definieert een stukje functionaliteit, en daarna bepaal je wat er gaat draaien, omdat het via een container gaat.
MH: En dat zou dan niet uitmaken of dat de edge is of de cloud?
IN11: Nee. Dat heeft echt die redenen, die daar staan, gebruiken wij om te zeggen van oke, draaien we die functionaliteit in de edge of in de cloud.
MH: Komt bekent voor, heb het vaker gehoord.
IN11: Dit is wel iets van de laatste 1,5 of 2 jaar dat het een beetje mogelijk wordt. Als je nu naar een dev event gaat, en er is geen container sessie, komt niemand. Het is gewoon hip. Vroeger hadden we server virtualisatie, en nu is het containers. Dus de IT heeft een dusdanige stap gemaakt, en dat heeft ook met cloud te maken want het is essentieel voor de cloud, maar daarom kan ik me voorstellen dat de literatuur zegt van hé dit is gaaf, maar dat het al de standaard is. En het geldt niet alleen voor ons, maar ook andere cloud vendors, die zijn hier mee bezig.
IN10: Amazon en Google zijn hier sowieso mee bezig.
MH: Helder, dan stel ik voor dat we naar de volgende blokjes toe gaan. Dus blokje 2, is nog steeds vanuit het consumenten perspectief. En dat heeft er mee te maken dat een consument al een bepaald systeem al heeft staan, of niet, en dan gaat hij naar een edge platform toe. En daarvoor heeft bij bepaalde switching costs die hij mee draagt. En wat ik heb geïdentificeerd, zijn twee dingen die daar impact op kunnen hebben. 1 is de easiness of platform openness. Aan de hand van open standaarden, APIs, libraries, etc. en aan de andere kant, in hoeverre kan het geïntegreerd worden met wat ze nu hebben. Dus ze hebben nu een systeem staan, en ze willen naar de edge infrastructuur gaan, en ze moeten alles weggooien wat ze hebben staan, dan heb je enorme switching costs. Maar stel ze hebben al Azure Cloud en ze doen Azure Stack erbij, en dat integreert heel makkelijk, dan zijn je switching costs wellicht een stuk lager. Hoe kijken jullie hier naar?
IN11: Ik heb laatst een case gehad over tunnels. En als je kijkt bij Rijkswaterstaat, dan zie je steeds meer wegdelen die worden ge-outsourced. Dat betekend dat de gene die de eigenaar is van de tunnel, die de dienst verleend, eigenaar is van de data. Maar de Rijkswaterstaat wil wel weten wat er gebeurt in die tunnel. En dan zie je dus dat er een nieuwe infrastructuur overheen wordt gelegd, los van de bestaande die dit doet. Dus dat je het oude laat staan, en dat je een nieuwe omgeving daar over heen hebt die dat monitort.
MH: Dat is wat je wil of juist niet?
IN11: Dat is wat je wil ja.
IN10: Je wil het oude niet vervangen, want dat levert geen waarde op. Waar de waarde uit komt is de data die er uit komt, en daar kan je de integratie laag overheen leggen.
IN11: En ook de scheiding is dat je dus ook een controle mechanisme hebt. In sommige gevallen kan je een eigen infrastructuur ergens overheen leggen, als je met andere partijen te maken hebt, juist als controle mechanisme. Want je ziet steeds meer de trend dat iets als dienst wordt aangeboden, maar dan wil je als afnemende partij wel een controle mechanisme hebben. En dat is dan soms een andere partij met een hele eigen infrastructuur.
MH: Kan ik me voorstellen. Zijn er andere dingen die relevant zijn voor switching costs? Dingen die die kosten daadwerkelijk veel hoger kunnen maken dan als ze bij cloud blijven of naar cloud gaan.
IN11: Wat is het alternatief. Wat draait er?
MH: Ze hebben nu iets draaien.
IN10: Heb je een scenario?
MH: Laten we zeggen predictive maintenance. Stel ze zitten te denken gaan we stukken in de edge doen, of alles in de cloud. En dan maken ze wel bepaalde kosten als ze naar de edge zouden gaan i.p.v. de cloud.
IN11: Als je predictive maintenance hebt, moet je naar de cloud. Dat heeft te maken met de oneindige verwerking die je hebt. De oneindige power en opslag die je in de cloud hebt, kan je in de edge nooit verwerken. Maar je ziet dus bij predictive maintenance twee dingen. Het algoritme creëren, dat is per default in de cloud. Maar het runnen, dus het algoritme runnen, dat is gewoon een excecutable, en dan kom je bij de bovenste dingen uit. Dat is een klein stukje code dat zegt ja of nee.
