Early stage innovation indicators for Urban Air Mobility

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Eduardo Díaz Torre Sánchez

Student number: 4995708

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Graduation committee

Chairperson	: Prof. dr. G.P. van Wee,	Transport and Logistics
First Supervisor	: Dr. J. A. Annema,	Transport and Logistics
Second Supervisor	: Dr. M. L. C. de Bruijne,	Organization and Governance
External Supervisor	: MSc L. Ribeiro Monteiro,	Embraer

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Preface

This thesis is the final step in a journey that began with the, at that time seemingly impossible, dream to study a master's degree abroad. Doing this thesis has been tougher than I imagined, but it has been a rewarding experience. I have grown as a person in all dimensions, intellectually, emotionally and spiritually, and I am profoundly grateful for this.

I want to thank Jan Anne for his support, for always being available, for his timely and useful feedback, and for his good humor. Thanks to Luciana for her time, her advice and her help in arranging the workshop. Thanks to Bert and Mark for their time to read my thesis, for their feedback and for pushing me to improve my thesis. I also want to thank the people I interviewed and the people who participated in the workshop for sharing their knowledge and experience.

Thanks to the Justus en Louise van Effen Excellence Scholarships for funding my studies. Thanks to my mother, my father and my sisters for accompanying me during this journey despite being far away physically. Thanks to Rafa for helping me to use both the ups and downs of this thesis project to give meaning to my work and to grow as a person.

Thanks to my friends and all the people who have supported me directly or indirectly along this journey, be it by sharing their experiences, by providing their viewpoints or simply by being there and having a nice time together. Thanks for listening and supporting me when I was happy, worried, disappointed, or excited. Thanks to Marisol, Francisco, Stanley, Samuel, Francesco, Rahul, Steffen, Ana, Elsa, Alejandro, Maria, Joseph, Sebastian, and to my housemates. Thanks to all the other persons that I have met during these amazing two years of my life. Finally, thanks to the creator, I am just an instrument in his hands and I am grateful because he allowed me to complete this thesis and this master's program.

Delft, June 2021

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Executive summary

People need to move from one place to another for different purposes, from education and work to leisure activities. Transportation means are a way to facilitate these movements. Nevertheless, the transportation sector generates negative externalities, the major ones being safety incidents, environmental impact, and traffic congestion (van Wee et al., 2013). Innovations in transportation can reduce the sector's negative externalities (Wiesenthal et al., 2015). Innovations can also benefit companies by accelerating growth and increasing profits (van der Panne et al., 2003). Urban Air Mobility (UAM) is a transport innovation that can be attractive from a societal and business perspective. UAM refers to an aerial transportation system operating within or traversing an urban area, with different applications, including passenger and goods movement, as well as emergency and surveillance services (Ragbir et al., 2020; Reiche et al., 2021; Straubinger et al., 2020; Winter et al., 2020). UAM can help to reduce traffic congestion, especially in large cities (Balac et al., 2019; Liu et al., 2017; Straubinger et al., 2020), can be safer than existing transport modes (Peksa & Bogenberger, 2020) and thanks to advances in battery technologies and in distributed electrical propulsion systems, UAM vehicles can be fully electric, generating zero local emissions (Straubinger et al., 2020). However, UAM faces significant challenges, including achieving a level of noise acceptable to society (Straubinger et al., 2020) as well as safety concerns that could hamper user adoption (Winter et al., 2020).

As explained above, materializing UAM innovations can bring benefits to society and companies, but it is challenging because UAM creates negative externalities. Innovation projects are risky and have a high probability of failure (van der Panne et al., 2003). A literature review process of what could make innovations succeed or fail showed that early stage innovation indicators are lacking. A better understanding of indicators for early stage innovations is still needed (Dziallas & Blind, 2019). Thus, a knowledge gap was identified, namely a lack of early stage innovation indicators. The early stage of an innovation starts with the initial innovation idea and ends before the formal development process begins (Dziallas & Blind, 2019; Eling & Herstatt, 2017). The early stage is important because the most critical decisions are made there (Cooper & Kleinschmidt, 1987). The use of indicators can improve decision making processes by ensuring decisions are made based on established criteria (Cooper, 1990). Assessing an innovation project before it enters the development phase can help companies identify projects that will likely fail and thus avoid investing resources in them (Dziallas, 2020; Martinsuo & Poskela, 2011).

In order to address the knowledge gap, the research question answered in this master thesis is: "*What indicators are important to support decision making at the early stage of the innovation process for Urban Air Mobility innovations?".* The following methodology was pursued to answer the research question. The first step was to obtain scientific literature from Scopus, which was coded using the qualitative content analysis software Atlas.ti, producing a code set of indicators. Secondly, gray literature was obtained via snowballing from scientific literature and with search queries in Google, which was coded to produce another code set of indicators. The independently generated code sets from scientific and gray literature were compared, serving as an initial validation, and used to produce the Indicator Set V1. Thirdly, case studies provided by the external thesis supervisor were coded to extract indicators, using the Indicator Set V1 as coding scheme. Fourthly, an interview protocol and an interview guide were created, and eight semi-structured interviews with experts from industry and academia were conducted. Interview transcripts were coded to elicit indicators. The indicators found at interviews were compared and merged with the Indicator Set V1, producing the Indicator Set V2. Additionally, a framework was created, showing how indicators can be used to make decisions at early stages of the innovation process. Finally, a workshop was conducted with experts from a company

manufacturing an UAM aircraft. The feedback obtained from the workshop was used to validate and revise the Indicator Set V2 and the framework, answering the research question.

The results of this thesis show that the actions that can be taken regarding early stage indicators fall into three types. Firstly, some indicators can be determined at the early stage, such as the fulfillment of key requirements, alignment with company strategy, synergy with company capabilities, and the value proposition. Secondly, there are indicators whose value can be influenced at the early stage, although these indicators are also dependent on later stages. Examples are production and operation costs, operational downtime, sustainability (which includes emissions and recyclability at the end of life), and user comfort. Thirdly, there are indicators that although they cannot be impacted at the early stage, they should still be identified early to assess if they could become showstoppers at later stages. Examples are the perception of UAM as visually polluting, and its perception as a service only benefiting people from higher income classes.

The thesis findings were compared with previous research, namely with Dziallas (2020), who investigated early stage indicators for incremental innovations in the automotive industry, with Cooper (2008), who listed a set of criteria to assess whether a new product should continue to the development phase, and with Feitelson & Salomon (2004), who proposed a model of how transport innovations are adopted. This comparison resulted in the following insights. Firstly, there are many indicators in common between this thesis and Dziallas (2020) and Cooper (2008), suggesting there are early stage indicators applicable to innovations in any industry. Secondly, some indicators found by Dziallas (2020) that were not elicited in this thesis seem to be relevant only for incremental innovations, while indicators found in this research not elicited by Dziallas (2020) seem to be only useful for radical innovations. Indicators related to the societal and political acceptance of the innovation are an example of those that are likely applicable to radical innovations only. Acceptance indicators are also absent at Gate 3 in the research of Cooper (2008). Finally, while the results of this thesis roughly confirm the Political Economy model proposed by Feitelson & Salomon (2004), namely that the factors that influence the adoption of an innovation are its technical feasibility, social and political feasibility and financial feasibility, this thesis contributes to the model in the following ways. It specifies that indicators belonging to the social and political feasibility should be identified at the early stage and it identifies early stage indicators belonging to the categories of user adoption and timing feasibility, which were not conceptualized in the Political Economy model.

The main takeaways resulting from this thesis are the following. Firstly, the early stage of the innovation process is critical because there are several indicators whose value is already determined at this stage, as well as indicators that although they are dependent on implementation, their value can already be influenced at the early stage. Even for indicators that are fully dependent on later stages, it is important to identify them early to assess the likelihood that these indicators become showstoppers, which aids companies to assess the risk of innovation projects and decide whether to continue them or not. Secondly, user adoption, which is critical for the innovation's success, can be addressed by involving potential users early in the design process. Ways to do this include employing surveys, interviews and simulators. Finally, societal and political acceptance are paramount for innovation success. The indicators relevant for them can be identified at the early stage in order to assess if they are likely to become showstoppers or if they are enablers that can be leveraged to boost the acceptance of the innovation. Then, companies can assess if they can be influenced early in the design process. For UAM, noise is an example of such an indicator. An UAM aircraft could comply with noise requirements from certification perspective and still not being allowed to fly in its target markets because the local regulators or the citizens consider the noise level generated as unacceptable. To avoid this, acceptable noise levels can be investigated at the early stage and translated into design requirements.

Investigating at the early stage what indicators drive societal and political acceptance can be useful to any transport innovation, and not only to UAM. Further research is needed to conclude about this and to better understand how to address social and political acceptance at the early stage of innovation. Possible avenues are researching how previous successful and failed innovations have dealt with acceptance, and how current candidate innovations in transportation or in other sectors are addressing these issues at the early stage. Other opportunities for future research are the following. Firstly, given that most of the indicators found in this thesis can only be evaluated qualitatively (soft indicators), future researchers can continue looking for early stage innovation indicators that can be evaluated quantitatively (hard indicators). Secondly, to investigate the differences between early stage indicators for incremental versus radical innovations. Thirdly, to determine which early stage indicators are applicable across different industries, and which are specific to an industry or to a specific innovation. Finally, to investigate decision making processes at the early stage of innovation in order to better understand them.

1 Introduction

1.1 Problem background

Moving from one place to another is a basic human need. People travel for several reasons including to go to work, to attend school, for tourism, to meet family and friends and for entertainment. Transportation means are a way to facilitate these movements. However, the transport sector creates negative externalities. The most important ones are a detrimental impact on the environment, safety incidents and traffic congestion (van Wee et al., 2013). Worldwide, the transport sector generates 16.2% greenhouse gas emissions (Ritchie & Roser, 2020). This figure includes the emissions caused by passenger and freight travel on road, sea and air. Traffic congestion results in travel time losses. Because of high congestion levels, in cities such as Mumbai, Bogota and Istanbul, a trip will take at least 50% more time than what it would under uncongested conditions (TomTom, 2020). Regarding safety, taking the European Union as example, although the number of road fatalities has been steadily decreasing, in 2020 there were 18,800 fatalities in the EU, versus a target of 14,800 (European Commission, 2020).

From a societal and policy perspective, it is important to innovate in transportation because new developments can reduce the sector's negative impacts (Wiesenthal et al., 2015). For example, innovations in airplane's cooling systems have enabled reductions in fuel consumption, which in turn have reduced emissions (Young, 2007). Another example is the catalytic converter, which reduces the acid emissions generated by internal combustion engines (van den Bergh et al., 2007). Innovation is also relevant from a business perspective. Innovations generally accelerate growth and help companies to achieve larger profits (van der Panne et al., 2003). For instance, innovations that increase airplane fuel efficiency are a selling factor for aircraft manufacturers (Wiesenthal et al., 2015).

Urban Air Mobility (UAM) is a transport innovation that can be attractive from a societal and business perspective but also causes negative impacts, as will be elaborated in the next paragraphs. UAM refers to an aerial transportation system operating within or traversing an urban area, with different applications, including passenger and goods movement, as well as emergency and surveillance services (Ragbir et al., 2020; Reiche et al., 2021; Straubinger et al., 2020; Winter et al., 2020). For scoping reasons, this thesis focused on passenger applications.

UAM promises to use the urban air space and thus help to reduce traffic congestion, especially in large cities (Balac et al., 2019; Liu et al., 2017; Straubinger et al., 2020). UAM could be safer than existing transport modes (Peksa & Bogenberger, 2020). Moreover, thanks to advances in battery technologies and in distributed electrical propulsion systems, UAM vehicles can be fully electric and thus, no local emissions will be generated (Straubinger et al., 2020). Most UAM applications employ flying vehicles capable of taking off and landing vertically (Straubinger et al., 2020). Because of this, few additional infrastructure is required to establish an UAM service when compared to building additional lanes or expanding a subway line. UAM can improve accessibility by providing transportation services in places where public transportation is deficient or non-existent, such as hilly regions, islands, or areas separated by lakes and rivers (Straubinger et al., 2020). Finally, UAM aircraft can be used to improve the time responsiveness during medical emergencies (Rajendran & Pagel, 2020). UAM is also attractive from a business perspective. UAM has the potential to become mass market, something that has not been achieved by helicopters, thanks to being four times quieter, 10 times less expensive and twice as safe as conventional helicopters (Grandl et al., 2018). Combining all different applications of UAM, it is estimated that by 2035, the UAM market will have a value of 74 billion USD (Grandl et al., 2018).

However, UAM faces significant challenges. Firstly, although a reduction in traffic congestion is mentioned as one of the promised benefits of UAM, its potential to significantly reduce congestion is low because of possible induced demand and because recent studies have estimated a rather low modal share for UAM (Straubinger et al., 2020). Secondly, although the noise signature of UAM aircraft is lower than conventional helicopters, the noise generated by UAM aircraft will still have a major impact on social acceptance (Al Haddad, Chaniotakis, et al., 2020). According to Straubinger et al. (2020), achieving an acceptable noise level and type is a considerable design challenge. Thirdly, safety concerns could hamper user adoption when UAM is introduced (Winter et al., 2020).

As elaborated above, materializing UAM innovations can bring benefits to society and companies, but it is challenging because UAM also creates negative externalities. Innovation projects are risky and have a high probability of failure (van der Panne et al., 2003). Therefore, it is relevant to research what could potentially make innovations succeed or fail. It was decided to do a literature review of the Success and Failure Factors (SFF) of innovations, especially within the transportation sector. The results of this review are described briefly in this chapter and in more detail in Chapter 2.

Major studies about SFF of innovation were analyzed by van der Panne et al. (2003), who reviewed 43 articles about SFF of innovation in multiple industries, and by Dziallas & Blind (2019), who reviewed 226 papers about indicators and success factors of both product and process innovations. The literature review process conducted by the author showed that it is important to better understand early stage innovation indicators since they can be used to assess the success potential of innovation ideas (Dziallas & Blind, 2019). This is because the most important decisions are made at the predevelopment or early stage (Cooper & Kleinschmidt, 1987). Therefore, the early stage is critical for the future success or failure of an innovation (Cooper, 1990).

Early stage indicators are useful for several reasons. Firstly, they can help companies to decide which innovation projects to stop. Assessing an innovation project before it enters the development phase can help companies identify projects that will likely fail and thus avoid investing resources in them (Dziallas, 2020; Martinsuo & Poskela, 2011). Secondly, it is usually less expensive to make design changes at an early stage. Thus, employing early stage indicators can save costs at later stages, apart from decreasing the likelihood of failure (Dziallas, 2020). Thirdly, the use of indicators can improve decision making processes at companies when deciding on which innovation projects to continue and which to stop. Making innovation decisions using early stage indicators renders the rationale behind decisions transparent and traceable (Dziallas, 2020), ensuring decisions are made based on established criteria instead of gut feeling (Cooper, 1990).

As explained above, early stage indicators are highly relevant. However, the way in which the early stage of the innovation process is managed is not well documented in literature (Eling & Herstatt, 2017). Moreover, a better understanding of indicators for early stage innovations is still needed (Dziallas & Blind, 2019). This thesis addresses this knowledge gap by investigating early stage innovation indicators for UAM. To ensure clarity, the concepts of the research gap are defined in the following section.

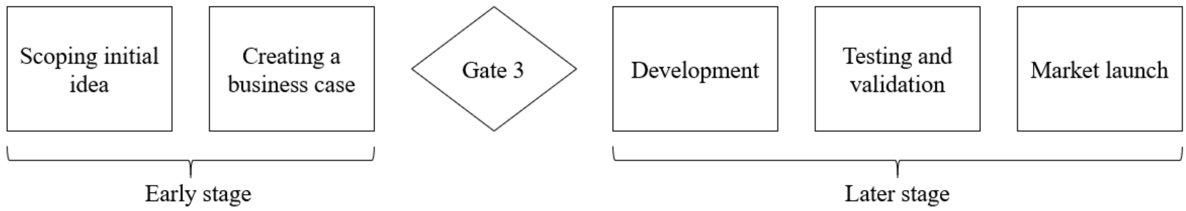
1.2 Definition of key concepts

The Oslo Manual defines an innovation as something that is substantially different from existing products or processes and that is accessible to its intended users (OECD/Eurostat, 2018). Weisshaar (2013) specifies that apart from being accessible, an innovation must be adopted by users. Innovations can be classified as radical or incremental. Radical innovations are disruptive and transform businesses, they have new technologies or breakthrough ideas as starting point and are associated with high risk, while incremental innovations are gradual improvements, they have existing products or processes as starting points and have lower risk than radical innovations (Dumay et al., 2013).

Indicators are measures that provide information about the innovation itself and potential problems related to it (Dziallas & Blind, 2019). Indicators can be either hard or soft. The former are those that can be associated with a numeric value, such as speed. The latter are those that have a qualitative value, such complexity level (which can be evaluated as high, medium or low, for example). Thus, an indicator is measurable, either quantitatively or qualitatively, distinguishing it from a factor, which cannot be measured directly. Instead, a factor needs one or more indicators so that it can be measured.

Finally, the early stage or front-end of the innovation process is the phase starting with the initial innovation idea and ending before the formal development process begins (Dziallas & Blind, 2019; Eling & Herstatt, 2017). The early stage involves identifying business opportunities, developing a product strategy, creating concepts and analyzing their commercial and technological feasibility and risks (Eling & Herstatt, 2017; Khurana & Rosenthal, 1998). An innovation idea is no longer at the early stage when the firm starts to dedicate significant resources to its development (Cooper, 1990; Eling & Herstatt, 2017). Figure 1, created based on Cooper's Stage-Gate ® process (Cooper, 2008), shows graphically what is meant with early stage in this thesis. An innovation that passes Cooper's Gate 3 and thus enters the development phase is no longer considered early stage.

Figure 1 Defining the early stage



1.3 Research questions

The objective of this thesis is to find a set of early stage innovation indicators for UAM. In order to achieve this, the main research question (MRQ) to be answered is:

What indicators are important to support decision making at the early stage of the innovation process for Urban Air Mobility innovations?

The indicators are meant to be used by decision makers at companies, especially those who decide whether an innovation project should be continued or not. The MRQ is split into the following sub-questions (SQ):

- SQ1. What indicators associated with the potential success of UAM are there?
- SQ2. Which indicators are applicable at the early stage of the innovation process of UAM?
- SQ3. How can the indicators from SQ2 be used to support decision making for early stage innovations in UAM?

1.4 Overview of UAM

UAM has a broad range of applications and a big market potential. Grandl et al., (2018) group UAM applications into four large clusters. The first cluster has an estimated market size of 34 billion USD in 2035 and includes drones used for purposes such as leisure, media, agriculture, forestry, inspections, security, research, and mapping. The second cluster, goods transport, has a value of 4 billion USD and includes cargo, express delivery and emergency transportation (of medicines, for example). The third cluster is for passenger applications, including commuting, tourism and emergency services, and has an estimated market of 32 billion USD. Finally, supporting services including maintenance, ATM, and operation of infrastructure are worth 4 billion USD.

There are several factors enabling the development of UAM. Firstly, advances in VTOL (vertical take-off and landing) technology can reduce the noise generated in comparison to helicopters (Balac et al., 2019). Secondly, UAM players will be able to achieve significant cost reductions thanks to low cost and high quality components that are commercially available (Straubinger et al., 2020). Finally, technological advances in battery energy storage and in electric and distributed propulsion systems will not only enable UAM to reduce costs but also to gain societal acceptance (Antoniou et al., 2018).

From the four UAM clusters distinguished by Grandl et al., (2018), this thesis focused on UAM innovations for passenger applications. Within this cluster, different use cases can be distinguished. UAM can be used to connect cities that are too close to have flights between them, usually with a flight range between 50 and 250 km (Baur et al., 2018). For shorter flight ranges, there are several possibilities. One of them is the so-called air taxi or air bus, which will cover distances between 15 and 50 km (Baur et al., 2018). Such services will be established from point A to point B within a city, or between a city and a nearby airport (Baur et al., 2018). Another potential use is to deploy the aircraft for emergency services, especially for ambulances (Booz Allen Hamilton, 2018).

Contrary to conventional passenger aviation, where there the tube and wing configuration is dominant, there are multiple aircraft configurations for UAM. The classification and description of configurations below was made based on Baur et al. (2018) and on eVTOL News (2021a).

- Fixed wing vectored thrust. Its thrusters can be used for both lift (vertical movement) and cruise (horizontal movement). An example is Lilium Jet.
- Tilt wing or convertible configurations. They have multiple propellers attached to fixed or tilting wings, allowing them to achieve different configurations depending on the flight phase. An example is the now defunct Airbus Vahana.
- Lift + cruise. This configuration has two independent set of thrusters, one set to generate lift and another for cruising. An example is Embraer EVE.
- Multicopter. This configuration is wingless. It has multiple thrusters to generate lift. An example is Volocopter VoloCity.
  - An especial case within multicopter configurations are quadrocopters, which have four fixed propellers. An example is Airbus Helicopters CityAirbus
  - Another especial case are personal flying devices, in which the person is standing or sitting on a saddle. An example is Talaria Hermes.
- Rotorcraft is a configuration that uses an electric rotor or a gyrocopter. An example is PAL-V International Liberty

Figure 2 below shows a picture of each of the example UAM aircraft mentioned.

Figure 2 Examples of UAM configurations

Airbus Vahana, tilt wing configuration, by (Rodriguez, 2019)

PAL-V International Liberty, gyrocopter configuration, by (PAL-V, 2021)

Embraer's EVE, lift + cruise configuration, by (EmbraerX, 2021)

Volocopter Volocity, multicopter configuration, by (Volocopter, 2021a)

Talaria Hermes, personal flying device, by (eVTOL News, 2021b)

Airbus Helicopters CityAirbus, quadrocopter configuration, by (Airbus Helicopters, 2019)

Lilium Jet, vectored thrust with fixed wings configuration, by (Lilium, 2021)

1.5 CoSEM perspective

UAM is an intervention in a sociotechnical system that could bring benefits to society, apart from being a considerable business opportunity for companies. Nevertheless, there are uncertainties regarding whether the promised benefits can be realized, as well as whether society and users will accept UAM. Therefore, it is interesting to study it in a master thesis of the Complex Systems Engineering and Management (CoSEM) program.

UAM has both societal and technical components. Based on a scheme by Geels (2002) showing the sociotechnical configuration for personal (car) transportation, the following elements can be identified in a future UAM system. The societal components or actors include Original Equipment Manufacturers (OEMs), this is, companies manufacturing UAM aircraft; suppliers providing parts to aircraft OEMs; operators of UAM services; companies providing maintenance and other services to operators; certification authorities such as the Federal Aviation Administration (FAA) in the USA and the European Union Aviation Safety Agency (EASA); local (city) regulators; the general public; users of UAM services; research networks; and financial institutions providing capital. The technical components are the infrastructure to charge and/or refuel aircraft, the infrastructure to take-off and land, the air traffic management (ATM) systems and the UAM aircraft.

When looking at the technical system only, the presence of large scale intangible systems, such as the ATM, as well as required investments in physical infrastructure with a long lifespan, contribute to the complexity of the sociotechnical configuration of UAM. When analyzing the multi-actor network, there are deep uncertainties regarding how many people will use UAM services and to what extent will the general population accept this new technology. From a company's perspective, UAM represents a big business opportunity. Nevertheless, the long development cycles for aerospace applications can increase risk and uncertainty. Events such as regulatory changes or geopolitical conflicts like the dispute between Airbus and Boeing (WTO, 2020) can happen during the development phase, modifying the assumptions made at the beginning of innovation projects. Moreover, aerospace companies have to comply with strict safety and security regulations (Wiesenthal et al., 2015), and UAM aircraft is not exempted from this. Additionally, UAM could cause power shifts in the aerospace industry with technology companies such as Uber and startups such as Lilium and Volocopter entering the sector. From a governmental perspective, the aerospace sector is highly important given its impact in the balance of trade and its knowledge intensiveness (MacHado & Hatakeyama, 2018). Moreover, new regulations will be needed for pilot licensing, determining the requirements that take-off and landing areas have to comply with, and especially, determining certification standards (Straubinger et al., 2020). Summing up, a high number of stakeholders, multiple interdependencies between their needs, the large scale and long life span of the technical system contribute to the complexity of materializing UAM innovations.

1.6 Structure of thesis report

The rest of the thesis is structured as follows. Chapter 2 contains the review of scientific literature that was used to underpin the knowledge gap, while Chapter 3 contains the scientific and gray literature that was used to answer the research questions. Chapter 3 also explains the methodology that was pursued, motivating the rationale for employing each of the chosen data gathering methods, describes the data that was collected and explains how it was analyzed. Chapter 4 presents the results obtained by following the methodology, presenting the answer to each of the SQs, which build upon each other in order to answer the MRQ. Chapter 5 discusses implications for society, environment and companies, reflects on the results obtained and compares them with previous research, and reflects on limitations. Finally, Chapter 6 concludes by presenting the main contributions of this thesis project and suggesting future research opportunities.

2 Literature review and knowledge gap

2.1 Reviewing literature on success and failure of innovation

Literature was reviewed to understand what has been researched about SFF of innovations in transportation and aerospace. Two final search strings were entered in Scopus. The first one, (*transport* OR aviation OR aerospace OR aircraft OR aeronautics AND success AND failure AND innovati* OR {r&d} OR {research and development}*), yielded 126 articles. The second one, (*success AND failure AND factor AND innovati* OR {r&d} OR {research and development} AND decision OR choose OR select AND NOT patient OR medic* OR health*), yielded 110 articles. Abstracts and titles were scanned, and based on the criteria "Success factors are about the innovation", 14 articles from the first string and 15 from the second were pre-selected. After reading abstracts and conclusions, five articles were selected from the first string based on the criteria "the articles refer to an innovation carried out by aerospace or transportation companies". Additionally, four articles were selected based on the criteria "the articles refer to an innovation carried out by companies". Afterwards, forward and backward snowballing yielded eight additional articles that fulfilled the aforementioned selection criteria. An overview of the articles reviewed is shown in Table 1.