IN10: En die kan op de edge.
IN11: En dat kan je bij wijze van spreken op je horloge zetten. Dus daar zit wel een verschil in. Dat is Obvious. En als die dingen als je kijkt naar machine learning of AI. Dan is de berekening per default op de cloud.
MH: Snap ik. Maar, als je het bijvoorbeeld hebt over camera's in Amsterdam. Je kan niet zomaar al die data naar de cloud sturen. Dan heb je een enorme bandbreedte nodig. Dan kan ik me voorstellen dat je dat eerst gaat pre-processen op de edge, en vervolgens naar de cloud stuurt voor berekeningen.

IN11: Pre-processen is het runnen van een machine learning model. Dus daar is altijd een combinatie, in één keer herken je al die beelden en zeg je, dat is een nummerbord, dat doe je in de cloud. En daar komt dan een kleine executabel uit, en die run je op de edge.
MH: Maar stream je dan alle data naar de cloud?
IN11: Nee dat hoeft alleen maar een trainingset hebt.
IN10: Volgens mij moet je de data naar de cloud sturen die relevant is, die je wil weten. Dus misschien zit er wel een cognitive services model overheen, dat op het moment dat er heel veel geschreeuw is, hij alle data even door stuurt. Maar dat betekent niet dat hij 24/7 hoeft te streamen. Dus dat is afhankelijk van wat je nodig hebt aan data en hoe je dat definieert.
MH: Kan ik me voorstellen.
IN11: Pre-processen gebeurt op de edge, processen op de cloud.
MH: Ik snap dat er vaak een samenwerking zal zijn.
IN11: Ook met die camera, het procressen gebeurt toch altijd op de cloud.
IN10: Een ander scenario. Een fabrikant van beveiligingscamera's kwam er achter dat ze deze ook intelligent konden maken. En deze verkochten ze met namen op de boorplatforms. En op boorplatforms, als je een witte help op hebt, mag je in een bepaald gebied niet komen, daar mag je alleen maar komen met een rode helm. Die camera detecteert het wel, maar nu kunnen we met intelligent software er overheen een alert laten afgaan als er iemand met een witte helm komt in een rood gebied. Dus, daar heb je bepaalde functionaliteit nodig in die camera. En tegelijkertijd een alert naar de cloud en dan heb je direct een reactie.
MH: Oke, kan ik me voorstellen. Als we het dan toch hebben over die switching costs, want stel ze willen naar een edge infrastructuur toe. Zitten daar hoge kosten ergens, of zeggen jullie van, hoe wij dat aanbieden valt dat wel mee.
IN10: Switching costs komen bij mij dan niet echt naar boven, maar het zijn kosten die je maakt als je de edge in gaat. Want hiermee zou je suggereren dat het een overstap is van de ene edge naar de andere.
MH: Nee, van een systeem dat je nu hebt, naar de edge.
IN10: Maar iets wat je nu hebt, een predictive maintenance scenario, kan bijvoorbeeld niet zonder de edge. En dan zijn het niet switching costs, maar dan zijn het kosten die je gaat maken voor de edge, om uiteindelijk een scenario te maken die je gaat verdienen.
MH: Dat is dus switching.
IN11: Met switching zou je alleen zeggen dat je iets uit zegt, en wat anders aan zet. Maar met edge is het meer dat je er iets bij zet.
MH: Oke, laten we het dan even als kosten van de klant om edge überhaupt te gebruiken, of ernaast te gebruiken, waar denk je dan aan.
IN10: Wat je net al noemde, de prijs van een device.
MH: Van een IoT device?
IN10: Ja. Ik ben nu bezig met een partij, die heeft 200 miljoen pallets. Of een andere partij die levert alle kratten voor supermarkten en groentes, marktleider voor 60%. Welk scenario ga je dan bedenken, dus het scenario is te bedenken, maar dan heb je het over de kosten om IoT aan te zetten. Je kan namelijk niet op elk apparaat een duur IoT device zetten als zo'n kratje 3 dollar kost. Dus je moet heel goed nadenken over het business scenario, het voordeel en dan de business-case maken. Want soms kom je tot de conclusie dat je de kratten bijvoorbeeld beter kan weg gooien dan dat je er een IoT device van maakt.
IN11: Dat is dus de combinatie van de sensor en van de connectiviteit. Dat zijn de twee kosten die een gevaarlijke rol spelen. Want connectiviteit zijn we enorm mee aan het stoeien. Dat gaat van LoRa, naar WiFi, en weet ik veel wat er allemaal tussen zit. En daar zitten enorme kosten in.
MH: En die edge nodes he, die stukjes die berekeningen doen. Wie beheert dat dan? Wie is de owner daarvan? Zijn jullie dat? Of is dat de klant?
IN10: Dat is bij ons ten alle tijden de klant die verantwoordelijk is voor dat specifieke scenario. Ik heb een voorbeeld van kassen, waar drones vliegen om te bepalen waar gewassen goed gaan of niet goed gaan. Die hoeven niet alle gewassen te… maar die kunnen wel de locatie doorgeven van het deel in de kas, waar extra water nodig is, of minder zon. Die koppelt het terug naar de kas, maar degene die verantwoordelijk is voor de kas, of de diensten in de kas levert, die is verantwoordelijk voor dit deel. En dat zijn niet wij, wij hopen dat er heel veel data los komt.
MH: Die IoT devices zijn jullie natuurlijk niet…
IN11: Wat wel belangrijk is, is hoe bedrijf xx zich positioneert, en dat is anders dan bijvoorbeeld Amazon. Wij spelen bewust de rol van infrastructuur leverraar. Waar Amazon bijvoorbeeld supermarkt wordt, dat gaan wij niet doen. Wat wij wel gaan doen, is dat we gaan samenwerken met Albert Heijn, en dat Albert Heijn de zelfde diensten kan leveren via ons platform. Als je bijvoorbeeld kijkt EY, die heeft een smart factory oplossing, samen gebouwd met Procter and Gamble op ons platform. Dus Procter and Gamble zal de eigenaar zijn van devices en al die dingen, EY biedt de dienst aan, en wij zitten alleen maar onder de infrastructuur. Dus Azure wordt gebruikt, en wat wij wel doen is dat we de infrastructuur zo inrichten dat het zo simpel mogelijk is om het in te richten, maar dat is dan de rol van bedrijf xx. Dus als je de vraag zegt, doen jullie dat, dan zeggen wij nee, natuurlijk niet, maar dit is de achtergrond.
IN10: Wij blijven een technology provider, en wij leveren het platform waarop eind klanten of partners hun diensten kunnen gaan bouwen.
MH: Maar, als bijvoorbeeld iemand gebruik maakt van de cloud, dan zijn jullie natuurlijk wel de eigenaar van het datacenter. Maar, als je het hebt over de edge nodes, de mini datacenters, dan zal dat dus….
IN10: Nee, dat is nooit van ons.
MH: Dat is een goede onderscheiding. Dat heb ik ook met andere partijen gezien, maar omdat jullie dus wel eigenaar zijn van de gecentraliseerde cloud, vroeg ik me af hoe dat zit met de edge.
IN11: Ja dat is dus bijna nooit zo. De klant koopt de infrastructuur, dus de hardware is van hen.
IN10: Ik weet niet precies het prijsmodel er achter zit, maar dat geeft aan dat we het nog niet heel vaak hebben verkocht. Maar, wat je dus wel ziet, is dat wij niet de eigenaar zijn van de IoT devices. Maar, je kan op de website wel een gecertificeerde devices zien waar een bedrijf xx stempel op staan. Die devices zijn niet van ons, maar voldoen wel aan de kwaliteitsstandaarden. En daarbij zie je wel dat we het hele ecosysteem bij elkaar willen brengen, maar als platform provider met partners.
MH: Precies. Dan stel ik voor dat we even door gaan. Laten we nog even bij die kosten blijven, dus gaan we naar 4. Wat dus de eerste assumptie van mij was, en dat komt door wat we ook net zeiden, is dat jullie de infrastructuur owner zouden zijn. Maar, dat is dus blijkbaar de klant. En als je dan kijkt naar de relatieve kosten voor het uitrollen, dan heeft de schaal van je implementatie een grote rol. Hoeveel edge nodes zet ik neer, en hoeveel data wil ik daar op processen. Stel je hebt een Raspberry Pi, dan kan je

het heel goedkoop uitrollen. Maar als je zelfrijdende auto's hebt, op landelijke schaal, kan ik me voorstellen dat het heel duur wordt.