Table 1 Overview of literature used to substantiate the knowledge gap

Authors and year	Title	Relevant findings
(Shenhar et al., 2020)	If You Need Innovation Success, Make Sure You've Got the Right Project	Proposes framework combining innovation and project management
(Cleophas et al., 2019)	Collaborative urban transportation: Recent advances in theory and practice	Social and political acceptance and support can be more important than technical challenges.
(Park, 2019)	Identification of overall innovation behavior by using a decision tree: The case of a Korean manufacturer	R&D, firm size and age positively correlate to innovation success.
(Dziallas & Blind, 2019)	Innovation indicators throughout the innovation process: An extensive literature analysis	Appropriate indicators for early stages are lacking. Future research is needed to aid decision makers.
(Naor et al., 2018)	Servitized business model innovation for sustainable transportation: Case study of failure to bridge the design-implementation gap	Explains why successful IT company failed in transport
(Vértesy, 2017)	Preconditions, windows of opportunity and innovation strategies: Successive leadership changes in the regional jet industry	Windows of opportunity and strategic responses explain success.
(Weisshaar, 2013)	Morphing aircraft systems: Historical perspectives and future challenges	Success happens when there is a clear need to improve or create a new product
(Dumay et al., 2013)	An intellectual capital-based differentiation theory of innovation practice	Further research needed to understand success of innovation. Links intellectual capital theory with innovation types.
(Moenaert et al., 2010)	Strategic innovation decisions: What you foresee is not what you get	Competitiveness, a factor neglected by decision-makers, was important success predictor
(Young, 2007)	Aircraft design innovation: Creating an environment for creativity	Identifies factors promoting and inhibiting innovation

(van den Bergh et al., 2007)	Social learning by doing in sustainable transport innovations: Ex-post analysis of common factors behind successes and failures	Political, process, socio-cultural and psychological factors have greatest impact on success
(Palmberg, 2006)	The sources and success of innovations - Determinants of commercialisation and break-even times	Innovations stemming from customer demand can reach market quicker than those stemming from inventions
(Woodside et al., 2005)	Modelling innovation, manufacturing, diffusion and adoption/rejection processes	Proposes IMDAR framework. Argues that success can occur even when success factors are absent
(Feitelson & Salomon, 2004)	Political economy of transport innovations	Proposes framework on adoption of transport innovations
(van der Panne et al., 2003)	Success and Failure of Innovation: A Literature Review	Identifies common and contested success factors in literature
(Balachandra & Friar, 1997)	Factors for success in R&D projects and new product innovation: a contextual framework	Based on review, proposes a 3-axes framework: technology, innovation and market
(Cooper & Kleinschmidt, 1987)	New products: What separates winners from losers?	The most critical decisions are made during predevelopment phase.

2.2 A need for early stage innovation indicators

Few literature was found about SFF of innovation in aerospace. Relevant articles found were a review of morphing aircraft innovations (Weisshaar, 2013), factors promoting and inhibiting design innovation in aerospace (Young, 2007), and case studies in the regional jet industry (Vértesy, 2017). Thus, the literature review process itself revealed a knowledge gap, namely SFF of innovation in aerospace. Given that not enough literature was found when restricting to SFF in aerospace, the search criteria were relaxed to include innovations carried out by companies in any sector.

SFF of innovation have been researched for a long time. Van der Panne et al. (2003) did literature review of major studies, starting at 1972 with SAPPHO research until a 1999 study by Brouwer et al. Although there have been many studies on SFF, it is still necessary to better understand what makes innovations succeed or fail (Dumay et al., 2013).

Research in the field has had different perspectives. Some studies have focused on one industrial sector and one country. Palmberg (2006) performed duration analysis to data from 600 Finnish manufacturing firms, while Park (2019) analyzed data from 8,075 Korean manufacturing companies. Other studies have combined data from several industries. Dumay et al. (2013) performed semi-structured interviews with executives of companies of several industrial sectors in Australia. In their literature review, van der Panne et al. (2003) included studies from electronics, medical instruments, manufacturing and high-tech industries. Another perspective is distinguishing SFF depending on type of innovation: radical, evolutionary, or incremental, as Dumay et al. (2013) did.

Other authors have focused on researching SFF according to the innovation process stage. By performing an ex-ante analysis, Moenaert et al. (2010) identified factors considered important by executives when making decisions in the early stage of the innovation process. Afterwards, an ex-post analysis revealed that competitiveness, a factor disregarded by executives, is an important predictor of success. This highlights the need for further research in early stages. Cooper & Kleinschmidt (1987) also identified predevelopment decisions, such as product screening and market assessment, as the most critical. This knowledge gap has been explicitly stated by Dziallas & Blind (2019), who did a literature review of innovation publications between 1980 and 2005, and recommended to investigate the effects that early stage indicators have on the future success of the innovation.

2.3 The importance of innovation indicators

Indicators are useful to dissect a complex system, allowing to evaluate smaller units of it separately (Castillo & Pitfield, 2010). Assessing an innovation's potential at early stages is more difficult than at later stages of the innovation process because fewer information is available at early stages (Dziallas, 2020). Still, using a set of predefined criteria to select ideas for advancement is better than deciding based on intuition (Eling et al., 2016).

There is disagreement regarding whether a formal evaluation process to identify the ideas with the highest success potential is beneficial or not. Martinsuo & Poskela (2011) found that the relation between a formal evaluation process and innovation performance is insignificant. In contrast, Eling et al. (2016) say that using formal processes to decide which innovation ideas should move forward in the development process results in a higher success rate (defining success as being adopted). This applies to both incremental and radical innovations (Eling et al., 2016)

Although there is no consensus about the usefulness of a formal evaluation process, both sources agree that using evaluation criteria is beneficial, helping to identify the ideas with the highest success potential. Eling et al. (2016) argue that using a set of predetermined indicators to select which innovation ideas should continue to the next stage of the development process increases the chances of success for both radical and incremental innovations while Martinsuo & Poskela (2011) found that using evaluation indicators is beneficial to assess the future potential of an idea at an early stage of the innovation process.

2.4 Positioning this master thesis within previous academic research

Building upon the indicators found previously by Dziallas & Blind (2019), Dziallas (2020) has researched indicators for early stage incremental innovations in the automotive industry. However, ESI indicators should still be further researched (Dziallas, 2020). Dziallas (2020) mentions the applicability of her findings to other industries as a limitation of her study. Thus, it is of scientific interest to research indicators in another industry, namely UAM, which is an innovation in aerospace.

Some studies have used indicators to assess UAM, although these studies have not focused specifically on the early stage. Via focus groups with 10 experts from industry, academia and Munich airport, Al Haddad, Fu, et al., (2020) obtained indicators to assess the potential of UAM integration with existing public transportation systems, without distinguishing stage in the innovation process. Additionally, Ploetner et al. (2020) used indicators to evaluate how can UAM complement public transportation. While integration with public transportation is important to the success of UAM, it is only one aspect to consider. To the author's knowledge, so far nobody has obtained a holistic set of indicators to evaluate the success potential of UAM innovations at early stages of the innovation process. To ensure that the set of indicators is as holistic as possible, scientific and gray literature, as well as case studies and interviews were used in this research to elicit UAM indicators, as explained in the next chapter.

3 Methodology

3.1 Overview of Methodology

This chapter is structured as follows. Section 3.2 presents the rationale to use scientific literature as a source to extract indicators, and explains how it was gathered and analyzed. Section 3.3 elaborates on why the author decided to use gray literature as second source to extract indicators, and explains how the data was gathered and analyzed. Section 3.4 presents the rationale to use case studies as a third indicator source, and how they were selected and analyzed. Section 3.5 motivates why and how semi-structured interviews were used, presents the interview protocol, explaining how interviewees were selected and how interviews were conducted, and describes how the data (the interview transcripts) were generated and analyzed. Finally, Section 3.6 explains the reason to use a workshop, describing its format and participants.

Figure 3 presents the methodology followed and how it was used to generate the results to answer the research questions. Figure 4 shows what parts of the methodology are explained in each of the sections of the Methodology Chapter, as well as their connection with the sections of the Results Chapter. This is explained in the following paragraph.

The first step in the methodology was to obtain scientific literature from Scopus, which was coded using the qualitative content analysis software Atlas.ti, producing a set of codes from scientific literature (Section 3.2). Secondly, gray literature was obtained via snowballing from scientific literature and with search queries in Google, which was also coded to produce another code set of indicators (Section 3.3). The independently generated code sets from scientific and gray literature were compared, serving as an initial validation of the findings. Moreover, the code sets were merged to create the Indicator Set V1. The indicators from this set were used to create the Framework V1. This is explained with further detail in Section 4.2. Thirdly, case studies provided by the external supervisor were coded, using the Indicator Set V1 as coding scheme (Section 3.4). This step served as validation because it allows to know whether the Indicator Set V1 can capture all indicators found in the case studies. In this way, scientific literature, gray literature and case studies were used to answer SQ1. Fourthly, an interview protocol and an interview guide were created, and semi-structured interviews were conducted. Interview transcripts were coded to elicit indicators (Section 3.5). The interview code set was compared with the Indicator Set V1 to validate it and produce the Indicator Set V2, answering SQ2. Additionally, the interview code set was used to create the Framework V2, which shows how indicators can be used to make decisions at early stages of the innovation process, answering SQ3 (Section 4.3). Finally, a workshop was planned and conducted (Section 3.6) and the feedback obtained from it was used to validate and revise the Indicator Set V2 and the Framework V2, answering the MRQ (Section 4.4).

Figure 3 Methodology

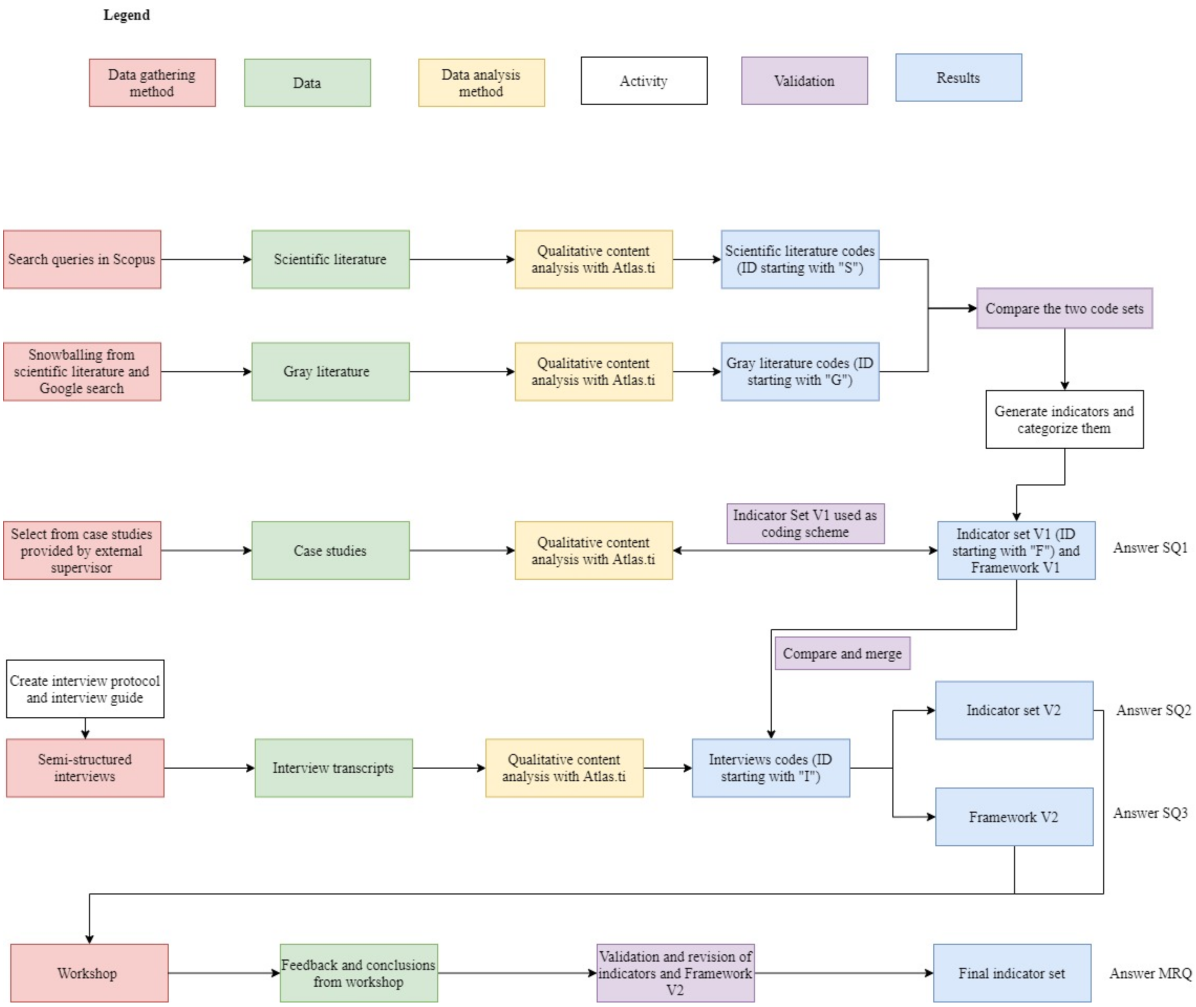
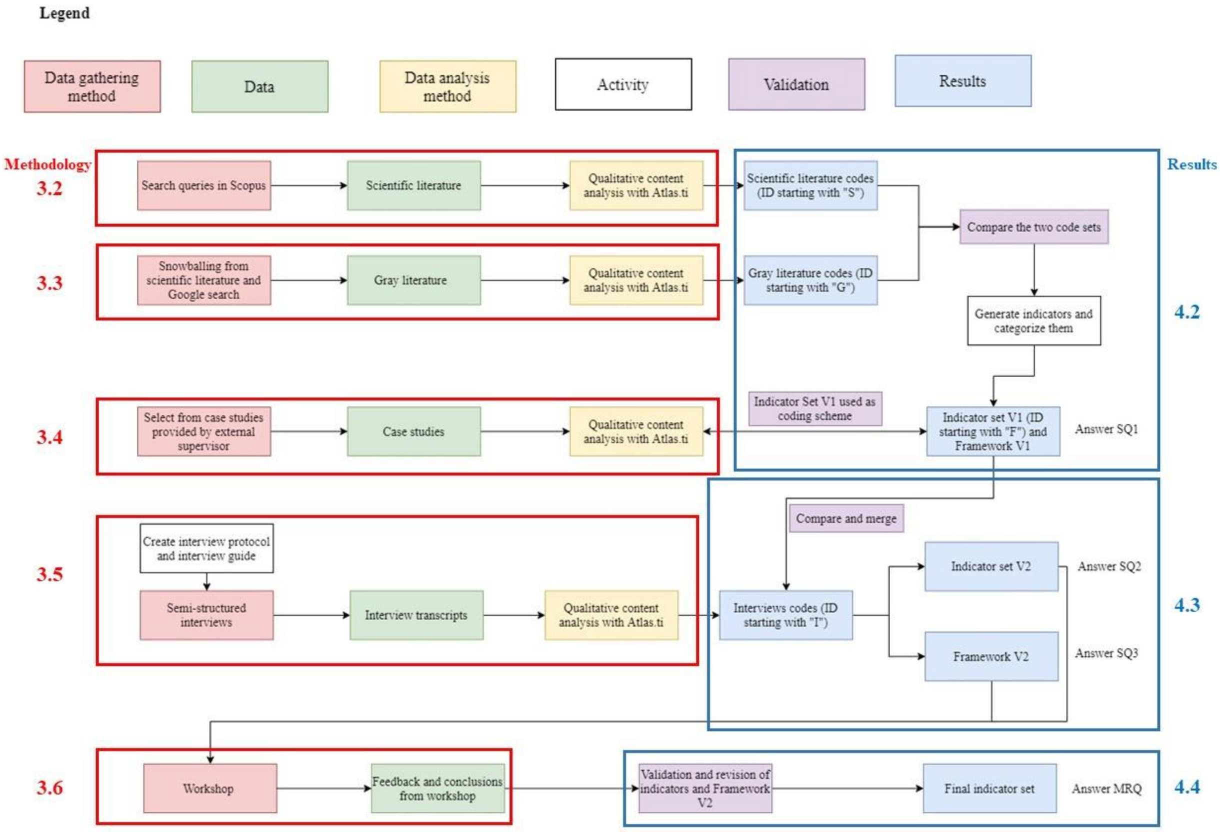


Figure 4 Structure of Chapter Methodology and connection with Chapter Results



3.2 Reviewing scientific literature about indicators for UAM

3.2.1 Rationale for using scientific literature

Scientific literature was chosen as a source to find indicators because it has high credibility and academic rigor. Moreover, analyzing academic literature is advantageous from a methodological perspective because its standard format and word limits facilitate the search, selection and content analysis of relevant articles.

3.2.2 Gathering scientific literature

A literature search in Scopus was made. An initial search with the string {urban air mobility} yielded 336 articles. This search was performed with few keyword because it was unknown if enough literature was available (at least 100 papers). Since more than 100 papers were found in this initial search, keywords were added to improve the quality of results, so that the papers obtained with the query were more likely to contain information to answer the research question. Three keywords were identified: "urban air mobility", "indicator", and "success" and synonyms for those keywords were obtained. After performing several exploratory queries, the final string used was ({urban air mobility} AND use OR adoption OR success OR implement* OR accept* OR viability OR factor OR indicator OR barrier), which yielded 122 articles.

The title and the parts of the abstract where the keywords appear were read to assess whether the article fulfilled the following selection criteria:

- UAM is the main topic of the paper
- They keyword "indicator" or a synonym, is an indicator of UAM

- The keyword “success” or a synonym refers to UAM

This resulted in 54 articles. To obtain the final selection of articles, the following final selection criteria were applied based on reading abstracts and conclusions:

- UAM is the main topic of the paper
- At least one indicator can be inferred from or is explicitly mentioned in the abstract or conclusion

This resulted in 15 articles. Additionally, forward and backward snowballing was performed to find articles that fulfilled the final selection criteria. Four articles were obtained in this way. The 19 articles that were analyzed can be found in Table 2.

Table 2 Analyzed scientific literature

Authors and year	Title
(Courtin et al., 2018)	Feasibility Study of Short Takeoff and Landing Urban Air Mobility Vehicles using Geometric Programming
(Rothfeld et al., 2018)	Initial Analysis of Urban Air Mobility’s Transport Performance in Sioux Falls
(Antoniou et al., 2018)	Agent-based Simulation of Urban Air Mobility
(Fu et al., 2019)	Exploring Preferences for Transportation Modes in an Urban Air Mobility Environment: Munich Case Study
(Maxa et al., 2019)	Security Challenges of Vehicle Recovery for Urban Air Mobility Contexts
(Balac et al., 2019)	The Prospects of on-demand Urban Air Mobility in Zurich, Switzerland
(Niklaß et al., 2020)	A Collaborative Approach for an Integrated Modelling of Urban Air Transportation Systems
(Winter et al., 2020)	A prediction model of Consumer’s willingness to fly in autonomous air taxis
(Straubinger et al., 2020)	An overview of current research and developments in urban air mobility - Setting the scene for UAM introduction
(Al Haddad, Fu, et al., 2020)	Choosing suitable indicators for the assessment of urban air mobility: A case study of upper Bavaria, Germany
(Peksa & Bogenberger, 2020)	Estimating UAM Network Load with Traffic Data for Munich
(Al Haddad, Chaniotakis, et al., 2020)	Factors affecting the adoption and use of urban air mobility
(Ragbir et al., 2020)	How Weather, Terrain, Flight Time, and Population Density Affect Consumer Willingness to Fly in Autonomous Air Taxis
(Thomas et al., 2020)	Multidisciplinary Systems Analysis of a Six Passenger Quadrotor Urban Air Mobility Vehicle Powertrain
(Rajendran & Pagel, 2020)	Recommendations for emerging air taxi network operations based on online review analysis of helicopter services
(Ploetner et al., 2020)	Long-term application potential of urban air mobility complementing public transport: an upper Bavaria example
(Rajendran & Shulman, 2020)	Study of emerging air taxi network operation using discrete-event systems simulation approach
(Ahmed et al., 2020)	The Flying Car — Challenges and Strategies Toward Future Adoption
(Reiche et al., 2021)	An Initial Assessment of the Potential Weather Barriers of Urban Air Mobility

3.2.3 Analyzing scientific literature

The data analysis method used for scientific literature and all other data sources of this thesis is qualitative content analysis. There are two main approaches that can be pursued when doing qualitative content analysis, namely inductive and deductive. An inductive content analysis is recommended when there is limited previous research about the phenomenon under consideration (Elo & Kyngäs, 2008). In contrast, a deductive approach is pursued when the researcher is starting from previous theories or when the purpose of the analysis is to test theory (Elo & Kyngäs, 2008). An inductive approach was pursued in this thesis since the objective is to find indicators that are currently lacking.

Qualitative content analysis is suitable to handle large volumes of text coming from diverse sources, as well as to contrast and corroborate the evidence found (Elo & Kyngäs, 2008). In this research, several data sources are used, namely scientific and gray literature, case studies and interview transcripts. The indicators found in academic and gray literature and case studies were compared against each other to create an indicator set. Thereafter, they were validated with the indicators found at the interviews.

Using qualitative content analysis can be challenging because the researcher can be lost amidst a vast amount of information. Another difficulty is that there are is no right way to do it and is thus dependent on the abilities of the researcher (Elo & Kyngäs, 2008). To address these limitations, the following actions were taken. Firstly, to decrease the dependency on the researcher's skills, the software Atlas.ti was used. This qualitative data analysis software has several functionalities that facilitate the coding process such as merging and splitting codes, creating code groups, importing and exporting coding schemes, keeping track of the number of times a code has been used, and providing an easy way to revise all the quotations that have the same code. Secondly, during the whole content analysis process, the research question was kept under consideration to remind the researcher of what should be extracted from the texts. According to Elo & Kyngäs (2008), this apparently simple action can help the investigator to differentiate what is relevant from what is not. Finally, a coding methodology was designed by the researcher. This methodology was based on Friese (2020), who provided guidance specific to Atlas.ti, and on Saldaña (2009), who explains several coding techniques without focusing on using a particular software. Having a coding method gave structure to the process, which is important for consistency and to speed up the analysis of texts.

The coding methodology followed is described below. This methodology was designed by the author, based on Friese (2020) and on Saldaña (2009).

First cycle

This step was a rough coding that consisted of free coding and creating categories.

- Free coding: This involved looking for pieces of text, called quotations, containing information related to the potential success of UAM. One or multiple codes were assigned to each quotation, trying to condense its essence (Saldaña, 2009). A new code was created only when the already existing codes didn't fully capture the essence of the quotation.
- Creating categories: After assigning free codes, categories were created to classify codes that shared something in common. The category name tried to capture that commonality. Inspired on Friese (2020), the following nomenclature was used for each code: "*category: indicator name / remark or sub-indicator*". Using this nomenclature makes it easy to filter all indicators belonging to the same category, which helps to identify redundant codes that should be merged. This will be useful in the second cycle of coding.
- Using special nomenclature: As suggested by Friese (2020), codes that didn't fit well in a category or that were problematic in any other way were marked with an asterisk in their name

for traceability, so that they could be processed later. Additionally, the author added the symbol "%" to indicators that, according to what was learned from literature, were particularly useful at early stages. This was done only as part of the author's thought process.

Second cycle

This step consisted of reviewing what was done in the first cycle by recoding, reviewing categories and reviewing assignment of codes to categories.

- Recoding involved merging and splitting codes. When assigning codes to categories, it became apparent that some codes expressed similar ideas. In this case, the codes were merged. The new code was either one of the original codes or a new code that captured both. Splitting was performed when codes were too generic, leading to losing detail. In these cases, quotations were reviewed, the original code was split into two or more codes and quotations were reassigned to them.
- Category names were checked and modified if necessary, with the objective of ensure they were non-overlapping.
- Since categories and codes were modified, the assignment of codes to categories was reviewed to ensure that that codes were assigned to the right categories.

Initially, five documents went through first and second cycle coding. These five documents were selected trying to choose those that were more different from each other. After completing that process, the remaining 14 papers were coded, switching between first and second cycle coding at discretion. The full list of codes can be found in Appendix A.

Third cycle

The objective of this step was to reduce the number of codes obtained in the second cycle. This had to be done to reduce the level of detail and thus obtain a set of indicators that is more manageable. One of the reasons for the large number of codes was that some of them were assigned to several categories. For example, safety belonged to the categories user acceptance, adoption, infrastructure and aircraft. In this case a single indicator, safety, was repeated four times. To be able to reflect that there some indicators had several dimensions, the Groups function of Altas.ti was used. For example, the indicator safety was assigned to the Groups user acceptance, adoption, infrastructure and aircraft. Additionally, some codes containing sub-indicators were merged. The set of indicators resulting from this process is found in Appendix B.

3.3 Reviewing gray literature about indicators for UAM

3.3.1 Rationale for using gray literature

The author decided to extract indicators from gray literature to complement and contrast the indicators found in scientific literature. Including gray literature enables a better understanding of contextual aspects, which is usually not possible when only looking for scientific literature obtained with strict inclusion criteria (Benzies et al., 2006). Moreover, gray literature can be more up to date than academic research because it does not have to go through the publication process; and that it is generally not subject to publication bias (Jewell, 2018). Nevertheless, designing search queries for gray literature is usually difficult and time consuming, its analysis is resource-intensive because it has no word limit or presentation format and there are usually no abstracts, which makes it difficult to quickly assess the relevance of the document (Benzies et al., 2006). These disadvantages were tackled by firstly, allocating sufficient time to find and process gray literature, finding relevant articles via snowballing from scientific literature and using judgement sampling (Elo & Kyngäs, 2008) during the coding process. Another disadvantage of gray literature is that it is difficult to assess its credibility (Benzies et al., 2006). This was tackled by contrasting it with findings from academic sources.

3.3.2 Gathering gray literature

Gray literature was obtained by backward snowballing from scientific literature. Additional documents were obtained by searching in Google for reports and white papers about UAM. When selecting which documents to include in the qualitative content analysis, the author strived to get variety in sources to obtain a wide perspective. The selection criteria used were that UAM should be the main topic of the document and that it has a holistic perspective on UAM. The final selection of documents is shown in Table 3.