IN10: Ja, je hebt dan te maken met de connectivity en de kosten van een IoT device. En dan hangt het wel af van de use-case. Want, als er zo veel waarde uit komt van de applicatie. Dus afhankelijk van de business-case kan je hogere connectivity kosten bijvoorbeeld wel of niet verantwoorden.
IN11: Waar een leuke scheiding zit, die wij als bedrijf xx hebben. We hebben Azure, dat zijn de datacenters, maar eigenlijk is onze grootste asset niet de datacenters, maar het netwerk tussen die datacenters. Dus we hebben over de hele wereld datacenters staan met een hele dikke kabel er tussen. Dus we kunnen heel snel data transporteren tussen die centers. Maar, dat laatste stuk dat doen we niet, dat doen echt de providers, dat doen KPN, Vodafone, etc. Of stel je zet een stuk neer in de middle of nowhere, dan heb je geen verbinding, dan moet dat via satelliet. En dat stuk doen we niet, dat is de verantwoordelijkheid van de klant. Wij doen alleen de connectiviteit tussen de datacenters en een dik netwerk met datacenters realiseren. Dat andere stuk moet de klant doen, of partners, bijvoorbeeld EY. KPN doet het bijvoorbeeld met, als je kijkt naar het LoRa netwerk, LoRa heeft een connector met Azure. Dus KPN zorgt voor de last-mile, zodat het bij ons in Azure kan.
MH: Oke, helder. Dan heb je box 3, op wat voor IoT applicaties gaan we targeten. Hoe kijken we naar die customer base. Hoe groot is die IoT applicatie nu al uitgerold, die baat zou kunnen hebben van zo'n infrastructuur. Aan de andere kant, wat is de potentiele markt er in.
IN11: Wat je bij ons wel duidelijk ziet, en ik gok dat het voor EY wel het zelfde is. Wij hebben verschillende soorten projecten, en de term die ik daar vaak voor gebruik is time to consume. Want waar wij van leven is consumptie in Azure. Als ik een tegenvoorbeeld neem, als wij SAP op Azure zetten is het meteen heel groot, en in een maand hebben we weet ik niet hoeveel consumptie. Bij IoT is het een lijn die heel langzaam gaat, en als het succesvol is, dan ga je steeds meer data genereren en gaat hij omhoog. En hoe meer data je hebt, hoe meer diensten jullie ook kunnen aanbieden, dus daar zit wel een soort verband in.
MH: Als jullie dan kijken naar target markets, kijken jullie dan inderdaad naar die time to consume?
IN11: Waar we heel duidelijk naar kijken is dat we een boekje hebben, en dan moeten we in zo'n boekje geld verdienen, dus we moeten een goede balans hebben van projecten die morgen consumptie opleveren, projecten die nu al consumptie opleveren, dingen die snel stappen maken en voor de lange termijn zijn deze dingen. Dat is dus een balans waar we naar aan het zoeken zijn, en dat is moeilijk.
MH: Dat zijn eigenlijk ook een beetje deze twee boxen. Dus aan de ene kant wat is er nu, wat kan je er nu op zetten. En aan de andere kant het potentieel van de toekomst. En verder kan je dan nog kijken, jullie noemde het al, hoeveel % van die data wil je nou echt op die edge zetten. Want dat bepaald dan ook wel echt of dat stukje op de edge echt de moeite waard is.
IN11: Edge zie ik eigenlijk wel als caching, je gaat nooit iets op de edge langdurig opslaan. Tenzij je natuurlijk compliancy dingen hebt, maar als je edge doet voor andere redenen is het alleen voor caching en doe je het heel tijdelijk. Want als dat ding gejat wordt, ben je het kwijt.
IN10: Wat ook belangrijk is hier, is dat het olievlek projecten zijn. Dus, we beginnen klein. We zien slimme mensen die een idee hebben. En dan is mijn beeld dat het technisch al werkt. Als je ziet wat voor investeringen we doen, we hebben vorig jaar aangekondigd dat we in totaal 5 miljard investeren, wereldwijd. Dan zie je het ook in de overnames die we doen, we hebben laatst ook een partij overgenomen, Express Logic, die een eigen Linux Based Kernal op de edge als operating system in zich heeft, maar wat je ziet is dat die projecten heel klein beginnen. Ons doel is dan om dat soort olievlekjes op het water te creëren. En een aantal verdwijnen er dan weer. Maar, een aantal groeien explosief. Dus die partij met 140.000 compressoren begonnen met 10, toen 1000, toen 10.000 en dan ineens allemaal. En dan hebben we een unit in België zitten. En dan gaan we dat nu uitrollen in Duitsland, waar er 400.000 aan gekoppeld moet worden. Dus we moeten er voor zorgen dat we nu zoveel mogelijk zaaien, en dan gaan er een heel aantal bomen groeien, maar die beginnen klein.
IN11: Ken je het Bridstone project?
MH: Nee, ken ik niet.
IN11: Moet je even navragen binnen EY. EY Nederland heeft een heel groot IoT project gedaan met Bridstone, eerst 1 fabriek, 1 lijn, en nu alle fabrieken in heel Europa van Bridstone, dat is precies het zelfde model als dit. Daar is heel veel informatie over.
MH: Zeker relevant, ik ga het even opzoeken. Ik moet zeggen dat de komende 2.5 weken wel echt thesis focus is, maar daarna ga ik er zeker naar kijken! Ik stel voor dat we even snel doorgaan.
IN10: We hebben nog een kwartier inderdaad.
MH: Precies, sommige stukjes even wat sneller doen. Dus, wat ook belangrijk is, is dat het hele ecosysteem van een IoT applicatie gezond is. En dan kan je kijken naar de partners die bezig zijn met zo'n IoT applicatie, waar je uiteindelijk mee in zee kan gaan, is dat ecosysteem healthy? Dat kan je zien aan de hand van deze 3 factoren. Dus aan de ene kant, de diversity, dus is er een grote variëteit aan partners die samen werken, die elkaar kunnen complementeren en verschillende sterkte en zwakte punten hebben. Verder, is het systeem productief, dus groeit het, en maakt het misschien ook nog wel een beetje winst. En aan de andere kant, is het robuust, dus is het here to stay. Soms kan het dus dat de organisatie heel robuust is, maar dan kan het dat de IoT applicatie een side-branch is, en dan kunnen ze er heel makkelijk uit stappen. En stel je gaat daar dan energie in steken terwijl het voor hen maar een bijzaak is, dan is het lastig.
IN10: Ik zou er scalability en excelleration willen toevoegen.
MH: Dus hoe snel….
IN10: Hoe snel ze heel groot kunnen worden. Dus als het een partij is die met 3 mensen wat heeft bedacht, kan het heel productief zijn, en robuust zijn. Maar, als je er 4 klanten neerlegt, ligt het plat, want dat kunnen ze niet aan.
IN11: Ik zou openness toevoegen aan de rechter kant. Want de grootste issue van IoT is standaarden. Iedereen heeft zijn eigen communicatie standaarden, en dat is heel lastig.
MH: Als je het dan hebt over technical complexity, wat het natuurlijk heel complex maakt, is als er geen standaarden zijn.
IN11: Maar je ziet nu dus dat partijen hele eigen oplossingen gaan bouwen die nergens mee competible zijn, en dat is gewoon hopeloos. En zeker met de keuze van het ecosysteem is dat heel relevant. Stel je zit helemaal vast aan dat bedrijf, en die gaan niet veranderen…
MH: Op hun eigen eilandje.
IN11: En dat is de grootste issue in die fabriekshallen, want die zitten vast aan die conservatieve partijen. En die veranderen nu wel, maar dat gebeurt heel sloom. En daar wil je niet afhankelijk van zijn.
MH: Goeie.
IN10: Dus openness hoort hier zeker bij.

IN11: En wat je daar dan aan de rechter kant hebt, is ook wel interessant hoor. Maar wat ik net benoemde is een van de grotere veranderingen binnen bedrijf xx.
MH: Oke. Dus Financieel Risico. Als jullie op een bepaalde markt gaan targeten, dan is het één heel belangrijk dat het ecosysteem robuust is. Stel die bedrijven hebben geen goede liquiditeit, zijn niet credit waardig, dan kunnen ze het niet eens terug betalen. Aan de andere kant, als ze uit die markt gaan, dan kan je heel veel energie hebben geïnvesteerd, maar als ze daar niet langer op getarget blijven is het eigenlijk verloren energie. Verder kan je kijken naar de maturity van een IoT applicatie. Als het echt nog in het begin stadium is, zijn er heel veel onzekerheden, dus waar gaat het naartoe, wordt het wel groot, welke kant op wordt het groot? Als je dan al een bepaalde richting in duikt, dan draagt dat wel een financieel risico met zich mee. En dan deze variabele, de laatste is gebaseerd op de premise dat jullie de infrastructuur beheren. Als je dat dus uitrolt op grote schraal, zitten er hele grote investeringen in, en stel je gaat dat terug verdienen op een pay-per-use base, dan heb je een groter risico dat je het niet terug gaat verdienen.