Table 3 Analyzed gray literature

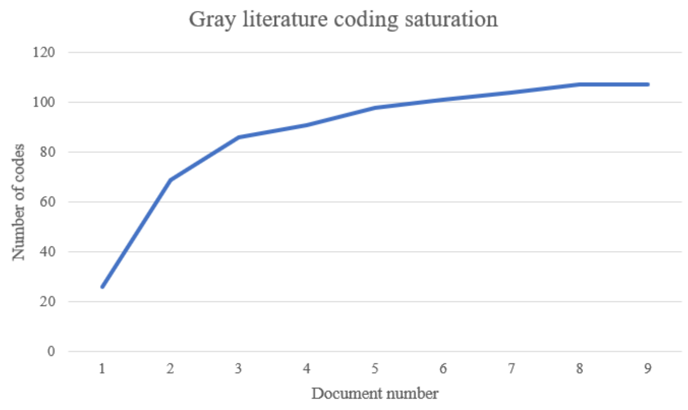
Authors and year	Title	Source
(Holden & Goel, 2016)	Fast-Forwarding to a Future of On-Demand Urban Air Transportation	Uber Elevate
(Booz Allen Hamilton, 2018)	Urban Air Mobility (UAM) Market Study	Booz Allen Hamilton, NASA
(Airbus, 2018)	Urban Air Mobility by Airbus	Airbus
(Grandl et al., 2018)	The Future of Vertical Mobility	Porsche Consulting
(Baur et al., 2018)	Urban air mobility The rise of a new mode of transportation	Roland Berger
(Ford et al., 2019)	How Public-Private Partnerships Will Lead Urban Air Mobility	UAM Geomatics
(Duvall et al., 2019)	Air-mobility solutions: What they'll need to take off	McKinsey & Company
(Boelens, 2019)	Pioneering the Urban Air Taxi Revolution	Volocopter
(Goldstein, 2020)	Despite Pandemic, EmbraerX Speeds Development Of ' Flying Cars '	Forbes, EmbraerX

3.3.3 Analyzing gray literature

The author had two options to code gray literature. The first one was to use the set of indicators obtained after the third cycle coding of scientific literature as a coding scheme. The second option was to start coding the documents from scratch, by following the steps described in the first and second cycle coding phases in Section 3.2.3. The second option was chosen because this would allow to check for consistency by contrasting the codes from scientific literature versus those from gray, serving as a proxy for peer coding. Appendix A shows the codes obtained from scientific and gray literature after second cycle coding.

A challenging aspect when analyzing gray literature was that some documents were very long. To cope with this challenge, judgement sampling (Elo & Kyngäs, 2008) was used, consisting of strategically selecting which parts of the documents to code. Judgement sampling was used with Uber Elevate and NASA documents, by coding only the executive summaries. To determine when to stop looking for and coding gray literature, saturation of codes was tracked, as shown in Figure 5, which shows that saturation was reached.

Figure 5 Coding saturation gray literature



3.4 UAM Case studies

3.4.1 Rationale for using case studies

To complement scientific and gray literature, a third source for indicators was selected, namely case studies about UAM. Case studies have the advantages of enabling a deep comprehension of complex issues, such as innovations in UAM, as well as exploring a phenomenon in its real-life environment (Crowe et al., 2011). Therefore, case studies could reveal indicators that were not elicited in the other source types. However, case studies can lack scientific rigor and do not allow to generalize results (Crowe et al., 2011). This limitation was addressed because academic sources were also analyzed.

3.4.2 Selecting case studies

The case studies used in this thesis were provided by the external supervisor, and were designed using scenarios development and trend analysis. The selection criteria to determine which of the cases to analyze are the following. Firstly, the case's overall topic must be UAM. Secondly, to obtain variety in the case's perspective, the final selection should contain cases conducted by students of different faculties. Thirdly, the case study should have a level of analysis that is neither too broad nor too narrow. Regarding the last criterion, case studies focusing on a particular city were deemed to have the right level of analysis, while those focusing on a specific population niche, such as people with reduced mobility, was considered too narrow. Based on these selection criteria, two case studies were chosen. The first case study focuses in UAM in the city of Los Angeles and was conducted by 10 students from the Aerospace Engineering bachelor program at TU Delft. This case study has an approach similar to what a company entering the UAM market could take; it starts by finding a suitable target city, followed by researching the city's characteristics: infrastructure, regulations, and stakeholder network. Based on this, vehicle requirements are defined, a manufacturing process is created and operational aspects are considered. The second case study explores how can Tokyo have a car-free city center with the help of UAM. Six students from the Industrial Design faculty of TU Delft individually conducted their own report, and two of them were chosen to be analyzed. The Tokyo case studies complement the approach from the case study in Los Angeles since the former focuses on the user experience, vehicle design and cultural aspects.

3.4.3 Analyzing case studies

The objective of performing qualitative content analysis to the case studies was to validate the Indicator Set V1 before conducting the interviews. Thus, this indicator set, shown in Table 6, was used as coding scheme. In this way, the author was able to verify if the indicators found in the case studies match the indicator set, or if some indicators must be added or merged. As in gray literature, judgement sampling (Elo & Kyngäs, 2008) was used to select which parts of the case studies to code. For Los Angeles case study, its executive summary was used to decide which sections to code. For Tokyo case study, the introduction or summary section was used for the same purpose.

In a first cycle of coding, the nomenclature *indicator: sub-indicator or remark* was used to capture a greater level of detail and be able to verify if the sub-indicators or remarks were already considered in the indicators from scientific and gray. In a second cycle of coding, indicators were merged, using the coding scheme to allow comparison and check if new indicators were found. The codes for both first and second cycle can be found in Appendix C.

3.5 Semi-structured interviews conducted

3.5.1 Rationale for using interviews

With the aim of validating the research findings with experts in the field of UAM, and to further increase the variety of sources of indicators, interviews were conducted. Interviews have the advantage of allowing the researcher to obtain a greater level of detail and dive deeper into certain aspects. With a written work, it is not possible to obtain detail beyond what is stated in the text, unless other documents are consulted. In contrast, at an interview the researcher can ask the interviewee to further elaborate on specific topics. Another advantage of interviews is that they allow to capture people's experiences (Rabionet, 2011). The author leveraged this advantage by capturing the opinion of experts regarding the evaluation of UAM at the early stage. Nevertheless, conducting interviews is also challenging. Creating interview protocols, and scheduling and transcribing interviews are time-intensive activities (Hove & Anda, 2005). This was tackled by allocating sufficient time in the research timeline, as well as by speeding up the interview transcription using specialized software. This will be elaborated in the Section 3.5.4.

3.5.2 Rationale for using semi-structured interviews

There are three main types of interviews: unstructured, semi-structured and structured interviews. The advantages and drawbacks of each type were analyzed to determine which is better suited for the research purposes of this thesis. In an unstructured interview, only the topic is defined, while the questions are not determined in advance. This can allow the interviewer to better leverage the expertise of the interviewee, by asking questions about interesting points that have been mentioned during the interview. Nevertheless, the lack of common questions across interviews make the results difficult to compare. Moreover, unstructured interviews have the risk of not eliciting the information needed to answer the research question (Rabionet, 2011).

At the other extreme are structured interviews, which consist of asking exactly the same questions, usually close-ended, to all interviewees (Adams, 2015). This format makes it straightforward to compare the answers of different interviewees. However, structured interviews don't allow to fully leverage the knowledge of each expert because the interviewer cannot ask questions that could be relevant for some but not all interviewees. Moreover, the lack of flexibility prevent the interviewer from asking questions to go deeper in certain topics or obtain clarification. This interview type was deemed unsuitable for the research purposes of this thesis because people with different experience levels, backgrounds and areas of expertise were to be interviewed, requiring some of the questions to be adapted. Moreover, given the exploratory nature of this research, questions might need to be added or deleted depending on what was found at previous interviews. This can be necessary if, for example, new indicators are found or if after some interviews, some indicators are deemed to be unimportant or not applicable.

The third type of interview, semi-structured, consists of combining general open-ended questions to elicit unexpected answers with directed questions related to testing foreseen information (Hove & Anda, 2005). Moreover, semi-structured interviews are flexible, allowing to add follow up questions when needed (Adams, 2015). While the answers are more difficult to compare across interviews in comparison with structured interviews, the interviewer gains flexibility to tailor further questions to the expert's answers and area of expertise. Semi-structured interviews are well suited for the author's research purposes because he aimed to find out what indicators are used by experts by asking two open-ended questions to all interviewees. Depending on each interviewee's answers, additional probes could be used to ask for elaboration about one or more of the indicators mentioned. And if necessary, questions could be asked about specific indicators that were not mentioned yet in the interview but were elicited in previous interviews or from literature.

Naturally, semi-structured interviews also have disadvantages. According to Adams (2015), their main drawbacks are that firstly, they require a significant amount of time and effort for preparation, execution, transcription and analysis; secondly, they are dependent on the interviewer's skills; and thirdly, the number of interviews is rarely large enough in relation to the population to allow to derive conclusions with statistical significance. The first disadvantage was tackled by considering the time and resource intensiveness of interviews in the research plan and timeline, as well as by recording the interviews using the recording functionalities of videoconferencing programs, and using software for automatic transcription of audio (Otter.ai) and for qualitative content analysis (Atlas.ti). The second disadvantage was addressed by creating an interview protocol based on what the author learned from reading literature about conducting interviews for qualitative research and asking for advice to people experienced with interviewing for research, namely the first and external supervisors of this thesis. Additionally, taking advantage of the fact that one of the experts to be interviewed was the external supervisor, this interview was conducted first, serving as a pilot interview. Regarding the third disadvantage of semi-structured interviews, it was not possible to tackle it because of time constraints.

3.5.3 Finding a suitable way to validate the indicator set with the interviews

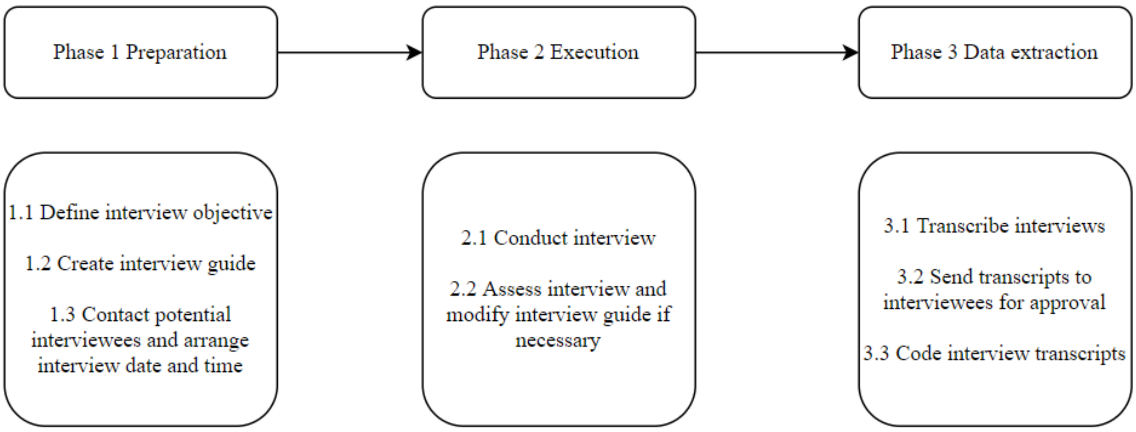
The purpose of the interviews was to validate the set of indicators obtained from the previous SQs. A methodological challenge was that the number of indicators was too large to allow discussing each of them during the interviews. Three possibilities were taken into account to solve this difficulty. The first option was sending a survey to the experts before the interviews, asking them to rate the importance of indicators, in order to focus only on the most important indicators during the interviews. This option was discarded because the experts might lose interest the interview if they had to complete a survey before, possibly resulting in experts rejecting the interview request. The second option was that the author selected the most relevant indicators himself, based on what he had learned from literature. This option was discarded because it was highly subjective. Additionally, the first and second options were discarded because they were biased towards the indicators that had already been found. This was undesirable because the objective of the interviews was to validate what had been found in previous SQs. The third possibility, which is the one that was pursued, was to elicit indicators from the interviews, instead of asking about the indicators that were previously found. In this way, the indicator set from previous SQs could be compared with the indicator set obtained from interviews. This approach not only served the validation purpose better than the other two, but also allowed for the elicitation of additional indicators.

Apparently, a disadvantage of the chosen approach versus a survey is that the latter will not produce a ranking of indicator according to their importance. Nevertheless, the usefulness of an indicator ranking is questionable. For example, even if safety is ranked higher than noise, it is possible that an UAM concept has a possibility to succeed only if it meets both safety and noise requirements. For this reason, it might be more relevant to distinguish between critical and non-critical indicators. This line of thought led the author to include a question to find out which indicators are deemed as showstoppers or knockouts by interviewees.

3.5.4 Interview protocol

Based on Adams (2015), Hove & Anda (2005) and Rabionet (2011), an interview protocol was created. The designed protocol has three phases: interview preparation, interview execution and data extraction. The preparation phase started by defining the objective of the interviews. Afterwards, an interview guide was designed, aimed at achieving the interview objective. Finally, potential interviewees were contacted and the date and time of interviews was arranged. The interviewees' background was researched to leverage their areas of expertise during the interviews, as well as to break the ice when starting the conversation. The execution phase started with conducting the interview. Afterwards, the interview was assessed to identify what went well and possible areas for improvement. Based on this assessment, the interview guide was modified if necessary. The third and final phase was extracting data from the interviews. This consisted of creating interview transcripts, which were sent to interviewees for approval. Afterwards, indicators were extracted from the transcripts using Atlas.ti. Figure 6 shows the interview protocol in a schematic way. The protocol is presented in detail afterwards.

Figure 6 Interview protocol



Interview Preparation

The objective of the interviews was to validate the set of indicators obtained from the previous SQs, as well as to identify which indicators can be used at the early state. This was achieved by eliciting early stage innovation indicators from interviewees. With this objective in mind, an interview guide was created, which can be consulted in Appendix D.

Interviewees were contacted by electronic means (mainly email and Linkedin). The author of this thesis decided who to contact by using the following selection criteria. Firstly, the interviewee must have knowledge of UAM, which can be proven by working on or supervising industrial or research projects related to UAM. Additionally, the interviewee must fulfill at least one of the following criteria: having expertise in the aerospace sector (industry or academia) or having expertise with the early stage of innovation.

Interview Execution

An overview of the interviews that were conducted is found in Table 4. As shown in Figure 7, the number of interviews to be conducted was decided based on saturation of codes obtained from them.

Table 4 Overview of conducted interviews

Int. Number	Sector	Type	Date	Duration (min)
Int. 1	Industry	Videocall	29/03/2021	60
Int. 2	TU Delft Student team	Videocall	02/04/2021	52
Int. 3	Academia	Videocall	06/04/2021	40
Int. 4	Academia	Videocall	08/04/2021	30
Int. 5	Research Institution	Phone call	12/04/2021	65
Int. 6	Industry	Phone call	12/04/2021	23
Int. 7	Industry	Videocall	15/04/2021	35
Int. 8	Industry	Written answers	04/05/2021	NA

Conducting the interview

In the beginning of the interviews the author thanked the expert for her/his time and reminded the expert of the topic and objective of the interview. Then, the author asked for permission to record, explaining how the transcripts will be used and how confidentiality will be handled. The interviewer explained that after the interview, the recording will be used to create a transcription, which will be sent by email to request its approval from the side of the interviewee and ask if it can be included in the appendix of this master thesis. The last element of the interview introduction was to clarify the main terms used in the questions in order to ensure a common understanding.

As can be seen in the interview guide (Appendix D), there are two structured questions. One of them had the objective of finding out which indicators would the expert use to assess the success potential of an UAM innovation or to make a decision between several UAM configurations. The other question was used to elicit specifically knockout indicators. The author started interviews with the first one because this is a broad question that helps to elicit multiple indicators. The author wrote down the indicators mentioned, in order to ask follow up questions about them later. These follow up questions were used to better understand how can the indicators mentioned by the expert be used at the early stage.

While asking the rest of the questions, the author tried to create a natural conversation, instead of following the exact order and formulation of the questions prepared in the interview guide. This was done by building upon the previous answers from the interviewee. For example, when answering the first structured question, some interviewees highlighted the importance of specific indicators. This was noted by the author and used to incorporate the second structured question about knockout indicators into the conversation. The same was done to incorporate the backup questions (see Appendix D) that were created using the indicator categories identified in the Indicator Set V1, as well as to incorporate questions about a specific indicator that was mentioned in previous interviews and required further exploration either because its applicability at the early stage was still not clear or because previous interviewees suggested further investigation of it because it was outside of their domain of expertise.

Assessing the interview

Regardless of the thoroughness of the preparation phase, an interview guide usually has to be revised after conducting an interview (Adams, 2015). For this reason, the author created a set of questions to assess an interview after it was finished. Some questions are based on Adams (2015), while most of them were created by the author of this thesis. This assessment allows to extract lessons learned to improve the interview guide. The questions are the following:

- What went well during the interview? (Identify actions to be repeated)
- What could have gone better? (Identify possible improvements)
- Were the questions presented in a logical order?
- Should the order in which questions are presented be modified?
- What comments were made by the interviewee about the questions themselves? (if any)
- Was the time (maximum one hour) sufficient to ask all questions? If not, what is the prioritization strategy for the next interview?
- To what extent are the questions producing answers aligned with the interview's objective?

Gathering and analyzing data from interviews

Data gathering: transcribing interviews and sending transcripts to interviewees for approval

Creating interview transcripts is a process with an interpretation and a representation components. The former involves making decisions about what to include in the transcripts, while the latter is about how speech is converted into written words (Bucholtz, 2000).

There are two approaches to transcription. The first one is naturalized transcription, which gives priority to creating a clear written text, which necessarily involves omitting features and nuances of oral speech. In contrast, a denaturalized transcription approach prioritizes fidelity to oral speech, which sometimes comes with the cost of making the transcriptions more difficult to read (Bucholtz, 2000). Under the second approach, some researchers even include non-verbal elements of the exchange in the transcripts (Bailey, 2008).

The transcription approach taken in this thesis was a combination of naturalized and denaturalized. The main rule followed during the transcription process was to keep fidelity to oral speech, only eliminating those words that made the transcription difficult to read but whose elimination will not interfere with the original meaning. For example, when people talk words are repeated and there are multiple false starts. Since their elimination does not change the original statement, they can be deleted. Pursuing this approach enables a clear distinction between what the expert said, which is present in the transcript, and the interviewer's interpretation, which happens during the coding process.

To speed up the transcription process, the software Otter.ai was used, which automatically transcribes audio files. The generated transcript was then fully read in parallel with the audio recording to verify its accuracy and make necessary corrections. Most of the transcript matched the recording. In general, only abbreviations and concepts such as VTOL or urban air mobility had to be manually corrected.

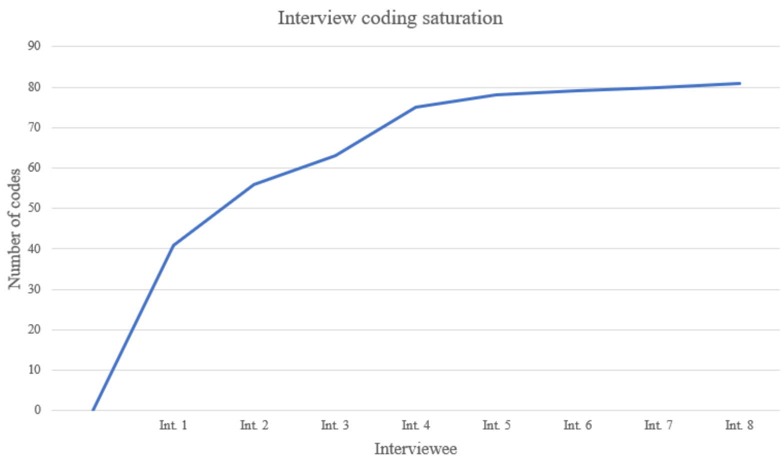
After finalizing the transcript, it was sent to the interviewee by electronic means. In this message, the author asked for permission to include the transcript in the appendix section of this thesis report (see Appendix E).

Data analysis: coding interview transcripts

Green et al. (2007) distinguish four steps to analyze interview transcripts. First, immersion, involving reading the transcripts and listening to recordings. Second, coding, this is, assigning tags or labels that describe pieces of text. Third, creating categories, which capture the relationship between several codes. Fourth, identifying themes, a step that goes beyond description, aiming to explain and interpret the findings from the interviews.

The immersion step was done when revising the transcripts and comparing them against the audio recordings. Regarding the second and third steps, coding and creation of categories, the methodology pursued is based on that described in Section 3.2.3. This methodology was revised using a set of questions available at Goodrick & Rogers (2015), which are specific to the coding of interview transcripts. Based on this questionnaire, the following considerations were made. The author aimed to use the interviews to validate the indicator set obtained from previous SQs. A limitation to the validation is that there was a bias towards the indicators that were previously found. Although it was not possible to completely eliminate this bias, the author addressed this limitation by starting the coding process from scratch. This means that codes and categories emerged from the interview transcripts, instead of using the codes and categories found in previous SQs. The transcripts were coded immediately after they were created, instead of waiting for all interviews to be conducted before starting the coding process. The decision rules followed while coding were firstly, only code text that contains information related to assessing innovations at the early stage. Secondly, in the same transcript, a piece of text with an indicator that was already mentioned in the transcript will be coded if this piece of text contains new information about the indicator. Finally, if during the conversation the interviewer paraphrased the expert's words and this piece of text contains an indicator, it can be coded only if it is clear that the expert agrees with the interviewer's paraphrased statement. Saturation of codes was tracked to know how many new codes (new information) was obtained with each additional interview. When saturation was reached, no more additional interviews were conducted, except for those that had already been arranged. Figure 7 shows saturation of codes.

Figure 7 Coding saturation interviews



3.6 Validation workshop

3.6.1 Rationale for using a workshop

According to Ørngreen & Levinsen (2017) a workshop is an event with a specific duration that has the objective of obtaining insights and feedback, creating a process or product or improving it. A workshop's participants share something in common such as having the same agenda or working in the same domain (Ørngreen & Levinsen, 2017). For the purposes of this thesis, a one hour workshop was conducted with three experts working at a company developing an UAM aircraft. The objective of the workshop was validating the early stage indicators obtained in this thesis, as well as validating and improving the Framework V2 (see Figure 11). The exact way in which this was done is explained in Section 3.6.2.

Workshops have the advantage that they function well in ill-defined and unpredictable domains (Ørngreen & Levinsen, 2017). For this reason, a workshop is well suited for a thesis about decision making at the early stage of innovation, which is subject to multiple uncertainties. Naturally, workshops also have disadvantages. A major one is that the literature provides little guidance on how exactly to obtain and analyze data from workshops (Ørngreen & Levinsen, 2017). To compensate for this, the author used his creativity to design a way to gather and use the workshop's data, as will be explained in the next section.

3.6.2 Workshop data gathering

The data collection had two phases. The first was a set of pre-workshop activities that were conducted with the objective of preparing the indicator set to be presented and discussed during the workshop. The second phase was conducting the workshop. These phases will be described in the following paragraphs.

Pre-workshop discussions

In order to prepare the indicator set to be presented at the workshop the following activities were conducted. Firstly, the condensed Framework V2 was presented to the external supervisor and notes were taken about the discussion that followed. Secondly, on May 5, 2021, there was a videocall with four experts from a company creating an UAM aircraft, the author of this thesis and three other students doing thesis projects in the field of UAM. During this videocall each student had 10 minutes to give a presentation. The author explained the objective of his thesis, a brief overview of methodology and explained the condensed Framework V2. Then, there was a question and answer session of 30 minutes. The author collected notes of the feedback and answers given by the experts. Thirdly, there was another call with the external supervisor to discuss the indicators. Based on the notes and feedback collected in these videocalls, the author determined which indicators from the Indicator Set V2 to include in the workshop.

The following changes were made in the Indicator Set V2 (refer to Table 5 to see which indicators fall under each case). First, some indicators were eliminated definitely from the indicator set because they are recommendations, rather than indicators (see also Table 7). Second, given the workshop's time constraints (one hour), it was not possible to present all the remaining indicators. Thus, the author had to prioritize which indicators to present during the workshop. It was decided that indicators for which the author had no additional questions were not going to be presented. Finally, six indicators were added, three of them coming from the Indicator Set V1 (ID starting with 'F') and three new ones (ID starting with 'PW', standing for pre-workshop). The outcome of this revision is the indicator set presented at the workshop, as shown in Table 5.