IN11: Heb je hier dan ook in zitten dat... bij ons de meeste IoT projecten die succesvol zijn, die olievlekken zijn. Dus, het begint klein, zit geen business case achter. Maar het is gewoon een heel goed idee van iemand, en dat bouwt zich dan uit.
MH: Ja, dus het begint vaak klein en je investeert dus juist vroeg. Zodat je er vroeg bij bent voordat het groot wordt.
IN11: Wat je dus ziet, en dat is de introductie van cloud, maar vroeger waren we er aan gewend om aan projecten te denken. En projecten zijn groot en duur, en daar moet dan ook een business case achter hangen. Terwijl we nu meer een avontuur aan gaan, en dan zien we wel of het wat wordt. En door cloud kan je redelijk makkelijk experimenteren. Want werkt het niet, kan je het gewoon uit zetten en heb je helemaal geen hoge investeringskosten. En zo kan je ongelimiteerd proberen. Dus, je krijgt een heel ander model dan we traditioneel gewent zijn. We gaan een IoT project doen met edge, en we hebben 3 miljoen nodig, dan moet er een business case achter hangen. Maar, mijn ervaring is dat daar weinig successen in worden behaald. En vroeger in de IT was dat altijd zo, maar nu in de cloud is het altijd zo.
MH: Zit misschien ook wel een beetje in de dynamiek in hoe deze factoren met elkaar om gaan. Laten we zeggen in wat je nu beschrijft, is de intial investment heel laag, en daarom kan je misschien ook wel op wat minder rijpe dingen targeten.
IN11: Ja.
MH: En in impliciet zou je wel kunnen redeneren, en het staat er niet precies, maar je kan redeneren dat als de initial investment heel laag is, en het is immature, dan is het risico redelijk laag. Maar als het heel immature is en je investment is heel hoog, dan is je risico heel hoog.
IN11: Ja, maar ik zou wat ik net noemde er wel bij zetten, want dat is nu wel echt heel relevant. En dat was 5 jaar geleden niet, maar is nu echt heel relevant. En ook voor IoT, als je kijkt naar Siemens, die zegt, geef mij maar een paar miljoen, en dan doen we je fabriek digitaliseren. En wat wij doen, is dat we beginnen met 50K
IN10: Een ander risico dat ik zie, en dat heb je hier nog niet. En dat is, ik houd niet van de term, maar ga m toch zeggen, en dat is de digital success van een klant. En dat heeft te maken dat hij moet transformeren van een machine fabriek, naar een digitale IoT factory. En dan heb je dus mensen nodig op C-level. Die inzien dat ze met het bedrijf een andere kant op moeten. En dat is het initiëren van vervolgens projecten, die er toe leiden dat dit kan worden geïmplementeerd. Wat wij namelijk veel hebben gezien in het verleden, is dat we zo'n olievlekje hebben gecreëerd bij bijvoorbeeld een technische afdeling, en dan waren zij enorm enthousiast, maar toen gebeurde er niks. Dat kwam vooral door de strategie van de organisatie.
IN11: En omdat het op korte termijn ook geld kost.
MH: Ik denk dat dit soort problemen vooral met de organisatorische complexiteit hebben te maken. Andere stukjes zijn ook, met hoe veel mensen ga je samen werken. Maar ook, wat is hun IT experience, wat is de ervaring van de klant en hoe groot is die transitie. En dan een stukje wat jij net ook benoemde.
IN10: Het heeft ook te maken met, ik weet niet of je dat boek van Moore kent, crossing the chasm, dat je te maken hebt met de early adopters.
MH: Ja.
IN10: En wat ik nu zie is echt dat de early adopters het aan het oppakken zijn, en langzamerhand komt de majority er achteraan. Maar die early adopters kan je vinden door de visie van het management naar de toekomst en de bereidheid om te investeren en te durven veranderen.
MH: Durven en willen veranderen.
IN11: Vaak vooral durven.