Table 5 Selecting indicators to discuss at workshop

ID	Indicator	Discuss at workshop?	Rationale to add / exclude
F32	Flexibility to serve other markets	yes	Added based on pre-workshop discussions
F6	Perception of UAM as only benefiting higher income classes (equity perception)	yes	Added based on pre-workshop discussions
F25	Availability of the technical know how	yes	Added based on pre-workshop discussions
ISV2-1	Presence of a market opportunity	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-2	Production and operation costs	yes	There are still questions about indicator
ISV2-3	Revenue (from selling eVTOLs, from passengers)	yes	There are still questions about indicator
ISV2-4	Financial feasibility	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-5	Technical feasibility	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-6	Timing feasibility	yes	There are still questions about indicator
ISV2-7	Closeness to existing certification regulations	no	It is clear that closeness to existing certifications equals less certification time
ISV2-8	Fulfillment of safety requirements	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-9	Fulfillment of noise requirements	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-10	Level of sustainability (emissions, recyclability at end of life)	yes	There are still questions about indicator
ISV2-11	Operational downtime (due to adverse weather, reliability of systems, charging of batteries)	yes	There are still questions about indicator
ISV2-12	Synergy with company's capabilities	yes	There are still questions about indicator
ISV2-13	Configuration's level of complexity	no	It is clear that less complexity equals less cost and certification time
ISV2-14	Fulfillment of aircraft requirements (including range, speed, weight, payload, energy efficiency)	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-15	Achievement of design objectives	no	No further discussion needed. If indicator is evaluated with a 'No', then it is a no go
ISV2-16	Time to obtain certification	yes	There are still questions about indicator

ISV2-17	Time for required physical infrastructure to be ready	yes	There are still questions about indicator
ISV2-18	Target time to market	yes	There are still questions about indicator
ISV2-19	Definition and alignment of use case(s) with configuration	no	Not an indicator
ISV2-20	User's trust of new technology (example autonomous)	yes	There are still questions about indicator
ISV2-21	Passenger comfort	yes	There are still questions about indicator
ISV2-22	Competitiveness of value proposition	yes	There are still questions about indicator
ISV2-23	Effectiveness in tackling uncertainty regarding local regulations	yes	There are still questions about indicator
ISV2-24	Integration with existing infrastructure / transport modes	yes	Validate if not applicable at early stage
ISV2-25	Perception of UAM as a threat to personal privacy	yes	Validate if not applicable at early stage
ISV2-26	Perception of UAM as visually polluting	yes	Validate if not applicable at early stage
ISV2-27	Reliability: on time performance	yes	Validate if not applicable at early stage
ISV2-28	Easiness to use an UAM service	yes	Validate if not applicable at early stage
ISV2-29	Perception of UAM as insecure	yes	Validate if not applicable at early stage
ISV2-30	Traffic management systems	no	Not an indicator
ISV2-31	Partnerships	no	Not an indicator
ISV2-32	Strategies to cope with regulatory uncertainty	no	Not an indicator
PW-1	Alignment with company's strategy	yes	Added based on pre-workshop discussions
PW-2	Perception of UAM as unsafe	yes	Added based on pre-workshop discussions
PW-3	Trust in the brand	yes	Added based on pre-workshop discussions

Workshop

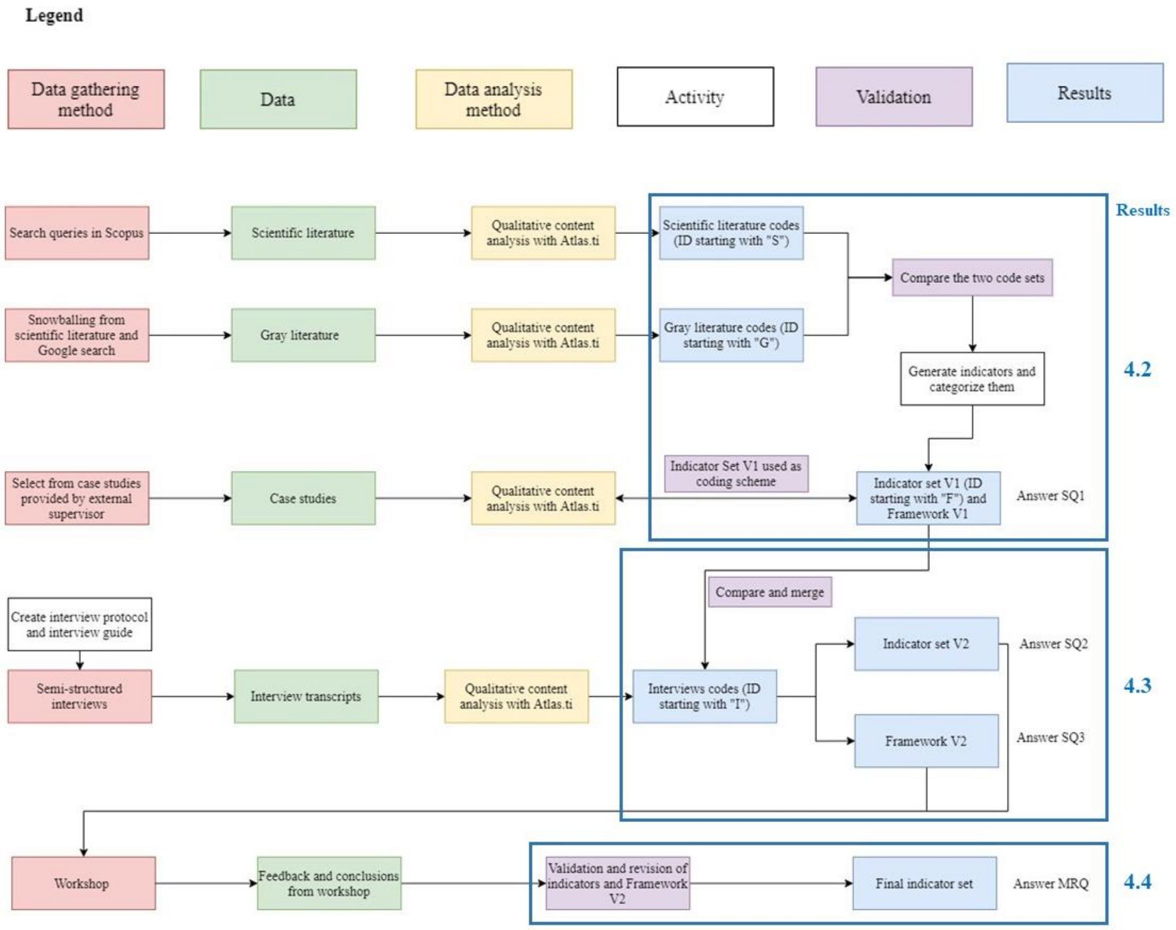
Two days before the workshop, an introductory document was sent to the participants to explain the workshop’s objective and format. This was done to save time during the workshop, given the limited time available for it. The workshop was conducted online on May 12, 2021, moderated by the author of this thesis. The workshop’s participants were three experts from a company creating an UAM aircraft, as well as the external supervisor. The workshop had two parts. In the first one, the detailed Framework V2 was presented and explained, followed by a question and answer session to collect the expert’s opinion and feedback about the framework. In the second part, for each of the indicators selected for discussion at the workshop, a question was asked about how to use the indicator at the early stage of the innovation process and judge whether the indicator is used or not. Given time constraints, most of the questions asked were close ended, asking for validation of examples of the applicability of indicators that were obtained during the pre-workshop preparations as well as from the company's website. The outcomes of the workshop are shown in Section 4.4.

4 Results

4.1 Overview of Results

The structure of this chapter (see Figure 8) is the following. Section 4.2 explains how the results from analyzing scientific literature, gray literature and case studies were used to generate the Indicator Set V1 and the Framework V1, which are the answer to SQ1. Section 4.3 explains how, by building upon the answer to SQ1, the semi-structured interviews were used to create the Indicator Set V2, which answers SQ2, and the Framework V2, which answers SQ3. Finally, Section 4.4 presents the results from the workshop, after which the MRQ is answered.

Figure 8 Structure of Chapter Results



4.2 Results from scientific and gray literature, and case studies

4.2.1 Indicator Set V1

The codes from scientific literature after third cycle and from gray literature after second cycle were used as input to create the indicator set. This was done in Excel and involved the following actions. Groups from Atlas.ti served as basis to refine the categories to group indicators. Some groups were kept (such as business case), others were merged (user adoption and public acceptance) while others were discarded (lessons learned). In the process, categories and code names were revised and changed if necessary, aiming for clarity.

After completing this process, an identifier (ID) was assigned to each indicator, to track which codes from gray and scientific literature were used to create the first set of indicators. This ID's also allow for traceability as the indicator set changes based on the answers to the next sub-questions. ID's start with 'F' for the Indicator Set V1, with 'S' for scientific literature codes after third cycle coding and with 'G' for gray literature codes after second cycle coding. The codes with their corresponding ID are in Appendix B. Table 6 shows which codes from gray and scientific literature were used to create each of the indicators. When coding the case studies by using the indicator set shown in Table 6, 26 out of the 32 indicators from scientific and gray literature were also found in the case studies. Although no new indicators were found, the case studies were useful to bring two indicators back to the indicator set, namely F14 and F30, which had been previously deemed too specific and thus merged into other indicators.

Indicators were separated according to their early stage applicability. An indicator was considered applicable if it is determined at the early stage (reason a) or depends on early stage decisions (reason b), or if a company can take action at the early stage regarding the indicator (reason c). An indicator was considered partly applicable if its value can only be partially impacted at the early stage given its dependence on later stages (reason d), or if early stage decisions can be made based on the indicator even when the indicator also depends on the later stages (reason e). Finally, an indicator was considered not applicable when it is exclusively dependent on the later stages. Indicators that are not applicable are kept in the indicator set for two reasons: firstly, because the next phase of this research (interviews) reassessed their applicability and secondly, because it is relevant to identify them at the early stage in order to assess the likelihood that they become showstoppers at later stages.

The Indicator Set V1 is shown in Table 6. Afterwards, all indicators are presented in a framework, arranged according to the categories shown in Table 6. Finally, each indicator is described in detail, explaining their applicability at the early stage.

Table 6 Indicator Set V1

ID Gray	ID Scientific	ID	Indicator name	Applicable at early stage?	Category
G53, G54	S10,S11, S12,S13	F16	Market size	Yes, reason a	Attractiveness of the business case
G74	S30	F17	Production & operation costs	Partly, reason d	
G71	S31	F18	Pricing & affordability	Partly, reason e	
G8, G96-G101	N/A	F19	Definition and alignment of use case(s)	Yes, reason a	
G16, G41	S8	F20	Business model	Partly, reason e	
G31-G34	S15	F25	Availability of the technical know how	Yes, reason a	Company
G85, G86	N/A	F31	Synergy concept-company	Yes, reason a	
G3	N/A	F32	Concept flexibility	Yes, reason c	
G107	S36	F8	Sensitivity to adverse weather	Partly, reason d	Impact of external factors
G37	N/A	F9	Sensitivity to other external factors	No	
G39, G45, G46	S29	F26	Physical infrastructure requirements	Partly, reason e	Infrastructure
G9, G10	S29	F27	ATM systems	No	

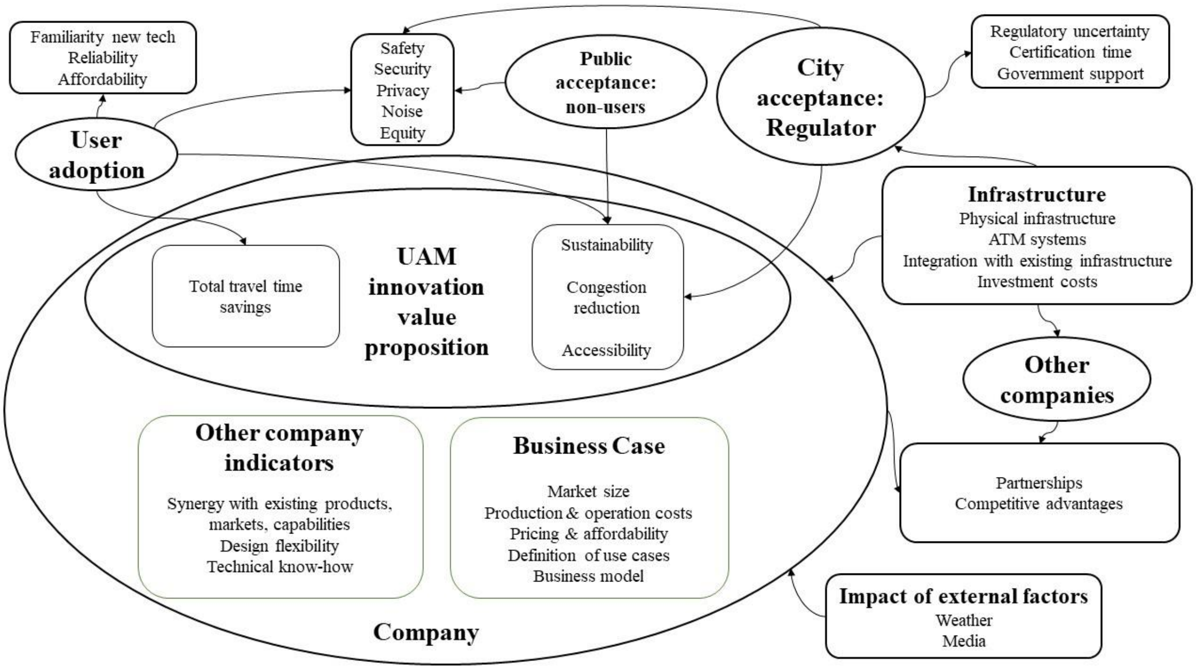
G43, G44	S22	F28	Integration with existing infrastructure	No	
G40-G42, G48	S29	F29	Infrastructure investment costs	No	
G61	N/A	F23	Partnerships	Yes, reason c	Interaction with other companies
G55	S28	F24	Competitive advantages	Yes, reason b	
G90, G17-G24	S25	F15	Time to obtain certification	Yes, reason b	Interaction with the regulator
G51	S26	F21	Strategies to cope with regulatory uncertainty	Yes, reason c	
N/A	S14	F22	Level of government support	Partly, reason e	
G78	S33	F1	Reliability	Partly, reason d	User adoption & public acceptance
G73	S32	F2	Privacy	No	
G73	S32	F3	Security	No	
G79-G81	S34	F4	Safety	Partly, reason d	
G36	S21	F5	Familiarity & trust of new technology	Partly, reason d	
G35	S16	F6	Equity	No	
G19, G65	S19	F7	Noise	Partly, reason d	
G27 - G29	S9	F14	Passenger experience & comfort	Partly, reason d	
N/A	S20	F30	Visual pollution and other negative effects	No	
G25	S17	F10	Level of ground congestion reduction	No	Value proposition
G84	S18	F11	Level of sustainability	Yes, reason b	
G94, G95, G104	S35	F12	Total travel time savings	Partly, reason d	
G1	S16	F13	Accessibility	Partly, reason d	

4.2.2 Framework V1

The Indicator Set V1 shown in Table 6 was converted into the Indicator Framework V1, as shown in Figure 9. The framework depicts how the different categories and indicators are interrelated, based on the findings from literature. These interrelationships suggest that the value proposition is highly important since it is related to user adoption, public acceptance and is also relevant to the regulator, as indicated by the arrows. The framework enables to distinguish between indicators that are requirements versus those that are part of the value proposition. For example, any UAM innovation must fulfill certain safety requirements. Thus, safety does not belong to the category of value proposition. In contrast, UAM innovations can differ in the total travel time savings to users, and are thus part of the value proposition.

The interrelationships shown in the framework provide insight into the considerations made and the challenges faced when making decisions at the early stages. UAM innovation decisions should consider not only user adoption and public acceptance but also the provision of and integration with infrastructure. The challenge is that indicators belonging to these categories are usually difficult to influence at the early stage (see Table 6). Realizing UAM requires multi-actor collaborations, and thus the interaction between the company, other partner or competing companies, and the regulatory bodies is important. Some actions can be taken at the early stage regarding these collaborations, as is explained in the next section.

Figure 9 Framework V1



4.2.3 Description of indicators from Indicator Set V1

Based on the findings from scientific and gray literature, the author of this thesis classified the indicators from Indicator Set V1 according to their applicability at the early stage. In the following paragraphs, they are described, elaborating upon their early stage applicability.

Indicators considered applicable at the early stage

Market size estimations can be useful at the early stage for two reasons. Firstly, to check whether the market potential is big enough to justify the risks the company will take, and secondly, to decide which application(s) to pursue. According to (Grandl et al., 2018), in 2035 the combined market size for all applications of UAM will amount to 74 billion USD. To put this number into perspective, the global market for business jets is expected to reach 35.5 billion USD in 2027 (Fortune Business Insights, 2020). For UAM, the spit between applications will be 45.9% for inspection drones, 28.4% for passenger trips within a city, 14.9% for trips between cities, 5.4% for goods transportation and 5.4% for supporting services (Grandl et al., 2018).

The level of sustainability is an indicator that encompasses emissions, energy consumption and lifecycle considerations (Al Haddad, Fu, et al., 2020), which are determined by decisions made at the early stage. Early investigations state that VTOL aircraft with at least three passengers could generate less emissions than both combustion engine and electric cars (Straubinger et al., 2020). A key enabler for sustainability is electric propulsion technology, which has zero local emissions (Baur et al., 2018; Holden & Goel, 2016). Nevertheless, fully electric VTOL aircraft will face the challenge that the current energy density of batteries could not be enough to provide a fully electric aircraft with the required flight range (Grandl et al., 2018; Ploetner et al., 2020). An hybrid power train can provide a solution to this, though this reduces its sustainability, apart from increasing the complexity of the vehicle and of infrastructure requirements (Ploetner et al., 2020). Still, battery technology is quickly improving, both in terms of energy density and charging capacity (Grandl et al., 2018), which will enable aircraft to be fully electric (so-called eVTOL). The third aspect of sustainability, the lifecycle, poses a major challenge to UAM's sustainability. According to (Grandl et al., 2018), batteries will have a lifespan of only 500 to 700 cycles. Moreover, the lifecycle of the aircraft itself is also short. According to (Boelens, 2019), UAM vehicles will reach the end of the useful life ten times faster than short range jets.

Design flexibility. Because of the uncertainty regarding aircraft design parameters such as seating capacity, as well as the question of whether users will be willing to fly in autonomous aircraft, flexible designs could be important for success. Previous studies state that potential passengers prefer piloted over autonomous aircraft (Fu et al., 2019; Winter et al., 2020) . However, this could change in the future when people become more familiar with autonomous technologies. Volocopter is an example of a company that is addressing this challenge at the early stage by designing a two-seater aircraft in which one of the seats will be occupied by a human pilot in the initial phases of UAM introduction, while in a later stage it will be turned into a passenger seat (Boelens, 2019).

Synergy with a company's existing products, markets and capabilities can be an advantage to enter the UAM market and could thus be considered in the early stages of development when defining the UAM markets to address. For example, EmbraerX can build on top of Embraer's traffic management systems for helicopters to create the ATM systems necessary for UAM (Goldstein, 2020). Another example is that companies such as Airbus and Embraer, which are already providing on-demand helicopter services in Sao Paulo and Mexico City, could not only manufacture UAM aircraft but also operate an UAM service (Al Haddad, Chaniotakis, et al., 2020; Goldstein, 2020).

Partnerships: Establishing partnerships at the early stages of development could increase the chances of success during implementation. High investment costs, especially to develop aircraft hardware and ATM systems, make partnerships indispensable (Grandl et al., 2018). A successful UAM initiative will require cooperation between companies manufacturing the UAM aircraft, developers of infrastructure, service providers and the government (Baur et al., 2018). Multiple partnerships to develop UAM have already been established such as the Uber Elevate network (Holden & Goel, 2016), a consortium between Eve Air Mobility, Skyports, Atech, the U.K. Civil Aviation Authority, Volocopter and Vertical Aerospace (Eve Air Mobility, 2021), and Skyways, a project between Airbus and the Civil Aviation Authority of Singapore (Airbus, 2018).

Competitive advantage. It is important that since the early stage companies consider what are their competitive advantages and assess how their UAM aircraft and business models compare versus those of the competition. From a business perspective, it makes no sense to invest in developing an aircraft before assessing how it compares versus the competition. Currently, there are around 250 prototypes of eVTOL under development and testing (Reiche et al., 2021). More than 70 manufacturers are entering the UAM market (Booz Allen Hamilton, 2018). There are players coming from the aerospace sector, such as Boeing and Airbus, new entrants from the mobility services sector such as Uber (Winter et al., 2020), technology companies such as Intel, automotive OEM's and startups such as Ehang and Volocopter (Grandl et al., 2018). It is expected that only a few UAM companies survive, with the market structure becoming an oligopoly (Straubinger et al., 2020).

Availability of the technical know-how. One of the reasons for the boom in UAM is the supposed availability of technologies that will make UAM possible. Technological advances in communications, energy storage, automation (Niklaß et al., 2020), as well as in electric and distributed propulsion (Ploetner et al., 2020) are enablers of UAM. Nevertheless, major improvements in battery technology are still needed, above all faster charging times and higher energy density (Grandl et al., 2018). According to (Holden & Goel, 2016), the current energy density of batteries cannot support long flight distances, the recharging rates are not suitable to establish an on-demand UAM service and the lifecycles of batteries are still too short to make UAM financially feasible. Finally, as of 2016, there was no economically viable aircraft with a distributed electrical propulsion system (Holden & Goel, 2016). For these reasons, it is important that UAM companies consider at the early stage how to obtain the technical know-how to develop the aforementioned technologies.

Time to obtain certification. Complying with certification requirements is one of the main challenges that UAM companies face (Straubinger et al., 2020). Decisions at the early stage of the innovation process have a significant impact on certification time. According to (Boelens, 2019), simpler designs will result in safer aircraft and thus a quicker certification process. In contrast, complex designs will struggle to prove that they can achieve the extremely low failure probabilities necessary for certification (Boelens, 2019). For example, a multirotor aircraft architecture will be quicker to obtain certification than most other architectures (Grandl et al., 2018). Another example are STOL aircraft, which have lower certification risk than VTOL aircraft (Courtin et al., 2018).

Strategies to cope with regulatory uncertainty. A major barrier to the introduction of UAM is that regulations are either non-existent or immature (Baur et al., 2018). It will likely take several years until the new regulations for autonomous UAM are defined (Straubinger et al., 2020). A way to cope with regulatory uncertainties at the early stage is to establish cooperation with governmental authorities to explore the introduction of UAM from a regulatory perspective. For example, Eve Air Mobility is cooperating with the U.K. Civil Aviation Authority to explore, within a regulatory sandbox, the possibility of using eVTOLs to transport passengers between the Heathrow and London City airports (Eve Air Mobility, 2021). Major regulatory uncertainties include regulations for liability in case of accidents (Fu et al., 2019), for safety and emissions (Baur et al., 2018), for pilot training and vehicle and infrastructure maintenance (Straubinger et al., 2020), as well as how will certification standards and the certification process be like (Thomas et al., 2020).

Definition of use cases: It is critical that the aircraft concept is aligned with its intended use case (Baur et al., 2018). For example, according to (Booz Allen Hamilton, 2018), eVTOL vehicles are not adequate for the air ambulance use case because long recharging times of batteries could make the aircraft unavailable when needed. Thus, a company wishing to serve the air ambulance market might consider employing a hybrid VTOL aircraft (Booz Allen Hamilton, 2018). Another example is that aircraft intended to serve as shuttle between urban areas and airports should consider the space and weight of passenger luggage (Baur et al., 2018). Finally, aircraft design parameters such as vertical and horizontal speeds as well as range will have different optimal values for the inter-city use case in comparison to intra-city (Baur et al., 2018).

Indicators considered partly applicable at the early stage

Production and operation costs. Keeping operation costs low is critical to enable UAM to be price-competitive against existing transport modes (Boelens, 2019; Straubinger et al., 2020) and is thus key to its future success. Although operation costs partly depend on implementation, early stage design decisions have a significant impact on these costs. Firstly, electric propulsion and autonomous flight technology will reduce operation costs by an order of magnitude in comparison to helicopters (Baur et al., 2018). Thus, fully electric and autonomous UAM concepts could have a cost advantage over concepts that do not have these features. Secondly, simple vehicle designs that avoid complex mechanical systems and leverage digital control can lead to significant cost reductions (Holden & Goel, 2016). For example, avoiding systems that require frequent inspections and maintenance greatly decrease operation costs (Boelens, 2019). Thirdly, it is important to maximize battery lifetime because they have a major cost impact (Boelens, 2019). Volocopter addresses this aspect by designing aircraft in which batteries can be changed easily. In this way, batteries can be charged properly at a charging station, instead of having to apply fast charging, which reduces battery lifetime (Boelens, 2019). (Grandl et al., 2018) estimates that intra-city passenger applications will incur operation costs of 1.8 USD per km.

Pricing & affordability. The feasibility of UAM will depend significantly on the price offered to potential passengers (Balac et al., 2019; Boelens, 2019; Ragbir et al., 2020; Straubinger et al., 2020), especially for the commuters use case (Peksa & Bogenberger, 2020). Estimations of customers' WTP can be used at the early stage by companies to get an idea of whether such a price level will allow them to be profitable, considering the estimated costs of their aircraft concepts. (Baur et al., 2018) estimate that a flying taxi service will be two or three times as expensive as a ground taxi while (Fu et al., 2019) found out that passengers WTP for autonomous aircraft is 44.68€/hour in the city of Munich, versus 27.55€/hour for car. In the same study, (Fu et al., 2019) estimated that a price of 4.94€/km will allow an UAM company to obtain a 5% profit margin.

Noise emission is one of the critical challenges to UAM (Al Haddad, Chaniotakis, et al., 2020; Goldstein, 2020; Holden & Goel, 2016; Peksa & Bogenberger, 2020). To attain public acceptance, noise emitted by UAM vehicles must be 15 dB below the noise signature of helicopters (Holden & Goel, 2016). The early stages in the development process are important to determine whether a concept vehicle will be able to achieve such noise level (Straubinger et al., 2020). For example, blade tip speeds and the size of cross sections of rotors have a significant impact on the noise generated (Boelens, 2019; Straubinger et al., 2020). Thus, rotor design can help reduce noise emissions (Rajendran & Shulman, 2020). Electric propulsion can also significantly reduce noise generated by engines and propellers (Holden & Goel, 2016). It is important to consider that not only the level but also the type of noise matters (Straubinger et al., 2020). Ideally, the generated noise must blend with the background (Holden & Goel, 2016). Cabin noise levels must also be considered for comfort and practical reasons, given that commuters might expect to be able to work and even make calls during the flight (Boelens, 2019). Another important consideration is that the total noise impact depends not only on the noise generated by an UAM vehicle but on the total number of vehicles and how often they take-off and land (Grandl et al., 2018). The location of vertiports also influences the level of noise disturbance (Rajendran & Pagel, 2020). Noise is thus a critical and multifaceted indicator that, although partially dependent on implementation, can be significantly influenced at early stages. Therefore, noise emissions will be a key differentiator among vehicle concepts (Holden & Goel, 2016).

Level of government support. Governmental support for UAM is important both for the early stage and for implementation. In the early stages of the innovation process, some countries are devoting public money for research in UAM-related topics. In the USA, the NASA is funding UAM-related research (Thomas et al., 2020), while in Europe the European Commission is supporting UAM projects (Al Haddad, Fu, et al., 2020). In the implementation phase, government support might be essential. For example, the government could subsidize vertiports, so that vertiport fees are affordable to operators of UAM services (Ploetner et al., 2020).

Familiarity and trust of new technology is highly important since it determines whether people will be willing to use the innovation (Straubinger et al., 2020; Winter et al., 2020). Publicity campaigns aimed at increasing the familiarity of the general population with the unfamiliar features of UAM could result in greater user adoption (Ragbir et al., 2020; Straubinger et al., 2020). In contrast, negative media publications can decrease people's trust. For example, safety incidents with autonomous ground vehicles have limited their pace of adoption (Ahmed et al., 2020). It is logical to think that the same would be true for autonomous aircraft. Several studies (Fu et al., 2019; Ragbir et al., 2020; Winter et al., 2020) have found that the general population has greater trust and is therefore more willing to ride human-piloted aircraft in comparison to autonomous aircraft. This is reflected in the fact that many UAM aircraft manufacturers will first introduce piloted vehicles.

Physical infrastructure requirements. Establishing the physical infrastructure needed for UAM is a considerable challenge to the success of UAM (Rajendran & Pagel, 2020). Since creating the necessary infrastructure will take a long time, UAM actors should start taking action today to prevent a scenario in which the aircraft are fully developed while the infrastructure is not ready (Duvall et al., 2019). Several early stage design decisions determine what type of physical infrastructure will be needed. Firstly, the type of take-off is important. STOL vehicles have different infrastructure requirements from VTOL aircraft. A VTOL configuration requires vertiports for taking-off and landing. Vertiports are critical for several reasons: take-off and landing are the highest risk phases of the flight; vertiport configuration will largely determine vehicle throughput; and vertiport location drives accessibility (Straubinger et al., 2020). Secondly, different propulsion types have different infrastructure requirements. Fully electrical vehicles will require recharging stations, while hybrid or hydrogen powered aircraft will require refueling infrastructure. According to (Ploetner et al., 2020), infrastructure for electrical charging will be significantly easier to develop than for fuel or hydrogen. Thirdly, vehicle size matters since larger vehicles require larger (and probably more expensive) infrastructure, with a higher impact on land use (Straubinger et al., 2020). Finally, the infrastructure for maintaining and parking aircraft should also be taken into account (Grandl et al., 2018).

Accessibility is one of the potential benefits of UAM. The type of accessibility provided by an UAM innovation depends on its intended use case. Areas that are difficult to access such as islands and mountains, as well as regions separated by lakes and rivers, can benefit from an UAM service, especially those that are underserved by existing transport modes (Straubinger et al., 2020). Other use cases are connecting airports and cities (Baur et al., 2018) as well as connecting people living in rural areas with public transportation nodes of urban centers (Straubinger et al., 2020). Depending on the accessibility needs of the target market, use cases will get certain level of user, public and political support. Since use cases are defined at an early stage, this is a useful indicator. Another aspect of accessibility is how easy it will be for passengers to arrive at and access vertiports. According to (Baur et al., 2018), well-located and easily accessible vertiports are important for the success of an UAM service. Nevertheless, this aspect of accessibility is not useful at the front-end since it depends on the implementation phase.

Sensitivity to adverse weather. Weather conditions can have a big impact on the performance of UAM (Booz Allen Hamilton, 2018) because adverse weather can lead to flight cancellations and delays (Holden & Goel, 2016). Moreover, extreme weather can make flying uncomfortable and unsafe (Baur et al., 2018). Sensitivity to adverse weather increases with smaller aircraft sizes (Reiche et al., 2021), something that must be accounted for in vehicle designs. It is estimated that 16% of the total operation time will be subject to unfavorable weather (Reiche et al., 2021). Still, the technological capabilities for UAM to safely operate under extreme weather conditions are still under development (Grandl et al., 2018). Therefore, the robustness of an UAM solution under extreme weather could be a differentiating factor. Moreover, companies developing UAM should consider the target market they want to serve given that some cities are more affected by weather than others. For example, (Reiche et al., 2021) found that Los Angeles and San Francisco have weather conditions more favorable to establishing an UAM service than New York and Washington D.C. In early stages of development, UAM vehicle manufacturers could consider creating designs optimized for operation under specific adverse weather conditions (Reiche et al., 2021) or for the weather of a specific set of target cities (Ploetner et al., 2020).

Total travel time savings in relation to existing transport modes is essential for user adoption of UAM (Balac et al., 2019; Grandl et al., 2018; Ragbir et al., 2020; Rothfeld et al., 2018) and is thus a fundamental part of UAM's value proposition (Holden & Goel, 2016; Straubinger et al., 2020). Several factors have an impact on travel time savings, namely the trip distance, vehicle speed and the time of ground operations. Taking into account the first and last mile travel time to and from the vertiports, as well as boarding times, (Baur et al., 2018) estimate that trips of 15-25 km are needed to be able to generate significant time savings. According to (Balac et al., 2019), vehicle speed has a substantial influence on demand. Ground operations have a significant impact on total travel time (Peksa & Bogenberger, 2020), mainly the time that passengers spend at the vertiports (Ploetner et al., 2020). According to (Rajendran & Pagel, 2020), passengers will spend time at vertiports when going through safety briefing, security screening and simply waiting for their ride. Waiting times can be caused by vehicles being unavailable due to the high demand at that moment or because additional passengers are needed to fill the remaining seats (Rajendran & Shulman, 2020). From the three aspects impacting travel time, vehicle speed and trip distance are relevant in the early stage and must be taken into account when defining use cases and the vehicle's range. In contrast, the time of ground operations could be difficult to influence at an early stage, since it largely depends on implementation.

Reliability is frequently mentioned as a desired feature of UAM (Al Haddad, Chaniotakis, et al., 2020; Baur et al., 2018; Reiche et al., 2021). Reliability has two aspects. The first is related to reliability of the service, the on-time performance of a future UAM service (Reiche et al., 2021). The applicability of this aspect in the front-end is questionable given that it will probably depend on implementation. In contrast, the second aspect of reliability, which is related to the technologies and systems used by an UAM vehicle (Rajendran & Pagel, 2020; Straubinger et al., 2020) can be relevant to make front-end decisions.

Safety is fundamental to user adoption (Al Haddad, Chaniotakis, et al., 2020; Fu et al., 2019; Ploetner et al., 2020; Ragbir et al., 2020). Thus, any safety incidents will likely slow down user adoption rates (Fu et al., 2019). Safety is a multi-faceted issue, depending on both vehicle and system aspects. The former are applicable at the early stage while the latter are implementation dependent. Regarding vehicle aspects, rotor placement and design is important for the safety of ground operations and of embarking and disembarking (Boelens, 2019; Straubinger et al., 2020). Interior vehicle design can also have an impact on safety. For instance, ensuring that luggage will not move around during the flight and that passengers will not accidentally or purposely interfere with the vehicle's controls are important to maintain safety (Boelens, 2019). Meeting the aircraft safety standards required for certification will be a significant challenge for UAM companies (Straubinger et al., 2020). Regarding system aspects, an increased number of flying objects results in greater safety risks because it decreases the margin of error of ATM systems (Rajendran & Shulman, 2020). A reliable 5G network will be necessary to handle communication between UAM vehicles, other flying objects and ATM systems and thus ensure a safe operation (Baur et al., 2018).

Robustness of the business model: Defining the business model is fundamental for the success of an UAM service (Straubinger et al., 2020). A solid business model will attract investment (Duvall et al., 2019). Nevertheless, it is still uncertain which business models and aircraft ownership structures will be superior when UAM is introduced to the market (Baur et al., 2018; Rothfeld et al., 2018). Important issues to take into account when defining UAM business models are how will infrastructure owners charge operators of UAM services (Duvall et al., 2019), how will market segmentation look like (Baur et al., 2018) and what would be the optimal seating capacity of an aircraft to maximize profitability (Boelens, 2019).

Indicators considered not applicable at the early stage

Privacy refers to the protection of personal data. Concerns about data privacy are barriers to user adoption (Al Haddad, Chaniotakis, et al., 2020). According to Straubinger et al. (2020), transparency on how personal information will be handled and protected is important for both user and public acceptance. Moreover, due to low flight altitudes, the general public is also concerned about personal privacy, so regulations must be in place to prevent flying vehicles to take pictures of people or private spaces (Baur et al., 2018; Grandl et al., 2018).

Security has two aspects: physical security and cybersecurity. Regarding the first aspect, potential users want security screening before boarding (Booz Allen Hamilton, 2018). Regarding cybersecurity, UAM vehicles can be hacked and used for criminal purposes (Grandl et al., 2018). However, it is still unclear how UAM systems can be protected against cybercriminals (Ahmed et al., 2020). A large number of sensors and subsystems, as well as a high number of connections between vehicles and ground control increase the number of interfaces that are vulnerable to cyberattacks (Maxa et al., 2019).

Equity refers to whether the benefits of UAM benefit all or only some population groups. Higher prices of UAM in relation to existing transport modes are expected and could be thus only affordable for people with higher income, which will hamper public acceptance (Niklaß et al., 2020). In contrast, in (Grandl et al., 2018) it is argued that UAM services can benefit everyone.

ATM systems. New ATM systems will be needed to handle the increase in the number of objects flying in the urban air space (Niklaß et al., 2020). Creating an ATM system that enables communication between vehicles and with the ground infrastructure is essential (Peksa & Bogenberger, 2020). Some players are developing both UATM systems and UAM aircraft, such as Eve Air Mobility (Eve Air Mobility, 2021). Others focus mainly on the first one, such as Amazon, who has developed and patented a flight management system (Duvall et al., 2019).

Level of difficulty of integration. Interaction and integration of UAM with existing transport infrastructure is important for its successful implementation (Antoniou et al., 2018; Grandl et al., 2018). Integration with both physical and digital infrastructure is required. UAM infrastructure must be located in a way that enables intermodal connections with existing transport systems such as train stations and airports, the integration with public transit being especially important (Straubinger et al., 2020). Integration with ATM systems will be needed as well (Niklaß et al., 2020).

Investment costs. The investment costs required to construct the physical infrastructure, vertiport costs being the largest contributor, are difficult to estimate at the early stage in which UAM currently is (Niklaß et al., 2020). The characteristics of the target area to be served will have a significant impact on infrastructure investment costs (Duvall et al., 2019). For example, if a significant number of rooftops and heliports can be converted into vertiports, this could reduce the required investment. Although investments costs might be substantial, an opportunity is that institutional investors are increasingly interested in investing on infrastructure development (Duvall et al., 2019). Companies entering the UAM market should consider which actors could make the necessary investments and start making agreements or partnerships with them.

A ***reduction in ground traffic congestion*** is a potential benefit of UAM (Al Haddad, Fu, et al., 2020; Balac et al., 2019; Ragbir et al., 2020). However, it is unclear to what extent will UAM be able to reduce congestion, especially given the modest estimated modal share of UAM. For example, (Rothfeld et al., 2018) simulated a modal share of 4%, while (Ploetner et al., 2020) estimate from 1 to 4%. (Straubinger et al., 2020) argue that it is unlikely that UAM creates a meaningful reduction in traffic congestion, based on the simulation results of other studies and UAM's induced demand. (Grandl et al., 2018) states that while UAM is not the ultimate solution to congestion, it will help to alleviate it, especially in highly dense cities. Given that this indicator depends on systemic aspects, instead of on aspects of a specific UAM aircraft, it is not be useful at the early stage.

Sensitivity to external factors. External factors, such as media publications and demographic trends can have an impact on the future success of UAM. Posts in social media could influence user adoption (Straubinger et al., 2020). Socio-demographic trends such as an increase in working from home could decrease the demand for UAM (Booz Allen Hamilton, 2018).

4.3 Results from semi-structured interviews

This section shows how, by building upon the answer to SQ1, the semi-structured interviews were used to answer SQ2 and SQ3, as was shown previously in Figure 8.

4.3.1 Indicator set V2

The code set from the interviews (ID starting with "I") was compared with the Indicator Set V1. This process involved the following steps. In Excel, indicators from the Indicator Set V1 were matched with the interview codes. The interview codes that had not been identified previously in Indicator Set V1 (those labeled with "N/A" in the second column of Table 7) were the basis to create new indicators in the Indicator Set V2. In this process, the comments from each interviewee were given the same value. Thus, it was enough if a code was mentioned by one interviewee to derive an indicator from it. Afterwards, indicator names were revised, some codes from the interview code set were eliminated because they were a category of indicators, instead of an indicator per se (an example is the code public acceptance), some indicators were split because they conveyed two different concepts (an example is the indicator reliability, which was split into reliability regarding on time performance and the reliability of systems, which was then clustered into the indicator operational downtime). A last iteration involved checking if some indicators should be merged. An example is the indicator total cost, which is the result of merging indicators of investment, production, operation, and maintenance costs. Following these steps resulted in creating a new set of indicators, called Indicator Set V2.

Afterwards, the usefulness of each indicator at the early stage was assessed. An indicator is applicable at the early stage if one or more of the following conditions is met: its value can be affected by design decisions, it determines technical requirements or is a requirement itself, it impacts the value of a requirement or a company can take action at the early stage regarding the indicator. In contrast, an indicator is not applicable at the early stage if no design decisions are associated with it or if the indicator is fully dependent on implementation. Table 7 shows the Indicator Set V2, and the rationale for the applicability of each indicator at the early stage.

Table 7 Indicator Set V2 and the applicability of indicators at the early stage

ID Interview code set	ID Indicator Set V1	ID	Indicator name (Indicator Set V2)	Applicability at early stage
I18	F16	ISV2-1	Market opportunity	Yes, determines what is the value proposition and the technical requirements
I12, I15, I29	F17, F29	ISV2-2	Total cost (investment, production, operation, maintenance)	Yes, costs are estimated, based on the technical decisions made, to assess financial feasibility
I40	F18	ISV2-3	Affordability (customer WTP)	Yes, should be estimated to check financial feasibility
I14	F20	ISV2-4	Financial feasibility	Yes, if infeasible, design iteration is needed
I14, I4	N/A	ISV2-5	Technical feasibility	Yes, if infeasible, design iteration is needed
N/A	N/A	ISV2-6	Timing feasibility*	Yes, if infeasible, design iteration is needed
I5, I6	N/A	ISV2-7	Closeness to existing regulations	Yes, reduces certification time
I35, I42	F4	ISV2-8	Safety	Yes, it is a requirement and design decisions have impact on it

I19	F7	ISV2-9	Noise	Yes, it is a requirement and design decisions have impact on it
I36	F11	ISV2-10	Sustainability	Yes, the market analysis could produce some sustainability-related requirements that the technical solution must comply with, design decisions have impact on it
I28, I50, I51	F1, F8	ISV2-11	Operational downtime (due to adverse weather, reliability of systems, charging of batteries)	Yes, estimated based on technical decisions made. Used when assessing financial feasibility
I7, I10	F25, F31, F32	ISV2-12	Leveraging company capabilities	Yes, can be a trigger for market opportunity. Can determine technical requirements
I11	N/A	ISV2-13	Configuration's level of complexity	Yes, impacts costs and certification time
I27, I30, I31, I33	N/A	ISV2-14	Fulfillment of key requirements (including range, speed, weight, payload, energy efficiency)	Yes, if key requirements determined by market analysis cannot be met, design iterations will be needed
I32, I34	N/A	ISV2-15	Achievement of design objectives	Yes, design objective is determined by the value proposition, which drives user adoption
I5, I6	F15	ISV2-16	Time to obtain certification	Yes, should be aligned with desired time to enter market, impacted by design decisions
I20	F26	ISV2-17	Time for required physical infrastructure to be ready	Yes, should be aligned with desired time to enter market
I38	N/A	ISV2-18	Time to market	Yes, if target time to market is not achieved, the market opportunity could be lost or diminished
I9	F19	ISV2-19	Definition and alignment of use case(s) with configuration	Yes, the chosen configuration must be aligned with the requirements of the use case
I13	F5	ISV2-20	Familiarity & trust of new technology	Yes, consider in market analysis to estimate user adoption. Can be affected by design decisions
I43, I44, I49	F14	ISV2-21	Passenger experience & comfort	Yes, consider in market analysis to estimate user adoption. Can be affected by design decisions
I8, I45, I47, I48	F12, F13, F24	ISV2-22	Value proposition	Yes, depends on the market opportunity identified
I26	N/A	ISV2-23	Local regulations	Yes, can determine requirements (noise, for example)
N/A	F23	ISV2-31	Partnerships	Yes, a company can take action at the early stage regarding it
N/A	F21	ISV2-32	Strategies to cope with regulatory uncertainty	Yes, a company can take action at the early stage regarding it
I16, I17	F28	ISV2-24	Integration with existing infrastructure / transport modes	No. Fully implementation dependent, no design decision is associated with it

I24	F2	ISV2-25	Privacy	No. Is relevant for public acceptance, but no design decision is associated with it
I22	F30	ISV2-26	Visual pollution	No. Is relevant for public acceptance, but no design decision is associated with it
I41	F1	ISV2-27	Reliability: on time performance	No. Fully implementation dependent, no design decision is associated with it
I39	F13	ISV2-28	Accessibility for users: easiness to use the UAM service	No. Fully implementation dependent, no design decision is associated with it
N/A	F3	ISV2-29	Security	No. Relevant for acceptance and adoption, but fully implementation dependent
I2	F27	ISV2-30	Traffic management systems	No. It is a recommendation applicable to any UAM aircraft

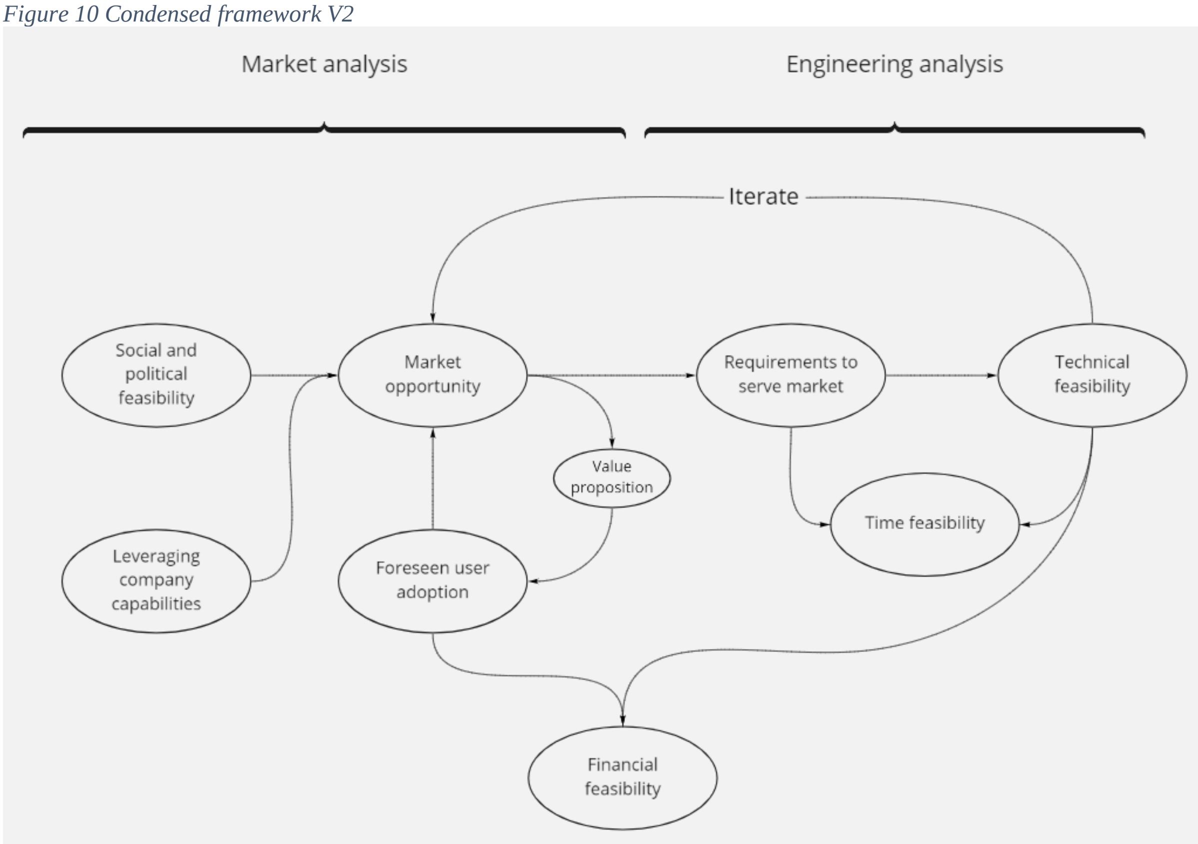
*Timing feasibility was not explicitly coded. Instead, it was derived when creating Framework V2.

4.3.2 Framework V2

As mentioned in Section 3.5.4, the fourth step to analyze interview transcripts mentioned by Green et al. (2007) is to identify themes. To achieve this, the author wrote down insights and thoughts that emerged while coding the interview transcripts. This is aligned with the advice of Goodrick & Rogers (2015), who recommend to start writing early during the coding process. Afterwards, the brainstorming online tool Miro was used to cluster indicators and graphically show the relationships between them. For example, the indicator "time to market" is linked with the indicator "certification time" by an arrow with the label "depends on". Multiple iterations were required to create this framework. The process involved rereading the original pieces of text of interviews, scientific and gray literature from which the indicators were derived. This was facilitated by the system of ID numbers associated with each indicator, as shown in Table 6 and in Table 7, which allows to trace indicators back to the codes and then to the original pieces of text. The last step in the creation of the framework was rereading the interview transcripts to check if the framework depicted what was said at conversations, as well as to look for additional insights that could have been skipped during the coding process. In this way, the interview results were used to create a framework illustrating how indicators could be used at the early stage to produce a feasible UAM aircraft configuration.

First, a condensed framework is introduced, shown in Figure 10, showing only the main relationships between indicators or categories of indicators. In the detailed framework shown in Figure 11, the components of the condensed framework are presented in greater detail.

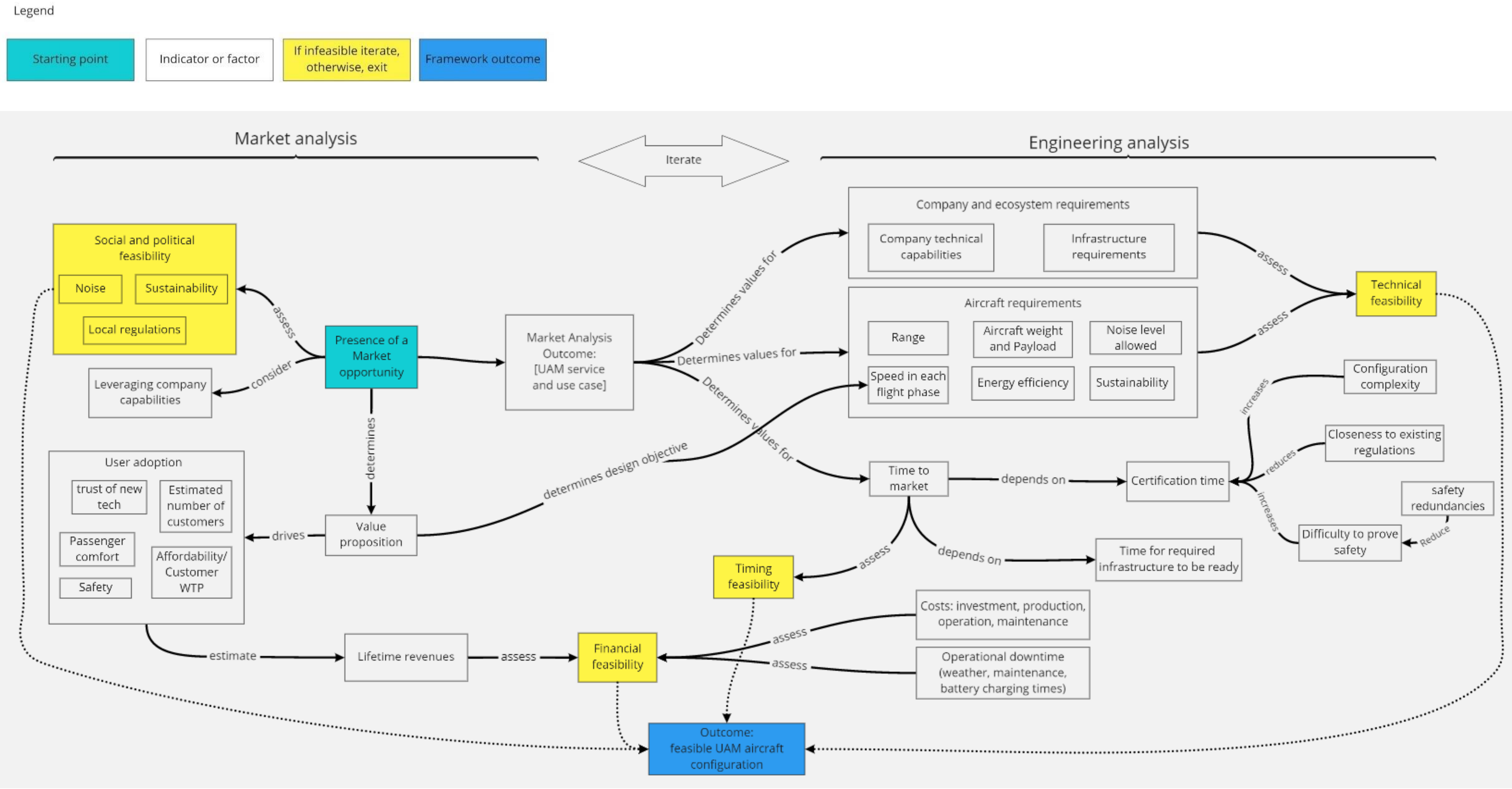
Figure 10 Condensed framework V2



4.3.3 Description of condensed Framework V2

The aim of the market analysis phase (see Figure 10) is to identify a market opportunity, and determine the requirements that must be met to serve the market. These requirements can stem from multiple sources. Firstly, the existing company's capabilities can be considered to assess which markets (if any) can be served by leveraging existing knowledge or technology. Secondly, market research can be done with potential users to find out what will drive future adoption of the solution, determining the value proposition and translating this into design requirements. Thirdly, a company can investigate what factors relevant for social and political acceptance can be reflected into design requirements. The resulting set of requirements is given to the engineering team, which will try to fulfill them, usually requiring multiple iterations between the market and engineering teams to readjust the requirements until a technically, financially and timing feasible configuration is achieved.