MH: Oke, en als we dan toch al bij die organisatorische complexiteit zijn, zijn er nog andere dingen naast deze twee dingen en naast wat je net al noemde?
IN10: Ik denk dat je meerdere typen rollen nodig hebt binnen een organisatie om dit soort dingen te implementeren. Je hebt bijvoorbeeld een security officer nodig, compliancy mensen, business mensen.
MH: De organizational readiness.
IN10: Je hebt IT nodig. We zijn nu bijvoorbeeld ook bezig met een partner, die gaat 500.000 mensen van een financiële instelling op het niveau van AI training geven. Puur om te zorgen dat de organisatie op een bepaald level zit, dat ze inzien wat ze met de nieuwe ontwikkeling moeten doen. Dus het is niet alleen maar plug het IoT device aan de edge, koppel de edge aan de cloud en top. Het is een veel breder geheel, waar de techniek voor mij echt een bijzaak is.
IN11: Dat is ook zo.
IN10: En ik durf zelfs te stellen dat wij voor 95% van de klanten voor de komende 3 jaar de technieken die ze nodig hebben op de plank hebben liggen. Want als we een klant willen helpen van A naar B, dan denken klanten vaak dat ze een raket nodig hebben voor een kilometer aftand.
MH: Terwijl het ook op de fiets kan.
IN10: Maar wij leveren dan inderdaad ook de fiets, en dat hebben we gewoon op voorraad. Dus het is ook aftasten waar de organisatie in zijn maturity model zit en in zijn digitale transformatie proces.
MH: Relevant inderdaad.
IN11: Wat je verder ziet is dat bedrijven tot nu toe, als je bijvoorbeeld kijkt naar Ford, die hebben heel veel mensen geoutsourced voor IT, maar ze willen alles weer naar binnen halen. Want, IT en data worden hun core business. En zeker hier, ze gaan weer nieuwe ITers werven, want ze willen niet afhankelijk zijn van externen. En dat is voor al dit soort bedrijven waar de business modellen digitaliseren, die gaan allemaal zelf mensen aannemen.
MH: Oke. Als we het dan toch nog een stukje hebben over de technische complexiteit. Dan kan je kijken naar de schaal, standaarden die het lastig kunnen maken als ze er niet zijn, en de heterogeniteit van devices en services, al kan dit wellicht deels opgelost worden met de juiste standaarden. Hoe kijken jullie hier tegenaan en zouden er nog andere dingen relevant zijn?

IN10: Als wij succesvol zijn met dit soort type projecten, is dit eigenlijk bijna nooit de bottleneck. In de fase waar we nu zitten is dit niet de bottleneck.
MH: Oke. En standaarden?
IN10: Is ook oplosbaar. Wat ik al zei, als je naar onze website gaat en je gaat naar de IoT sector, en je klikt aan welke IoT device je wil, dan zijn er allemaal varianten van. Nou openness ook niet.
IN11: Het is haast het tegenovergestelde, we kunnen eigenlijk alles. Als je dat uitgangspunt neemt, en dan moet je ons maar vertellen, wat wil je dat we doen. In de BI wereld, we hebben op al uw vragen antwoord, maar wat is uw vraag. Dan blijft het heel lang stil.
IN10: En de technische complexiteit hangt ook weer samen met de business-case. Vindt maar eens een IoT device van een dubbeltje die voldoet aan de connectivity. Bijvoorbeeld weer dat product van de baksteen, of met de krat.
MH: Ja, kan ik me voorstellen.
IN10: Dus deze hangt weer af van het business scenario. Als dat business scenario klopt, en je kan dit er in passen, dan is het geen issue.
IN11: Ja de combinatie.
MH: Dan gaan we naar het laatste stukje toe, de financiële complexiteit, dat is anders dan het risico. Dus kan je de hele funding wel rond krijgen. Dus aan de ene kant, hoe groot is de initiële investering, en dan ga je daarna kijken, wat zijn de resources van de klant en hoe bereid is hij om deze beschikbaar te stellen. Waar zie je hier de problemen?
IN11: IK zie hier wel het pay-per-use model dat een probleem is. Dus door een pay-per-use model weten klanten niet wat ze er aan kwijt zijn. Als die devices heel veel gaan genereren kan je heel veel data opslag krijgen, of heel veel data over de lijn, dus de onzekerheid zit m in de pay-per-use. Dus de onzekerheid van de kosten.
MH: Top, dan wil ik nog naar het laatste onderdeel toegaan. Het ranken.