Figure 11 Detailed framework V2



4.3.4 Description of detailed Framework V2

The detailed Framework V2 (Figure 11) will be described in the following paragraphs, ordered by the elements shown in the condensed Framework V2 (Figure 10). The framework contains indicators that are taken into account at the early stage of the innovation process.

Market opportunity

The inception of an innovation starts with identifying a market opportunity. "The first thing is to understand if there is a market" (Interviewee 1). Doing a market analysis will result in a set of requirements that a technical solution must comply with in order to serve the market. For example, a company might find out that building an aircraft that can serve the intracity market to transport passengers is a good market opportunity. Based on this, requirements for indicators such as speed at different phases of flight, noise, flight range, number of passengers and energy efficiency will be specified. These requirements will be given to the engineering department, who will aim to design a configuration that fulfills them.

Social and political feasibility

Social acceptance is extremely important. "Social acceptance is the one thing, I think, that will hold this whole operation back" (Interviewee 5). Although at the early stage it is not possible to know with certainty whether society will accept the innovation or not once it is introduced, social acceptance could be taken into account when determining the aircraft requirements. There are some indicators related to public acceptance whose value can be impacted at the early stage. An example is investigating the noise level that the general public is willing to accept, and translating this into a design requirement. "Community acceptance is critical: and noise is very important for it" (Interviewee 3). Regarding political acceptance, local regulations in the target markets could also be considering when defining aircraft requirements. Examples are local laws regarding noise and emissions levels.

Leveraging company capabilities

The existing company capabilities can also play a role in identifying a market opportunity. "We evaluate the markets, the mission that fits in the possible markets, and what fits with our company backgrounds and capabilities in order to manufacture and certify the solution" (Interviewee 1). It is possible that the desire to use existing technological capabilities is the trigger to search for a market where these capabilities can be used, as suggested by Interviewees 3 and 7. A company might look for a market that can be served by an aircraft that leverages the technologies or knowledge that were already developed for an existing aircraft. Interviewee 7 commented regarding a family of executive jets "if you look on the fuselage itself, if you look on most of their components, they have a lot of commonality, okay, so you reduce the development costs when you instead of having completely different or completely segregated four aircraft programs, you can reuse most of the things". Interviewee 7 also mentioned the Volocopter case as an example of leveraging company capabilities. Volocopter first developed the VoloCity to serve passenger applications, specifically the air taxi market. Then they created the VoloDrone which has synergies with the already existing Volocopter platform, but is used for cargo applications (Volocopter, 2021b).

Foreseen user adoption

Similar to social acceptance, user adoption cannot be fully known at the early stage. However, it is possible to do market research with potential users to understand their needs and identify those that can already be converted into design requirements. "Once the market intelligence understands what is out there, they have some basic requirements, from interviewing people, going to the customers and putting surveys” (Interviewee 7).

Safety is a critical aspect for user adoption. An aircraft can comply with safety requirements of certification and thus be considered safe. Nevertheless, safety perception from users should also be taken into account. “Perhaps some people will end up naturally perceiving some configurations as being safer” (Interviewee 1). As part of their market research, companies could investigate what features in a future UAM aircraft will make users perceive it as being safe and then incorporate these features into the aircraft design.

Another aspect to consider is passengers’ willingness to fly in fully autonomous aircraft. “A lot of these companies are investing heavily in this autonomous market, but I think they will have trouble succeeding if they don't make a first version, which takes a pilot and is commercially viable” (Interviewee 2). Thus, UAM aircraft for passenger applications should probably be designed in a way that enables both piloted and fully autonomous operation. As expressed by Interviewee 5:

> “First, you have to start an operation with a pilot, of course. Then you have a time where the pilot is still there, but is not in control. So basically, the vehicle is autonomous, but the pilot is there just in case. And after many years of flying that way, you will transition into an autonomous operation”

Another aspect that can be assessed in the market research is the importance of passenger comfort. As interviewee 4 said “And then maybe the final thing that might be important here is the comfort level of the passengers. How comfortable are the passengers going to be inside this machine?”. It is unclear to what extent will passenger comfort matter for user adoption. “Weather conditions also have impact on passenger comfort but given short duration of trips it is probably not so important” (Interviewee 3). Via interactions with potential users at the early stage, the importance of comfort and users desires about it can be investigated and translated into requirements. An example of a comfort related parameter that can and should be addressed at the early stage is legroom.

Value proposition

During the market analysis, the value proposition that the solution will bring to its future users is defined. This is important because firstly, user adoption depends on it and secondly, it determines which are the design objectives. For example, for intracity passenger transportation for commuting purposes, the key value proposition could be time savings compared to other transportation means, weighted against cost. Thus, the design objectives for an aircraft serving this market will include minimizing takeoff and landing times, maximizing cruise speed and minimizing total cost. A different value proposition will have different design objectives. For example, the value proposition of PAL-V International Liberty is to provide end to end mobility. In order to do so, it has to be able to both fly and drive on the streets. To achieve this, PAL-V Liberty uses a gyrocopter configuration, which is slower than a fixed wing, but has the advantage that the rotors can be folded, allowing the vehicle to drive on the streets (Interviewee 6).

Time feasibility

The outcome of analyzing the market opportunity is a set of requirements that a technical solution must comply with in order to serve the target market. Within these requirements, a critical one is time because not only the technical feasibility must be assessed, but also whether the aircraft will be ready to enter the market at the required time window. As expressed by Interviewee 1 “if it would fit also the timeline that we had foreseen for a nice suitable entry for the product. Otherwise if we lose this window, then game over.”

The time at which the innovation enters the market is an important early stage indicator because it can be related to the company's strategy to penetrate the market. Interviewee 7 stated "It is important to be the first but when something is so open as we already talked it, maybe the first will not be the best solution" while Interviewee 1 said that: "I believe some companies don't need to be the first because from some that will enter in the markets, we will learn a lot…. But of course, they have the benefits that being the first perhaps they can get part of the market for them already".

Different configurations will take a different time to be certified. Thus, when making decisions about the configuration, it is important to consider whether the estimated certification time is aligned with the time at which the company wants to enter the market. According to Grandl et al. (2018), a multirotor configuration will be the quickest to obtain certification, followed by lift and cruise. Tilt configurations (tilt-wing, tilt rotor or tilt-duct) will be the slowest to be certified.

There are multiple factors influencing certification time, namely the closeness to existing regulations, the complexity of the configuration, and the difficulty to prove safety. Configurations that are close to existing regulations will be quicker to be certified. "The closer it is to current regulation, so if the regulator can match it with current regulation, then the certification will be easier" (Interviewee 5). Interviewee 4 gave some examples of existing EASA regulations that could be used to certify some UAM aircraft, such as CS-23 for Normal, Utility, Aerobatic and Commuter Aeroplanes, CS-27 for Small Rotorcraft and for CS-29 Large Rotorcraft. A higher complexity level of the configuration increases certification time. For example, tilt mechanisms have higher complexity because they have rotating components involved when shifting from lift to cruise, resulting in a higher risk of having a single point of failure (Grandl et al., 2018). Naturally, "Simple configurations will be quicker to certify", as pointed by Interviewee 3. Still, aiming for short certification time has tradeoffs. For example, according to Interviewee 8, a tilt-wing configuration has a better cruise performance than other configurations. Finally, the harder it is to prove safety, the longer the certification process will take. Thus, having safety redundancies can decrease certification time. As mentioned by Interviewee 3, "if multi rotors configurations can prove that they can safely land after losing one or more rotors, this could speed up their certification".

Technical feasibility

The technical feasibility answers whether the company can create an aircraft that works technically and fulfills the requirements determined by the market analysis. It is possible that not all requirements can be fulfilled. Then, the required values for the requirements will be discussed and revised in multiple iterations. "… engineering and market intelligence start to interact between them to see what is possible, what is not possible, if this is a hard requirement, or there is some flexibility on that requirement." (Interviewee 7).

Relevant indicators or requirements that should be met by a technical solution include speed at different phases of flight, noise emissions, flight range, number of passengers, energy efficiency, weight, payload, operational downtime, sustainability, infrastructure requirements and the company's technical capabilities. The last three will be elaborated upon. Early stage decisions can have an impact on sustainability, especially regarding recyclability of the aircraft components and the emissions generated, as mentioned by Interviewee 1 "the end of life, the recyclability of the airframe and … during the operation, the emissions". Infrastructure requirements should also be taken into account at the early stage. For example, infrastructure requirements can rule out STOL configurations because they need a short runway to take off and land, making them lose the advantage of being able to operate inside cities. "If UAM aircraft needs a runway, even if it is STOL, you are losing the advantages of proximity to the customer" (Interviewee 3). Another example is PAL-V Liberty, which was designed in such a way that it does not require any additional infrastructure to be able to operate (Interviewee 6). Finally, the company's technical capabilities are taken into account when evaluating the technical feasibility of a solution, as expressed by Interviewee 1 "understanding the knowledge capabilities and technologies required to manufacture this possible product".

Financial feasibility

Based on the technical decisions made, the total costs can be estimated, including how much will the company invest in development, the costs to manufacture the aircraft and finally, operation costs such as maintenance. Based on the market analysis, the total number of customers and the revenue per customer can be estimated, to obtain the lifetime revenues. The operational downtime caused by adverse weather, maintenance, and battery charging times should be taken into account in the revenue estimations. With these considerations, the financial feasibility can be estimated. "It is really to understand what is out there and to put a business plan, that you know what the risks are, what is the investment required, what are the efforts, what is the revenue, what is the net gain" (Interviewee 7).

Iterations

Making early stage innovation decisions is an iterative process in which multiple indicators and tradeoffs must be considered simultaneously, requiring constant communication between the market and engineering departments. As expressed by Interviewee 7, it is "… a result of a huge multidisciplinary optimization problem." In the following paragraphs, three examples of the dependencies and tradeoffs between indicators are given.

The outcome of the market analysis phase can be that a fully electric aircraft with a range of 300 km is needed. However, because of the current energy density of batteries, the weight of the batteries needed to achieve this flight range becomes prohibitive, making the design infeasible (based on example given by Interviewee 4). Still, it is possible to play with another indicator, namely the time to market. If the time to market set by the market analysis is aligned with the estimated time at which battery technology could enable the desired range, then a feasible design could be achieved.

It is possible to decrease the operational downtime of an aircraft caused by adverse weather. This can be achieved by giving the aircraft an all-weather capability. Nevertheless, this will have a significant impact on cost. "The question is, what does it cost you, right to have an all-weather capability? So practically speaking, it probably comes down to overpowering your airplane, over controlling your airplane, increasing the control power on your airplane" (Interviewee 4).

A final example is to have safety redundancies which will decrease the difficulty to prove safety and could thus decrease the time to obtain certification. However, these redundancies will drive up costs and weight, as mentioned by Interviewee 4 "redundancy in your systems, for example, that drive up the weight of the airplane, that in turn drive up the cost or the energy consumption".

Framework outcome

The framework supports decision making at the early stage by depicting the dependencies between indicators and the tradeoffs that have to be made. The outcome of the framework is deciding on the characteristics of an UAM aircraft configuration that best addresses the identified market opportunity and that is technical, financial, timing, social and politically feasible. The resulting aircraft configuration can then be evaluated to decide whether to continue to the development phase or not.

4.4 Results from workshop

4.4.1 Final Framework and indicators with examples of applicability at the early stage

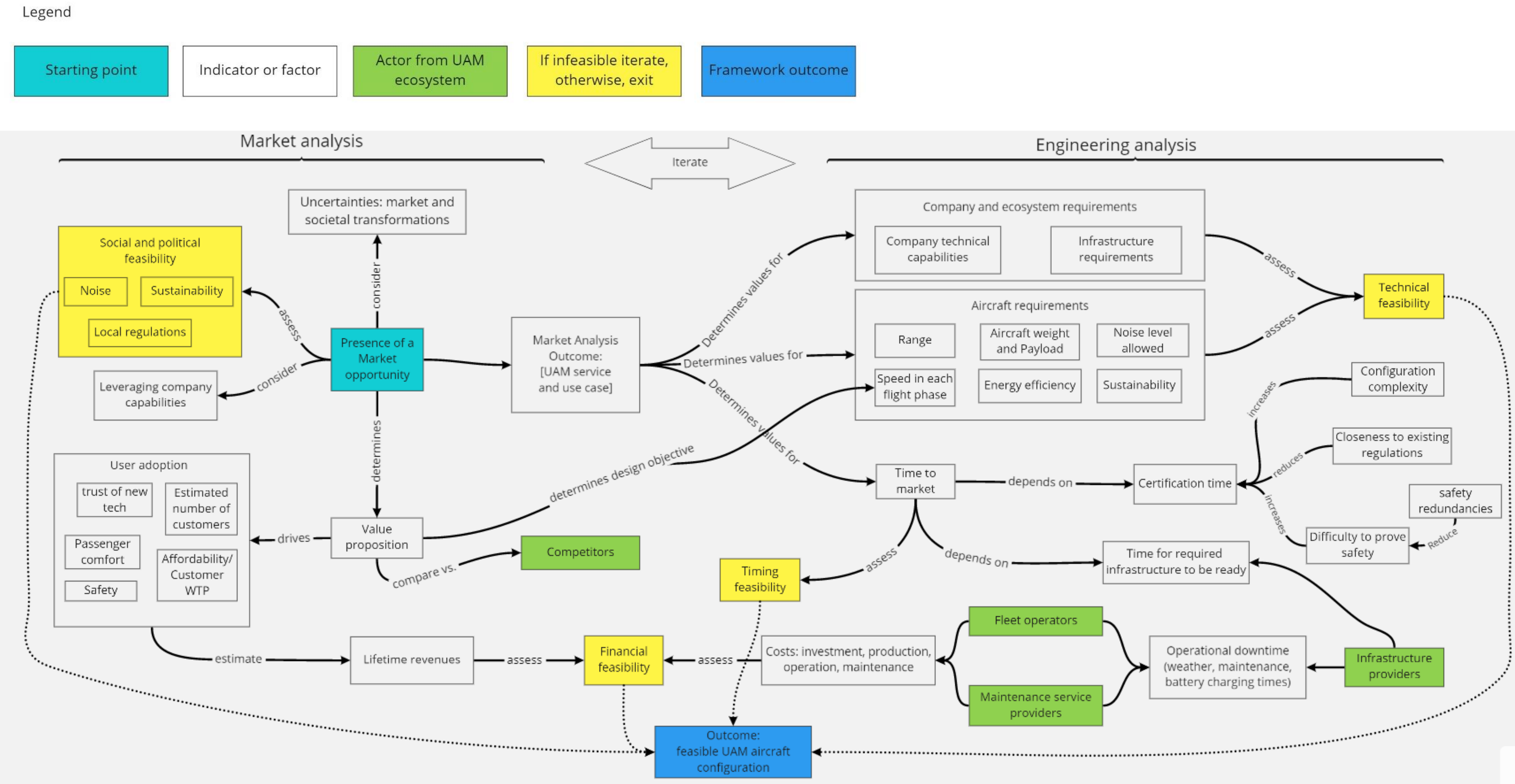
A summary of the feedback and comments of the experts regarding the Framework V2 is presented in this section, followed by Table 8, which contains the findings of the pre-workshop discussions and the workshop itself.

The experts commented that the Framework V2 provides a good map of what happens at the early stage of the innovation process for an UAM innovation. They said that it highlights the main indicators that are considered. They mentioned that it is worth it to further investigate each of the components of the framework. Each of the indicators could become a full research project by itself. For example, estimating the revenue that an UAM aircraft manufacturer might obtain is a challenging research project.

The experts highlighted three aspects of the framework. Firstly, that it is good that it shows that creating an UAM aircraft is not a straightforward process and multiple iterations are needed. Secondly, they said that the interactions between the different elements of the framework and especially the interaction between the market and engineering components are an important part of what happens when developing an UAM aircraft. Finally, they stated that the value proposition of an UAM aircraft is extremely important, since it is the key differentiator against the competition. Thus, it is important to have a clear value proposition at the early stage, which will determine what requirement(s) is the most important. This will aid when making design tradeoffs. For instance, it is not possible to optimize range, speed energy efficiency and weight at the same time. Thus, which requirement to prioritize will depend on the value proposition.

The experts made the following suggestions to improve the framework. Firstly, to mention the assumption made when creating it, namely that it is done from the perspective of a company manufacturing an UAM vehicle. This is relevant because a vehicle manufacturer focuses both on the market and engineering analyses, while a company that only seeks to provide an UAM service will focus less on the engineering analysis (the right hand part of the framework). Secondly, they mentioned that the framework can be expanded to include the larger UAM ecosystem, namely the services around an UAM vehicle such as maintenance, fleet operations, and infrastructure. Finally, the experts said that something that is missing in the framework is to include possible future scenarios. The market is under continuous transformation. Society is changing as well. Based on this comment, the Final Framework depicts that UAM innovations are subject to these transformations and uncertainties. The current pandemic is an example of these unexpected transformations (the indicator with ID W-1 was added based on this suggestion). Based on the experts' feedback, the Framework V2 was revised. The revised version is called Final Framework and shown in Figure 12.

Figure 12 Final Framework: Conceptualizing how a feasible UAM configuration is created at the early stage of the innovation process



Moving to the second part of the workshop, Table 8 contains the set of indicators that were presented. The examples of how to use each indicator at the early stage were obtained from the pre-workshop discussions, the company's website and the workshop itself.

Table 8 Workshop results

ID	Indicator	Example how to use indicator at early stage
F32	Flexibility to serve other markets	Defining the market(s) to be served is one of the considerations made during the market analysis phase. The tradeoff of an aircraft that can be flexible to serve multiple markets is that it will not be optimized for any of them
F6	Perception of UAM as only benefiting higher income classes	Engage with community to assess impact of indicator
F25	Availability of the technical know how	Not considered. What matters is having the right product and timing.
ISV2-2	Production and operation costs	Most technical decisions influence this, such as choice of materials
ISV2-3	Revenue (from selling eVTOLs, from passengers)	Estimate based on market research
ISV2-6	Timing feasibility	When choosing configuration, align certification time with desired time to market and with time for the required infrastructure to be ready
ISV2-10	Level of sustainability (emissions, recyclability at end of life)	Propulsion type impacts emissions, choice of materials impacts recyclability
ISV2-11	Operational downtime (due to adverse weather, reliability of systems, charging of batteries)	Decisions regarding batteries are made at early stage, which will impact charging times. Complex configurations (those with tilting components) will have high maintenance time
ISV2-12	Synergy with company's capabilities	Embraer choosing to address the passenger market before cargo because its core competencies are related to serving passenger markets and thus they can differentiate themselves from competition
ISV2-16	Time to obtain certification	One of the reasons for choosing a lift + cruise configuration is its certification time
ISV2-17	Time for required physical infrastructure to be ready	Investigations must be done to estimate this time since it should be aligned with the desired time to enter the market.
ISV2-18	Time to market	Desired value defined at market analysis phase
ISV2-20	User's trust of autonomous technology	The aircraft will first have a pilot onboard, then remotely piloted, finally fully autonomous. Also, use the design to communicate peace of mind to the user.
ISV2-21	Passenger comfort	Investigate with surveys, interviews with potential users. Human-centered design
ISV2-22	Competitiveness of value proposition	The first thing is to ensure that UAM brings value to the user. Then ensuring that value proposition for the user is delivered by the aircraft. Then, assess if it is a differentiator vs. competitors (other UAM players and existing transport modes)
ISV2-23	Uncertainty regarding local regulations	Partner with local regulators, such the company does with UK Civil Aviation Authority

ISV2-24	Integration with existing infrastructure / transport modes	Considered in the market research to estimate total travel time savings and thus modal share
ISV2-25	Perception of UAM as a threat to personal privacy	Engage with community to assess impact of indicator
ISV2-26	Perception of UAM as visually polluting	Engage with community to assess impact of indicator
ISV2-27	Reliability: on time performance	It should be estimated (via simulations for example), especially since it can be connected to value proposition (travel time savings)
ISV2-28	Easiness to use an UAM service	With simulations and / or living life settings investigate user requirements for easy boarding and deboarding and consider special needs: wheelchair, elderly, children
ISV2-29	Perception of UAM as insecure	Engage with community to assess impact of indicator
PW-1	Alignment with company's strategy	"The creation of the UAM ecosystem requires innovative solutions, which is also a fundamental pillar of Embraer´s growth strategy" Daniel Moczydlower, President & CEO of EmbraerX (EmbraerX, 2020)
PW-2	Perception of UAM as unsafe	Rotors are placed high above to communicate safety to the users
PW-3	Trust in the brand	Trust in Embraer's brand leveraged. Potential users were involved when defining the UAM aircraft's name to enhance user connection with the product and brand

4.4.2 Preparing the answer to MRQ

The Final Indicator Set that answers the MRQ was compiled by combining the indicators discussed at the workshop with those indicators that were not included at the workshop given that no further discussion was needed (see Table 5). Then, as suggested by workshop participants, indicator F25 was eliminated because it is not considered by them, indicators ISV2-2 and ISV2-11 were split because they contain multiple indicators, and indicators W-1 and W-2 were added. Afterwards, as shown in Table 9, the way to evaluate each indicator was specified: hard indicators are evaluated numerically, while soft indicators can be evaluated with a yes/no or with a high-medium-low scale. Finally, each indicator was assigned to a type according to its applicability at the early stage: type 1 is an indicator whose value is determined at the early stage. Type 2 is an indicator that can be influenced or is considered at early stage, but it also depends on implementation. Type 3 is assigned when nothing can be done at the early stage regarding the indicator. Still, it must be identified at the early stage in order to assess if it could become a showstopper at later stages. All indicators are meant to be used to assess whether a conceptual UAM aircraft should continue to the development phase.

4.4.3 Answer to the MRQ

The answer to the MRQ "*What indicators are important to support decision making at the early stage of the innovation process for Urban Air Mobility innovations?*" is the Final Indicator Set in Table 9.

Table 9 Final Indicator Set

ID	Indicator	Evaluation	Early stage applicability	Category
ISV2-7	Closeness to existing certification regulations	high-medium-low	Type 2	Certification
ISV2-10	Level of sustainability (emissions, recyclability at end of life)	high-medium-low	Type 2	
ISV2-23	Uncertainty regarding local regulations	high-medium-low	Type 2	
ISV2-12	Synergy with company's capabilities	high-medium-low	Type 1	Company
PW-1	Alignment with company's strategy	high-medium-low	Type 1	
PW-3	Trust in the brand	high-medium-low	Type 1	
ISV2-2	Production costs	Numeric	Type 2	Financial feasibility (ISV2-4)
ISV2-2	Operation costs	Numeric	Type 2	
ISV2-3	Revenue (from selling eVTOLs, from passengers)	Numeric	Type 2	
ISV2-11	Operational downtime due to adverse weather	Numeric	Type 2	
ISV2-11	Operational downtime due to maintenance	Numeric	Type 2	
ISV2-11	Operational downtime due to charging of batteries	Numeric	Type 2	
ISV2-1	Presence of a market opportunity	yes/no	Type 1	Market entry
F32	Flexibility to serve other markets	high-medium-low	Type 2	
ISV2-8	Fulfillment of safety requirements	yes/no	Type 1	Social and political feasibility
ISV2-9	Fulfillment of noise requirements	yes/no	Type 1	
F6	Perception of UAM as only benefiting higher income classes	high-medium-low	Type 3	
ISV2-25	Perception of UAM as a threat to personal privacy	high-medium-low	Type 3	
ISV2-26	Perception of UAM as visually polluting	high-medium-low	Type 3	
ISV2-29	Perception of UAM as insecure	high-medium-low	Type 3	
ISV2-14	Fulfillment of aircraft requirements (e.g. range, speed, weight)	yes/no	Type 1	Technical feasibility (ISV2-5)
ISV2-15	Achievement of design objectives	yes/no	Type 1	
ISV2-13	Configuration's level of complexity	high-medium-low	Type 1	
ISV2-16	Time to obtain certification	Numeric	Type 2	Timing feasibility (ISV2-6)
ISV2-17	Time for required physical infrastructure to be ready	Numeric	Type 2	
ISV2-18	Time to market	Numeric	Type 2	
ISV2-22	Competitiveness of value proposition	high-medium-low	Type 2	UAM ecosystem
W-1	Impact of uncertain market/societal changes (e.g. pandemic)	high-medium-low	Type 3	

ISV2-24	Integration with existing infrastructure / transport modes	high-medium-low	Type 2	
W-2	Having a well-defined value proposition	yes/no	Type 1	User adoption
ISV2-27	Reliability: on time performance	Numeric	Type 2	
ISV2-20	User's trust of autonomous technology	high-medium-low	Type 2	
ISV2-21	Passenger comfort	high-medium-low	Type 2	
ISV2-28	Easiness to use an UAM service	high-medium-low	Type 2	
PW-2	Perception of UAM as unsafe	high-medium-low	Type 2	

5 Discussion

This chapter reflects on the findings and the scientific contributions of this thesis by comparing them with previous academic research, discusses the implications for society, the environment and companies, and reflects on the limitations of this research.

5.1 Reflection on the findings obtained

The gap addressed by this thesis is a lack of early stage innovation indicators. In the introduction indicators were defined as measures that can be evaluated quantitatively (hard indicators) or qualitatively (soft indicators). Thus, an indicator is measurable, in contrast with a factor, which cannot be measured directly but needs one or more indicators so that it can be measured. The author acknowledges that in Sections 4.2 and 4.3, the findings are called indicators, although they are a mix of indicators and factors. Only the answer to the MRQ (Section 4.4.3) is formed by hard and soft indicators exclusively. As shown in the third column of Table 9, a few hard indicators were found (numeric evaluation), while the majority of indicators are soft (evaluated as high-medium-low or as yes/no). This suggests that there is a knowledge gap that can be addressed in future research, namely early stage innovation indicators that can be evaluated numerically (i.e. hard indicators). This thesis provides a starting point towards addressing this gap by finding a few hard indicators, as well as several soft indicators that can help to find hard indicators. Section 6.2 elaborates on how future researchers can proceed.

5.2 Comparison with previous academic research

This section discusses where this thesis stands in relation to previous academic research and reflects on how the findings of this thesis have contributed to it and to address the scientific knowledge gap identified, namely a lack of early stage innovation indicators for UAM.

5.2.1 Comparison with research on indicators for aerospace and for UAM

Regarding the articles found in the literature review done (see Chapter 2) containing information about SFF or indicators specific to aerospace, Weisshaar (2013) found that aircraft morphing systems innovations were successful when there was a clear or perceived need for something new. This matches the findings of Framework V2, which explains that the market analysis phase should lead to the identification of a need that has not been addressed yet, which is then reflected in the value proposition of the UAM aircraft.

One of the key findings of Vértesy (2017) is that windows of opportunity and strategic responses explain why challenger companies in the regional jet industry were successful in becoming the market leaders. Regarding the windows of opportunity, Vértesy (2017) highlighted the importance of timing, which enabled challenger companies to address a market niche with reduced competition. This is consistent with an early stage indicator found in this thesis, namely the timing feasibility, which refers to the fact that the time to obtain certification must be aligned with the desired time to enter the market. Otherwise, if the innovation fails to reach the market at the required time, the market opportunity might be lost.

Regarding previous research on UAM, two articles were found within the scientific literature that explicitly listed indicators for UAM, namely those by Al Haddad, Fu, et al., (2020), who used indicators to assess the potential of UAM integration with existing public transportation systems, and by Ploetner et al., (2020), who used indicators to evaluate how can UAM complement public transportation. The indicator set resulting from this thesis integrates these indicators with those of other academic and business sources, focusing on their applicability at the early stage. The findings of this thesis can contribute to future researchers who need a set of early stage indicators to evaluate UAM or another transport innovation. An example is using some or all of the indicators of this thesis in a multi-criteria analysis.

5.2.2 Comparison with research by Dziallas (2020)

Dziallas (2020) researched the importance and applicability of early stage indicators for incremental innovations in the automotive industry. The set of indicators that she assessed was created by taking as starting point a set of 26 early stage indicators found by Dziallas & Blind (2019), and then modifying this set according to what the interviewed experts from the automotive industry said. It is important to mention that the aim of Dziallas (2020) was to assess the importance and ease of applicability of these indicators, while the aim of this thesis was to find indicators, rather than evaluating their importance. Thus, the comparison done in this discussion is only regarding the indicators themselves.

Indicators that are the same or very similar between Dziallas (2020) and this thesis are the following (if the indicator name is different, the indicator of this thesis is shown in parenthesis): having a unique selling proposition (or value proposition), technical feasibility, sustainability, resistance of innovation (similar to familiarity and trust of the new technologies of the innovation), synergy potential (which refers to leveraging company capabilities), the time to market and customer satisfaction, brand defining (similar to trust in the brand), ease of use for the customer and customer orientation (these three are all part of the user adoption).

Regarding indicators found by Dziallas (2020) but not in this thesis, they can be classified in three types. For the first type, they are clearly not applicable to UAM. An example is the package potential. This suggests that some early stage indicators are only relevant to some innovations. For the second type, the author hypothesizes that they are only applicable to incremental innovations, rather than to radical innovations such as UAM. Example of these indicators are the degree of novelty and degree of maturity, which are not useful to differentiate among different radical innovations because they are always new and immature. The third type are indicators that might be applicable to UAM, such the future product lifetime. These findings open avenues for future research, as discussed in Section 6.2.

To finalize the comparison, there are some indicators found in this thesis that were not previously found by Dziallas (2020). These can also be classified into two types. The first type are those that could be applicable to innovations in other industries, regardless of whether they are radical or incremental. Examples of these indicators are the fulfillment of key requirements, the achievement of design objectives and the innovation's level of complexity. The second type are those that are applicable to radical innovations but not to incremental ones. Examples are the closeness with existing regulations (irrelevant for incremental regulations given that they can simply operate with the existing laws), the indicators within the categories of social and political acceptance (incremental innovations are unlikely to face acceptance issues), and the timing feasibility (incremental innovations only need to consider the time to market, while UAM innovations should also consider that the time to obtain certification, and the time for new technologies and infrastructure to be ready are aligned with the desired time to enter the market). The applicability of indicators to other industries and which indicators are relevant for incremental in comparison to radical innovations are opportunities for future research (Section 6.2).

5.2.3 Comparison with research by Cooper (2008)

Cooper (2008) listed six factors, each of them with their corresponding indicators, to evaluate new products at Gate 3 of his Stage Gate model. Such indicators were compared with the indicators found in this thesis. Gate 3 was selected because before this gate an innovation is still in the early stage, while innovations that pass the gate are not early stage anymore. Indicators that are similar are the alignment with the company's strategy, the value proposition, the synergy with company's capabilities or competencies, the level of complexity and indicators within the category of financial feasibility, namely revenue, production costs and operation costs. Indicators found by this thesis that are not found in Gate 3 are those belonging to the categories timing feasibility, certifiability and social and political feasibility (see Table 9). Certifiability is specific to the aerospace industry and thus it is not surprising that indicators to evaluate it are not present in Gate 3. In contrast, indicators of the categories timing feasibility and social and political feasibility can be useful to evaluate innovations at the early stage, helping to identify innovations that should not continue to the development phase, potentially saving time and financial resources to companies.

When defining the key concepts in Section 1.2, this thesis used Cooper's Stage Gate (Cooper, 2008) to depict graphically what is meant with the early stage. As explained in Chapter 1, the objective of this thesis was to find early stage innovation indicators, and thus the Stage Gate model was only used for definition purposes. The next two paragraphs briefly reflect on criticisms and improvements to the Stage Gate model.

The Stage Gate system proposed by Cooper (1990) has been criticized for being linear and rigid (Bhatia et al., 2017). The findings of this thesis suggest that decision making processes at the early stage are non-linear. Instead, they are subject to iterations, as conceptualized in Figure 12. For example, the aircraft requirements provided by the market analysis team to the engineering team could be technically infeasible, and should thus be revised (see Section 4.3.4). The "linearity" issue was addressed in the 2008 version of the Stage Gate model (Cooper, 2008), which incorporates iterations and allows for activities to be performed in parallel.

Another shortcoming is that gates are sometimes ineffective, failing to stop bad projects because companies struggle to assign qualified decision makers as gatekeepers (Bhatia et al., 2017). The stage gate system has also been criticized for being inflexible and unable to properly adapt to external elements like changing customer requirements (Bhatia et al., 2017). The second issue is consistent with the findings of this thesis, namely that external societal and market transformation can change the requirements elicited when identifying a market opportunity, as pointed out by experts during the workshop. Trying to solve the shortcomings of previous models, the Stage Gate system has been combined with agile principles in the Agile Stage Gate methodology by Cooper & Sommer (2016). In this model, people working on new products have constant interaction with customers and users already at the early stage, making it better at detecting and responding to changing customer needs (Bhatia et al., 2017). Agile Stage Gate is also better at preventing that bad projects are continued since an increased user involvement makes it easier to identify products that will be rejected by users (Bhatia et al., 2017). This is consistent with one of the findings of this thesis, namely that involving users in the early stage of the innovation process is a way to address uncertainties in the early stage. Nevertheless, this thesis argued that not only users should be involved at the early stage, but also non-users and authorities. The exact way in which this can be done is an opportunity for future research (see Section 6.2).

5.2.4 Comparison with research by Feitelson & Salomon (2004)

The results of this thesis roughly confirm the Political Economy model proposed by Feitelson & Salomon (2004), namely that the factors that influence the adoption of a transport innovation are its technical feasibility, social and political feasibility and economic or financial feasibility. However, there are some differences. Firstly, this thesis specifies that indicators belonging to the social and political feasibility should be identified at the early stage (see Section 5.3). Doing so can help companies identify potential showstoppers and if they turn out to be unsolvable, the innovation project should be stopped to avoid investing resources in projects that will likely fail during implementation due to societal or political pressure. The second difference is that this thesis identified early stage indicators belonging to the categories of user adoption and timing feasibility (Table 9), which were not conceptualized in the Political Economy model. Indicators for user adoption should be considered at the early stage to avoid that businesses invest resources in an innovation that does not meet the needs of its intended users. Indicators for timing feasibility are important because the company's market penetration strategy depends on reaching the market at a determined time (see Section 4.3.4).

5.3 Implications for society and the environment

The findings from both literature and semi-structured interviews point out that the societal and political acceptance of an innovation are critical to the innovation's success, which is consistent with Feitelson & Salomon (2004). However, Feitelson & Salomon (2004) did not specify when to assess the societal and political feasibility. The contribution brought by this thesis in this regard is stating that the indicators impacting societal and political acceptance should be identified at the early stage in order to assess which of these indicators are knockouts or showstoppers, meaning that failing to address them will likely result in the rejection of the innovation. For example, the noise generated by an UAM aircraft is a knockout indicator related to societal and political acceptance. This thesis argues that it is important that already at the early stage companies investigate what noise levels are likely to be accepted by citizens. In this way, companies can verify at the early stage whether the aircraft can achieve these levels. If they cannot be achieved, then the innovation project should be stopped given that it will be rejected by society when it reaches the market.

Regarding the societal benefits of UAM, several things are worth noting, based on the findings in Section 4.2.3. Firstly, its potential to reduce traffic congestion is unclear. In literature it is cited as a promised benefit (Balac et al., 2019; Liu et al., 2017; Straubinger et al., 2020) but its real impact is put into question (Straubinger et al., 2020). Secondly, for use cases in which the value proposition is travel time savings, such as inter and intra city passenger transportation, this societal benefit is limited to the users of UAM. Another criticism is that UAM might only benefit the higher income classes. Whether UAM services could be affordable for the majority of the population, with a ticket price similar to that of a conventional taxi for example, is still unclear. Thirdly, the value proposition of some UAM use cases is centered around accessibility. Given that UAM requires significantly less infrastructure than other transport modes to operate, it can provide a societal benefit by connecting areas that are currently underserved by ground (road) infrastructure. For instance, UAM can provide transportation services in areas difficult to access such as islands, hilly regions and areas separated by rivers and lakes, as well as in areas where it is not economically viable to build roads. Still, the financial feasibility of an UAM service in those regions is unclear. Fourthly, a use case that can provide significant benefits to society is special purpose aircraft. This includes UAM aircraft for medical emergency, rescue during natural disasters and transportation of humanitarian aid.

The environmental impact of UAM is explained in this paragraph, based on the results shown in Section 4.2.3. UAM aircraft are electric and thus no local emissions are generated. Under specific conditions, a VTOL with three or more passengers making a trip of at least 100 km will generate 6% less emissions per passenger kilometer than an electric car, estimating an average of 1.54 passengers traveling in it (Straubinger et al., 2020). However, in most cases the energy consumption to transport people with UAM can be higher in comparison to ground transportation, as was mentioned by Interviewee 2. Even if vehicles are electric and the electricity comes from renewable sources, UAM could still be consuming more resources than ground transport. Therefore, this higher energy consumption should be weighed against its benefits. For instance, it might be justifiable for emergency and humanitarian aid UAM aircraft, but not for an airport shuttle. A final consideration about UAM's sustainability is that battery lifetimes are very short (Grandl et al., 2018) and the useful lifecycle of UAM aircraft is ten times shorter than for small jets (Boelens, 2019). This can result in a negative environmental impact.

5.4 Implications for companies

Decisions at the early stage of innovation are critical. When an innovation reaches the market, it is very difficult to change what was decided early in the innovation process. For example, it is not possible to change the aircraft's chosen configuration if it is already in the market entry phase. In contrast, indicators that are implementation dependent, such as the on time performance of a new transport mode or its integration with first and last mile modes are relatively easy to change during the implementation phase. For this reason, it is important to identify early stage innovation indicators. The value this thesis brings to companies is compiling a set of early stage indicators based on the input of multiple academic and business sources. The set of indicators produced can serve as a checklist of items that can be relevant for the success of transport innovations such as UAM. As shown in Table 9, three types of indicators are produced. Indicators type 1 are those that can already be evaluated at the early stage. Withing this type, it is noteworthy that the fulfillment of safety and noise requirements, two showstoppers related to user adoption and societal and political acceptance of UAM, fall within this category since safety and noise requirements for certification can be known at the early stage. Nevertheless, it is possible that an UAM aircraft fulfills these requirements from a certification perspective but is still rejected by users or the general public. To avoid this, the noise levels acceptable to citizens and how to improve UAM's safety perception can be investigated. However, they can only be estimated but not fully known at the early stage. Thus, indicators such as UAM safety perception are classified as type 2, which contains all indicators that although their value is still uncertain and they can only be fully known until the innovation is implemented, it is possible to make decisions at the early stage that will impact the value of the indicator. Most indicators fall in this type. This suggests that the early stage is critical because even though there will still be uncertainties regarding the value of the indicators at later stages, the early stage has an impact on them. Finally, for indicators type 3, although nothing can be done at the early stage regarding them, they must be identified to assess if they could become showstoppers during the later stages. This can allow companies to assess risks at the early stage. If for instance noise fell within this type, it could be too risky to continue with the innovation project given that there is a showstopper but nothing can be done about it. In contrast, although nothing can be done at the early stage regarding visual pollution the risk of continuing with the innovation project could be acceptable since it is unlikely that visual pollution becomes a showstopper at later stages.

Additional implications and recommendations for players in the UAM market are explained in this and the next paragraphs. UAM applications for cargo will likely happen before passenger applications, given that unmanned operations have less safety concerns than manned ones. Although it is possible that some companies first address the freight market and then leverage the capabilities developed to address passenger markets, others will not pursue that direction. For example, as found during the workshop (refer to Table 8) the company is focusing only on passenger applications because this market is closer to their core competencies and better aligned with the company's strategy and vision.

A strategy that UAM manufacturers could pursue is to create aircraft platforms that can be adapted to more than one use case, an implication stemming from indicator F32 "Flexibility to serve other markets". An example is a platform designed to be used for both cargo and passenger applications. While this can save development costs, it comes with the cost that the platform will not be optimized for any of the applications. Another course of action that companies could take is targeting niche markets with high societal and political acceptance, especially if these markets are aligned with their strategy. Such niche markets include emergency services, humanitarian aid, natural disasters, and access to remote areas.

As explained in Section 4.3.4, the transition towards fully autonomous UAM aircraft will probably happen in stages. In a first stage, aircraft will be piloted by humans, then there will be a phase in which the pilot is still on board but the aircraft is already autonomous, until finally UAM will be pilotless and autonomous. (Interviewee 5). There could also be a phase in which pilotless aircraft are controlled from the ground (Interviewee 3). A similar transition will happen from centralized ATM towards decentralized air traffic control. In the initial phases of implementation, UAM vehicles will operate using existing ATM systems, followed by a stage in which although UAM aircrafts are still be visible in ATM systems, they are doing the separation themselves. Finally, UAM will be fully decoupled from ATM (Interviewee 5).

A significant challenge is that many indicators driving the success of UAM are implementation dependent (see indicators type 2 in Table 9). Examples are the integration with existing infrastructure and transport modes, as well as indicators related to user adoption. Still, it is possible to partially address some of them at the early stage. For example, as mentioned in the workshop, involving potential users in the design phases by making surveys and interviews can be helpful to understand what is relevant for passenger comfort (see Table 8). Cooperating with the authorities of cities where an UAM service can be established can help to reduce regulatory uncertainty and increase the chances of a successful implementation. An example is establishing a regulatory sandbox to experiment in a real life setting how could UAM be implemented (Eve Air Mobility, 2021). Establishing partnerships or consortia between companies in order to share aircraft development and infrastructure construction costs is another avenue that companies could pursue (Ford et al., 2019; Grandl et al., 2018). Similar strategies can be followed when developing other radical transport innovations.

Finally, the future operation costs of UAM innovations can be impacted by early stage decisions, as explained in Section 4.2.3. For example, aircraft designs with swappable batteries will help to maximize battery lifetime by making it possible to charge them at a charging station, instead of having to apply fast charging, which reduces battery lifetime (Boelens, 2019). Another example is that simpler configurations will incur less maintenance costs than those that employ complex mechanisms such as tilting wings or tilting rotors.

5.5 Limitations of this thesis project

Regarding the limitations of the data analysis method employed, qualitative content analysis is subject to bias from the researcher since it depends on the researcher's judgement. Several measures were taken to decrease subjectiveness as much as possible. As explained in Section 3.2.3, this limitation was addressed by using Atlas.ti and designing and following a coding process. Still, it is possible that a different person would have assigned different codes to quotations or created different indicator categories. When researchers work as part of a team, this is addressed by using peer coding. Since this thesis is an individual work, peer coding was not feasible. As a proxy for peer coding, the author decided that instead of using the code set obtained from scientific literature as a coding scheme for gray literature and the interview transcripts, those texts were to be coded from scratch. Then, the independently generated code sets could be compared. The author acknowledges that despite taking these measures it was not possible to completely eliminate subjectivity from the qualitative content analysis process. The impact of this limitation on the findings is small because firstly, multiple validations were performed by comparing the code sets generated with the different indicator sources (scientific literature, gray literature, case studies and interview transcripts) and secondly, because indicators are explained in detail, which reduces the importance of whether a different person would have given a different name to an indicator.

Regarding the limitations of the data gathering methods employed, the selection process to determine which articles from literature to analyze and which not, as well as which experts to interview, can be subjective. The author tried to overcome this limitation by defining and explicitly stating selection criteria. Still, whether an article fulfilled the selection criteria is also subjective. The impact of this limitation on the thesis results is minimum because indicators were mentioned in more than one source. Thus, whether a specific article was selected for analysis or not has no impact on the final set of indicators obtained. Regarding the selection criteria to select interviewees, in hindsight the author realizes that it would have been valuable to interview experts in the early stage of the innovation process even if they were not familiar with the UAM field. This could have provided a better understanding of which indicators can be used at the early stage. Future research can be done along this direction. Finally, the workshop, which was used to gather feedback and validate the findings, also carries limitations. The first is that it is biased towards the viewpoint of one UAM company. It was not possible to address this limitation given time constraints and a lack of access to experts from other UAM companies. This limitation can be addressed in future research by comparing the early stage indicators that are considered relevant by several UAM aircraft manufacturers.

Other limitations of this research are the following. Firstly, due to the exploratory nature of this research, results are not conclusive. The results are qualitative and thus their interpretation is subject to the author’s judgement. This limitation can be addressed in future research by pursuing a quantitative approach that will allow to test the results obtained in this thesis. Secondly, this research is biased towards one company given that two out of eight interviewees and all workshop participants belong to the same company. This limitation exists given limited access to experts from companies and can be addressed in future research. Thirdly, no clear guidelines exist to determine which indicators are applicable at the early stage and which are not. Attempting to address this limitation, the author established criteria (see Section 4.3.1) that must be fulfilled so that an indicator is considered applicable at the early stage. Nevertheless, these criteria are based on the assumptions that design decisions are made exclusively at the early stage and that all requirements are determined at the early stage. Future research can test whether these assumptions are true by further investigating what indicators are used by companies at the early stage and based on this determine what characteristics make an indicator applicable at the early stage. The opportunities for future research that were briefly mentioned in this paragraph are described with more detail in Section 6.2.

6 Conclusion

6.1 Main contributions

This thesis argues that decisions and considerations made at the early stage of the innovation process are critical for the future success of the innovation. Even when many early stage indicators are dependent on later stages, it is important to identify them and act upon them early in the innovation process, as illustrated by the following examples. First, the propulsion type and the choice of materials for the airframe have a large impact on the sustainability of the aircraft regarding emissions and recyclability at the end of life, as well as on production and operation costs. Second, the chosen configuration impacts the markets that can be served with the aircraft, the expected time to obtain certification and thus to enter the market, as well as maintenance costs. Finally, it is important to have a clearly defined value proposition and evaluate it against the competition, even if only educated guesses can be made about its competitiveness. For instance, if the value proposition of an UAM aircraft is travel time savings, simulations can be run to estimate the possible market share, informing companies what travel time savings must be achieved to obtain the desired number of customers.

The way in which early stage decisions are made for UAM innovations has similarities with conventional aircraft, starting with finding a market opportunity and based on this, defining the aircraft requirements that a technical design must fulfill. Then, after multiple iterations between the market and engineering teams, an aircraft that can serve the target market is designed. However, there is a major difference between the early stage of UAM versus conventional aircraft. When developing a new airplane, companies know that it will be accepted by the regulator as long as it complies with certification standards, and that once it enters the market, people will fly on it and society will accept it. In contrast, even if an UAM aircraft can work technically and is certified, there are still uncertainties regarding user adoption, acceptance by local regulators and acceptance by non-users. The findings of this thesis point that user adoption, societal and political acceptance are critical for the success of transport innovations such as UAM, and that these aspects can already be considered at the early stage. The indicators that are relevant for adoption and acceptance can be identified early in order to assess which are likely to become showstoppers at later stages and what actions can be taken at the early stage. For instance, to investigate at the initial stages what might drive user adoption companies can involve potential users in the UAM aircraft design, using simulations, surveys and interviews. This can help to address one of the major showstoppers related to adoption, namely safety perception. In a similar fashion, it is possible to investigate what noise levels would be acceptable by the general population of cities in which UAM will be introduced. Finally, to address political acceptance, an option is to work together with the regulator of a city that wants to introduce UAM. Joining a regulatory sandbox is an example of this. In summary, the uncertainties regarding user adoption and societal and political acceptance could be addressed by companies pursuing transport innovations by involving users, non-users and authorities in the early stage of the innovation process.

As shown in the discussion, this thesis argues that the importance of the early stage for the innovation's success and specifically the relevance of identifying and addressing societal and political acceptance indicators at the early stage can be applicable not only to UAM, but also to other innovations in transportation. Investigating and trying to tackle acceptance at the early stage could help companies to identify showstoppers and assess what actions can be taken to mitigate them. If showstoppers prove to be unsolvable because the company has no control over them, the probability of implementation failure can be high. Thus, it could be wise to stop the innovation project to avoid spending company resources in something that will likely fail. Conversely, if the company can take actions about the identified showstoppers, their early identification can improve the innovation's performance when it enters the market. This is an opportunity for future research, as explained in the next section.

6.2 Future research opportunities

As discussed in the previous chapter, a few hard indicators were obtained in this thesis, while mainly soft indicators were found. This suggests that it is worthwhile to continue looking for early stage innovation indicators that can be evaluated numerically (i.e. hard indicators). The soft indicators resulting from this thesis are a starting point, providing guidance about what aspects important for business decision makers require hard indicators. Future researchers should first assess the effort and time resources needed to find hard indicators. To do so, challenges that future researchers should consider are the following. Firstly, that there is no single or correct metric and thus different researchers could produce different hard indicators. Secondly, that some indicators require not only to propose a numerical way to measure them, but also to specify their target value. Finding this value could require significant resources. An example is finding what noise levels will be acceptable to citizens. This can be a master thesis or even a PhD project by itself, requiring to consider not only the noise emitted by a single UAM aircraft but also the overall noise impact of multiple aircraft flying simultaneously in an urban zone. A third challenge is that it is not enough to propose hard indicators. Instead, hard indicators should be validated with experts, preferably in a real life setting with a company that is assessing an UAM aircraft that it is currently developing. In summary, it is possible to find hard indicators, but the time and effort resources required to find them can be considerable.

The findings of this thesis suggest that societal and political acceptance, as well as user adoption, are critical to a successful implementation of transport innovations such as UAM. It has been argued that what can be done at the early stage in this regard is to involve stakeholders in the innovation process. Still, further research is needed to better understand how to address social and political acceptance and user adoption at the early stage of innovation. Possible avenues are researching how past successful and failed innovations have dealt with adoption and acceptance, and how current candidate innovations in transportation, such as Hyperloop, or in other sectors, are addressing these issues at the early stage

The indicators found could be applicable to other innovations in transportation and even in other sectors. Thus, an opportunity for future research is to further investigate early stage innovation indicators that can be applicable to innovations in general. One suggestion is to find indicators specific to another early stage innovation, and then compare versus the findings of this thesis. The aim of such future research can be to determine which early stage indicators are applicable across different industries, and which are specific to an industry or even to an innovation. Moreover, the author identified some indicators in previous research that might be applicable to UAM but were not elicited in this thesis. Finding out whether these indicators are relevant for UAM can be further researched.

For some indicators found in this thesis that were not mentioned in previous research by Dziallas (2020), the author hypothesizes that they are applicable to radical innovations but not to incremental ones. In a similar manner, some indicators found by Dziallas (2020) that were not elicited in this thesis are probably only applicable to incremental innovations, rather than to radical innovations such as UAM. For this reason, investigating the differences between early stage indicators for incremental versus radical innovations is an avenue for further research.

With the Final Framework (Figure 12) this thesis provided insights into how a possible process to evaluate early stage innovations could look like, depicting that it is an iterative process in which iterations are performed to try to achieve an UAM configuration that is financially, timing, technically, socially and politically feasible. This provides a starting point for additional research on early stage evaluation processes. Another research opportunity is thus to further investigate decision making processes at the early stage of innovation. This research gap is also mentioned by Aristodemou et al., (2020), who argued that processes at the front end of the innovation are still unclear. For instance, the author of this thesis noticed that a large number of people are involved in early stage decisions. Investigating in detail the roles of the people involved and comparing them across companies and sectors is a possible direction of future research. Another direction can be to investigate the iterative nature of the innovation process, trying to answer questions like how is the feasibility of a solution assessed, what is the duration of iterations, and whether this varies across industries.

From a methodological perspective, it can be beneficial to investigate early stage innovation indicators by pursuing a quantitative or a mixed methods research approach. This will allow to determine with statistical significance which indicators are considered important by businesses and which are less relevant, as well as defining the characteristics that, according to industry experts, make an indicator applicable at the early stage. Such future research can include surveys, supplemented with semi-structured interviews, for example. It should be considered that there are significant challenges to overcome including firstly that it is not straightforward to determine the size of the sample size, secondly that it is difficult to collect information about early stage innovation given that it is usually strategic to companies, and thirdly that significant time resources can be needed.

Finally, future research about early stage innovation indicators can include interviews with experts from multiple companies in which the number of participants from each company is balanced to avoid bias towards one company. Moreover, such research will also benefit from interviewing people from different departments involved in innovation projects, such as market analysis, engineering and project management. This will allow to compare the use of early stage innovation indicators not only across companies but also among departments.

References

Adams, W. C. (2015). Conducting Semi-Structured Interviews. In K. Newcomer, H. Hatry, & J. Wholey (Eds.), *Handbook of Practical Program Evaluation* (pp. 492–505). Wiley. https://doi.org/10.1002/9781119171386.ch19

Ahmed, S. S., Hulme, K. F., Fountas, G., & Eker, U. (2020). *The Flying Car — Challenges and Strategies Toward Future Adoption*. *6*(July), 1–11. https://doi.org/10.3389/fbuil.2020.00106

Airbus. (2018). *Urban Air Mobility by Airbus*. https://www.airbus.com/content/dam/corporate-topics/publications/backgrounders/Urban-Air-Mobility-Backgrounder-E.pdf

Airbus Helicopters. (2019). *City Airbus*. https://www.airbus.com/search.image.html?q=cityairbus&lang=en&newsroom=true#searchresult-image-all-14

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. *Transportation Research Part A*, *132*(November 2019), 696–712. https://doi.org/10.1016/j.tra.2019.12.020

Al Haddad, C., Fu, M., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Choosing Suitable Indicators for the Assessment of Urban Air Mobility: A Case Study of Upper Bavaria, Germany. *European Journal of Transport and Infrastructure Research*, *4*(20), 214–232. https://doi.org/https://doi.org/10.18757/ejtir.2020.20.4.4464

Antoniou, C., Balac, M., Ploetner, K. O., & Rothfeld, R. L. (2018). Agent-based Simulation of Urban Air Mobility. *2018 Modeling and Simulation Technologies Conference*, 1–10. https://doi.org/https://doi.org/10.2514/6.2018-3891

Aristodemou, L., Tietze, F., & Shaw, M. (2020). Stage Gate Decision Making: A Scoping Review of Technology Strategic Selection Criteria for Early-Stage Projects. *IEEE Engineering Management Review*, *48*(2), 118–135. https://doi.org/10.1109/EMR.2020.2985040

Bailey, J. (2008). First steps in qualitative data analysis: transcribing. *Family Practice*, *25*(2), 127–131. https://doi.org/10.1093/fampra/cmn003

Balac, M., Rothfeld, R. L., & Hörl, S. (2019). The Prospects of on-demand Urban Air Mobility in Zurich , Switzerland. *2019 IEEE Intelligent Transportation Systems Conference (ITSC)*, 906–913. https://doi.org/10.1109/ITSC.2019.8916972

Balachandra, R., & Friar, J. H. (1997). Factors for Success in R & D Projects and New Product Innovation: A Contextual Framework. *IEEE Transactions on Engineering Management*, *44*(3), 276–287. https://doi.org/https://doi.org/10.1109/17.618169

Baur, S., Schickram, S., Homulenko, A., Martinez, N., & Dyskin, A. (2018). *Urban air mobility: The rise of a new mode of transportation*. Roland Berger Focus. https://www.rolandberger.com/publications/publication_pdf/Roland_Berger_Urban_Air_Mobility.pdf

Benzies, K. M., Premji, S., Hayden, K. A., & Serrett, K. (2006). State-of-the-evidence reviews: Advantages and challenges of including grey literature. *Worldviews on Evidence-Based Nursing*, *3*(2), 55–61. https://doi.org/10.1111/j.1741-6787.2006.00051.x

Bhatia, A., Cheng, J., Salek, S., Chokshi, V., & Jetter, A. (2017). Improving the Effectiveness of Fuzzy Front End Management: Expanding Stage-Gate Methodologies Through Agile. *2017 Portland International Conference on Management of Engineering and Technology*, 1–8. https://doi.org/https://doi.org/10.23919/PICMET.2017.8125390

Boelens, J.-H. (2019). *Pioneering the Urban Air Taxi Revolution*. Volocopter. https://press.volocopter.com/images/pdf/Volocopter-WhitePaper-1-0.pdf

Booz Allen Hamilton. (2018). *Urban Air Mobility (UAM) Market Study*. https://ntrs.nasa.gov/api/citations/20190000519/downloads/20190000519.pdf

Bucholtz, M. (2000). The politics of transcription. *Journal of Pragmatics*, *32*(10), 1439–1465. https://doi.org/https://doi.org/10.1016/S0378-2166(99)00094-6

Castillo, H., & Pitfield, D. E. (2010). ELASTIC – A methodological framework for identifying and selecting sustainable transport indicators. *Transportation Research Part D*, *15*(4), 179–188. https://doi.org/10.1016/j.trd.2009.09.002

Cleophas, C., Cottrill, C., Fabian, J., & Tierney, K. (2019). Collaborative urban transportation : Recent advances in theory and practice. *European Journal of Operational Research*, *273*(3), 801–816. https://doi.org/10.1016/j.ejor.2018.04.037

Cooper, R. G. (1990). Stage-Gate Systems: A New Tool for Managing New Products. *Business Horizons*, *33*(3), 44–54. https://doi.org/https://doi.org/10.1016/0007-6813(90)90040-I

Cooper, R. G. (2008). Perspective: The Stage-Gate Idea-to-Launch Process—Update, What's New, and NexGen Systems. *Journal of Product Innovation Management*, *25*(3), 213–232. https://doi.org/https://doi.org/10.1111/j.1540-5885.2008.00296.x

Cooper, R. G., & Kleinschmidt, E. J. (1987). New products: What separates winners from losers? *The Journal of Product Innovation Management*, *4*(3), 169–184. https://doi.org/10.1016/0737-6782(87)90002-6

Cooper, R. G., & Sommer, A. F. (2016). Agile-Stage-Gate: New idea-to-launch method for manufactured new products is faster, more responsive. *Industrial Marketing Management*, *59*(November 2016), 167–180. https://doi.org/https://doi.org/10.1016/j.indmarman.2016.10.006

Courtin, C., Burton, M., Butler, P., Yu, A., Vascik, P. D., & Hansman, R. J. (2018). Feasibility Study of Short Takeoff and Landing Urban Air Mobility Vehicles using Geometric Programming. *2018 Aviation Technology, Integration, and Operations Conference*, *June*, 1–24. https://doi.org/https://doi.org/10.2514/6.2018-4151

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, *11*(1), 100. https://doi.org/10.1186/1471-2288-11-100

Dumay, J., Rooney, J., & Marini, L. (2013). An intellectual capital-based differentiation theory of innovation practice. *Journal of Intellectual Capital*, *14*(4), 608–633. https://doi.org/10.1108/JIC-02-2013-0024

Duvall, T., Green, A., Langstaff, M., & Miele, K. (2019). *Air-mobility solutions: What they'll need to take off*. McKinsey & Company. https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/air-mobility-solutions-what-theyll-need-to-take-off

Dziallas, M. (2020). How to evaluate innovative ideas and concepts at the front-end ? A front-end perspective of the automotive innovation process. *Journal of Business Research*, *110*, 502–518. https://doi.org/10.1016/j.jbusres.2018.05.008

Dziallas, M., & Blind, K. (2019). Technovation Innovation indicators throughout the innovation process : An extensive literature analysis. *Technovation*, *80–81*, 3–29. https://doi.org/10.1016/j.technovation.2018.05.005

Eling, K., Griffin, A., & Langerak, F. (2016). Consistency Matters in Formally Selecting Incremental and Radical New Product Ideas for Advancement. *Journal of Product Innovation Management*, *33*, 20–33. https://doi.org/10.1111/jpim.12320

Eling, K., & Herstatt, C. (2017). Managing the Front End of Innovation—Less Fuzzy, Yet Still Not Fully Understood. *Journal of Product Innovation Management*, *34*(6), 864–874. https://doi.org/10.1111/jpim.12415

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

EmbraerX. (2020). *EmbraerX and Airservices Australia release Concept of Operations for Urban Air Mobility*. https://embraerx.embraer.com/global/en/news?slug=1206817-embraerx-and-airservices-australia-release-concept-of-operations-for-urban-air-mobility

EmbraerX. (2021). *eVTOL*. https://embraerx.embraer.com/global/en/media

European Commission. (2020). *2020 road safety statistics: what is behind the figures?* https://ec.europa.eu/transport/modes/road/news/2021-04-20-road-safety-statistics-2020_en

Eve Air Mobility. (2021). *Eve-led aviation consortium joins UK Civil Aviation Authority to develop Urban Air Mobility Concept of Operations*. https://eveairmobility.com/eve-led-aviation-consortium-joins-uk-civil-aviation-authority-to-develop-urban-air-mobility-concept-of-operations/

eVTOL News. (2021a). *eVTOL Aircraft Directory*. https://evtol.news/aircraft

eVTOL News. (2021b). *Talaria Hermes I*. https://evtol.news/aerodelft-hermes-i/

Feitelson, E., & Salomon, I. (2004). Political economy of transport innovations. In M. Beuthe, V. Himanen, A. Reggiani, & L. Zamparini (Eds.), *Transport Developments and Innovations in an Evolving World* (pp. 11–23). Springer.

Ford, J., Dyment, P., & Miller, D. (2019). *How Public-Private Partnerships Will Lead Urban Air Mobility*. UAMG Series White Paper. https://www.nexa-uam.com/post/how-public-private-partnerships-will-lead-urban-air-mobility

Fortune Business Insights. (2020). *Business Jet Market*. https://www.fortunebusinessinsights.com/industry-reports/business-jet-market-101585

Friese, S. (2020). *Creating a Coding Scheme with ATLAS.ti*. ATLAS.Ti Research Blog. https://atlasti.com/2020/01/31/creating-a-coding-scheme-with-atlas-ti-by-susanne-friese/

Fu, M., Rothfeld, R., & Antoniou, C. (2019). Exploring Preferences for Transportation Modes in an Urban Air Mobility Environment: Munich Case Study. *Journal of the Transportation Research Board*, *2673*(10), 427–442. https://doi.org/10.1177/0361198119843858

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Goldstein, M. (2020). *Despite Pandemic, EmbraerX Speeds Development Of "Flying Cars."* Forbes. https://www.forbes.com/sites/michaelgoldstein/2020/08/05/embraerx-speeds-development-of-its-evtol-flying-cars-for-uber-elevate-and-beyond/#:~:text=Despite Pandemic%2C EmbraerX Speeds Development Of "Flying Cars",-Michael Goldstein&text=A graphic of flying

Goodrick, D., & Rogers, P. J. (2015). Qualitative data analysis. In K. Newcomer, H. Hatry, & J. Wholey (Eds.), *Handbook of Practical Program Evaluation* (pp. 561–595). Wiley. https://doi.org/https://doi.org/10.1002/9781119171386.ch22

Grandl, G., Ostgathe, M., Cachay, J., Doppler, S., Salib, J., & Ross, H. (2018). *The Future of Vertical Mobility*. Porsche Consulting. https://fedotov.co/wp-content/uploads/2018/03/Future-of-Vertical-Mobility.pdf

Green, J., Willis, K., Hughes, E., Small, R., Welch, N., Gibbs, L., & Daly, J. (2007). Generating best evidence from qualitative research: the role of data analysis. *Australian and New Zealand Journal of Public Health*, *31*(6), 545–550. https://doi.org/10.1111/j.1753-6405.2007.00141.x

Holden, J., & Goel, N. (2016). *Fast-Forwarding to a Future of On-Demand Urban Air Transportation*. Uber Elevate. https://www.uber.com/elevate.pdf

Hove, S. E., & Anda, B. (2005). Experiences from conducting semi-structured interviews in empirical software engineering research. *11th IEEE International Software Metrics Symposium (METRICS'05)*. https://doi.org/10.1109/METRICS.2005.24

Jewell, S. T. (2018). Providing meaningful information: Part D—Current awareness. In A. P. DeRosa (Ed.), *A Practical Guide for Informationists* (pp. 63–70). Elsevier. https://doi.org/10.1016/b978-0-08-102017-3.00006-1

Khurana, A., & Rosenthal, S. R. (1998). Towards Holistic "Front Ends" In New Product Development. *Journal of Product Innovation Management*, *15*(1), 57–74. https://doi.org/https://doi.org/10.1016/S0737-6782(97)00066-0

Lilium. (2021). *Lilium Jet*. https://lilium.com/jet

Liu, Y., Kreimeier, M., Stumpf, E., Zhou, Y., & Liu, H. (2017). Overview of recent endeavors on personal aerial vehicles: A focus on the US and Europe led research activities. *Progress in Aerospace Sciences*, *91*, 53–66. https://doi.org/10.1016/j.paerosci.2017.03.001

MacHado, M. A., & Hatakeyama, K. (2018). From technology transfer to disruptive innovation: The case of EMBRAER. *Proceedings of PICMET'18: Technology Management for Interconnected World*. https://doi.org/10.23919/PICMET.2018.8481903

Martinsuo, M., & Poskela, J. (2011). Use of evaluation criteria and innovation performance in the front end of innovation. *Journal of Product Innovation Management, 28*(6), 896–914. https://doi.org/10.1111/j.1540-5885.2011.00844.x

Maxa, J. A., Blaize, R., & Longuy, S. (2019). Security Challenges of Vehicle Recovery for Urban Air Mobility Contexts. *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*. https://doi.org/https://doi.org/10.1109/DASC43569.2019.9081808

Moenaert, R. K., Robben, H., Antioco, M., Schamphelaere, V. De, & Roks, E. (2010). Strategic Innovation Decisions: What You Foresee Is Not What You Get. *Journal of Product Innovation Management*, *27*(6), 840–855. https://doi.org/https://doi.org/10.1111/j.1540-5885.2010.00755.x

Naor, M., Druehl, C., & Bernardes, E. S. (2018). Servitized business model innovation for sustainable transportation : Case study of failure to bridge the design-implementation gap. *Journal of Cleaner Production*, *170*, 1219–1230. https://doi.org/10.1016/j.jclepro.2017.09.221

Niklaß, M., Dzikus, N., Swaid, M., & Berling, J. (2020). A Collaborative Approach for an Integrated Modeling of Urban Air Transportation Systems. *Aerospace, 7*(5), 1–34. https://doi.org/10.3390/aerospace7050050

OECD/Eurostat. (2018). Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation. In *The Measurement of Scientific, Technological and Innovation Activities* (4th editio). OECD Publishing. https://doi.org/10.1787/9789264304604-en

Ørngreen, R., & Levinsen, K. T. (2017). Workshops as a research methodology. *The Electronic Journal of E-Learning*, *15*(1), 70–81. https://doi.org/available online at www.ejel.org

PAL-V. (2021). *Explore the PAL-V*. https://www.pal-v.com/en/explore-pal-v

Palmberg, C. (2006). The sources and success of innovations — Determinants of commercialisation and break-even times. *Technovation*, *26*(11), 1253–1267. https://doi.org/https://doi.org/10.1016/j.technovation.2005.09.019

Park, S. (2019). Identification of Overall Innovation Behavior by Using a Decision Tree : The Case of a Korean Manufacturer. *Sustainability*, *11*(22), 1–54. https://doi.org/doi:10.3390/su11226207

Peksa, M., & Bogenberger, K. (2020). Estimating UAM Network Load with Traffic Data for Munich. *39th Digital Avionics Systems Conference (DASC)*. https://doi.org/10.1109/DASC50938.2020.9256525

Ploetner, K. O., Al Haddad, C., Antoniou, C., Frank, F., Fu, M., Kabel, S., Llorca, C., Moeckel, R., Moreno, A. T., Pukhova, A., Rothfeld, R., Shamiyeh, M., Straubinger, A., Wagner, H., & Zhang, Q. (2020). Long - term application potential of urban air mobility complementing public transport : an upper Bavaria example. *CEAS Aeronautical Journal*, *11*, 991–1007. https://doi.org/10.1007/s13272-020-00468-5

Rabionet, S. E. (2011). How I Learned to Design and Conduct Semi-structured Interviews: An Ongoing and Continuous Journey. *The Qualitative Report*, *16*(2), 563–566. https://doi.org/https://doi.org/10.46743/2160-3715/2011.1070

Ragbir, N. K., Rice, S., Winter, S. R., Choy, E. C., & Milner, M. N. (2020). How Weather, Terrain, Flight Time, and Population Density Affect Consumer Willingness to Fly in Autonomous Air Taxis. *Collegiate Aviation Review International*, *38*(1), 69–87. https://doi.org/https://doi.org/10.22488/okstate.20.100205

Rajendran, S., & Pagel, E. (2020). Recommendations for emerging air taxi network operations based on online review analysis of helicopter services. *Heliyon*, *6*(12), 1–8. https://doi.org/https://doi.org/10.1016/j.heliyon.2020.e05581

Rajendran, S., & Shulman, J. (2020). Study of emerging air taxi network operation using discrete-event systems simulation approach. *Journal of Air Transport Management*, *87*, 1–9. https://doi.org/10.1016/j.jairtraman.2020.101857

Reiche, C., Cohen, A. P., & Fernando, C. (2021). An Initial Assessment of the Potential Weather Barriers of Urban Air Mobility. *IEEE Transactions on Intelligent Transportation Systems*, 1–10. https://doi.org/https://doi.org/10.1109/TITS.2020.3048364

Ritchie, H., & Roser, M. (2020). *Emissions by sector*. Our World in Data. https://ourworldindata.org/emissions-by-sector#energy-electricity-heat-and-transport-73-2

Rodriguez, B. (2019). *Vahana, Airbus all-electric vehicle demonstrator*. Airbus. https://www.airbus.com/search.image.html?q=vahana&lang=en&newsroom=true#searchresult-image-all-20

Rothfeld, R. L., Balac, M., Ploetner, K. O., & Antoniou, C. (2018). Initial Analysis of Urban Air Mobility's Transport Performance in Sioux Falls. *2018 Aviation Technology, Integration, and Operations Conference*, 1–13. https://doi.org/https://doi.org/10.2514/6.2018-2886

Saldaña, J. (2009). *Coding Manual for Qualitative Researchers*. SAGE Publications, Ltd.

Shenhar, A., Holzmann, V., Dvir, D., Shabtai, M., Zonnenshain, A., & Orhof, O. (2020). If You Need Innovation Success, Make Sure You've Got the Right Project. *IEEE Engineering Management Review*, *48*(1), 113–126. https://doi.org/10.1109/EMR.2020.2974698

Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K.-D., Kaiser, J., & Ploetner, K. O. (2020). An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction. *Journal of Air Transport Management*, *87*, 1–12. https://doi.org/10.1016/j.jairtraman.2020.101852

Thomas, G. L., Chapman, J. W., Alencar, J., Hasseeb, H., Sadey, D., & Csank, J. (2020). Multidisciplinary Systems Analysis of a Six Passenger Quadrotor Urban Air Mobility Vehicle Powertrain. *2020 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)*, 1–22. https://doi.org/https://doi.org/10.2514/6.2020-3564

TomTom. (2020). *Traffic index ranking*. https://www.tomtom.com/en_gb/traffic-index/ranking/

van den Bergh, J. C. J. M., van Leeuwen, E. S., Oosterhuis, F. H., Rietveld, P., & Verhoef, E. T. (2007). Social learning by doing in sustainable transport innovations: Ex-post analysis of common factors behind successes and failures. *Research Policy, 36*(2), 247–259. https://doi.org/10.1016/j.respol.2006.11.001

van der Panne, G., van Beers, C., & Kleinknecht, A. (2003). Success and Failure of Innovation: A Literature Review. *International Journal of Innovation Management*, *07*(03), 309–338. https://doi.org/10.1142/s1363919603000830

van Wee, B., Annema, J. A., & Banister, D. (2013). *The transport system and transport policy: an introduction*. Edward Elgar Publishing Limited.

Vértesy, D. (2017). Preconditions, windows of opportunity and innovation strategies: Successive leadership changes in the regional jet industry. *Research Policy*, *46*(2), 388–403. https://doi.org/10.1016/j.respol.2016.09.011

Volocopter. (2021a). *Urban Air Mobility*. https://www.volocopter.com/urban-air-mobility/

Volocopter. (2021b). *Volodrone*. https://www.volocopter.com/solutions/volodrone/

Weisshaar, T. A. (2013). Morphing Aircraft Systems : Historical Perspectives and Future Challenges. *Journal of Aircraft*, *50*(2), 337–353. https://doi.org/10.2514/1.C031456

Wiesenthal, T., Condeço-Melhorado, A., & Leduc, G. (2015). Innovation in the European transport sector: A review. *Transport Policy*, *42*, 86–93. https://doi.org/10.1016/j.tranpol.2015.05.003

Winter, S. R., Rice, S., & Lamb, T. L. (2020). A prediction model of Consumer ' s willingness to fly in autonomous air taxis. *Journal of Air Transport Management*, *89*, 1–9. https://doi.org/10.1016/j.jairtraman.2020.101926

Woodside, A. G., College, B., & Hill, C. (2005). Modeling innovation , manufacturing , diffusion and adoption / rejection processes. *Journal of Business and Industrial Marketing, 7,* 380–393. https://doi.org/10.1108/08858620510628614

WTO. (2020). *European Communities and Certain member States — Measures Affecting Trade in Large Civil Aircraft*. World Trade Organization. https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds316_e.htm

Young, T. M. (2007). Aircraft design innovation: creating an environment for creativity. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *221*, 165–174. https://doi.org/10.1243/09544100JAERO129

Appendix A

Scientific after second cycle coding	Gray after second cycle coding
AIRCRAFT	
aircraft: design flexibility %	aircraft architecture
aircraft: flight altitude	aircraft design flexibility
aircraft: noise%	Aircraft propulsion and lift
aircraft: power train type%	aircraft speed
aircraft: reliability	aircraft speed / metric
aircraft: requirements uncertainty	dominant design
aircraft: safety&security	aircraft: seating capacity
aircraft: size * metric%	range: inter-city / metric
aircraft: size&seating capacity%	range: intra-city / metric
aircraft: speed-efficiency	
aircraft: V vs S TOL%	
aircraft: vehicle range	
aircraft: weather / recommendation%	
aircraft: weight * metric	
BUSINESS CASE	
business case: benefits / accesibility	benefits
business case: benefits / more sustainable	benefits: reduce urban pop density
business case: benefits / more sustainable* NOT	business case attractive to investors
business case: benefits / reduce congestion	business case: passengers per trip
business case: benefits / reduce congestion NOT	business case: useful lifetime & amortization / metric
business case: benefits / shorter travel time	congestion
business case: business model%	congestion in the air
business case: customer WTP&fare %	business model uncertainty
business case: enabler / low component cost	enabler: autonomous flight tech
business case: enabler / tech advances	enabler: electric propulsion
business case: enabler / tech advances * noise	enabler: other tech
business case: governmental support%	enabler: 5G
business case: investment	time to market
business case: operation cost * uncertainty%	timing
business case: operation cost%	improving battery tech (enabler and challenge)
business case: scalability	value chain split
business case: vehicle utilization	value proposition vs. other transport modes
	synergy existing markets
	synergy existing products
	timing / metric
	Total cost of ownership
	production & operation cost
	operation cost / avoid complicated mechanisms

	operation cost / battery
	Price & WTP
	price / metric
	vehicles per city / metric
	new tech developments risk
	pilot training
	impact of external factors / trends
	marketing
DEMAND	
demand: dependent on / access time	market size forecasts
demand: dependent on / fare	market size sensitivity & constraints
demand: dependent on / trip distance	market: alternative applications
demand: dependent on / vehicle speed	market: inter-city
demand: size / favorable forecasts%	market: intra-city
demand: size / modal share	market: trip purposes
demand: size / uncertainty%	use case airport shuttle
demand: target markets / age dependent	use case ambulance
demand: target markets / cities	use case cargo and parcel
demand: target markets / commuters	use case congested city
demand: target markets / commuters * NOT	use case inter-city
demand: target markets / educated	use case intra-city
demand: target markets / inter or intra city	testing locations
demand: target markets / PT users NOT	alignment concept with use case
demand: target markets / tourism & others	
INFRASTRUCTURE	
infrastructure: charging-refueling	infrastructure charging
infrastructure: cost	infrastructure investment
infrastructure: cost / uncertainty	infrastructure investment / business model
infrastructure: digital	infrastructure investment / low
infrastructure: integration / ATM%	infrastructure: integration / ATM
infrastructure: integration / transport systems%	infrastructure: integration / existing transport systems
infrastructure: placement-land use	infrastructure: vertiport cost / metric
infrastructure: placement-land use / noise	infrastructure: vertiport number / metric
infrastructure: safety	ANS
infrastructure: time impact	ATM & ATC systems
infrastructure: TOL%	Investment hardware and supporting systems
infrastructure: vertiport capacity	UTM systems
infrastructure: vertiport capacity * metric%	integrated mobility
infrastructure: visual&noise pollution	
LESSONS LEARNED%	
lessons learned: autonomous airplanes	lessons learned: ground taxis
lessons learned: autonomous vehicles	lessons learned: helicopters
lessons learned: computer simulations	live pilot projects

lessons learned: drones	simulation and testing
lessons learned: flight tests	
lessons learned: helicopters	
lessons learned: other	
lessons learned: theoretical frameworks	
MARKET STRUCTURE	
market structure: competition%	multi actor collaboration & partnerships
market structure: partnerships%	service providers
market structure: power of actors	network neutrality
	market structure
PUBLIC ACCEPTANCE AND/OR USER ADOPTION	
public acceptance: equity	accessibility
public acceptance: flight altitude	equity
public acceptance: key challenge	familiarity / trust of new tech
public acceptance: new tech awareness / familiarity	total travel time
public acceptance: noise%	total travel time / metric
public acceptance: privacy	visual pollution
public acceptance: safety	weather
public acceptance: vertiport location	time savings
user adoption: comfort	time savings metric
user adoption: comfort / no impact	Noise
user adoption: cultural norms	privacy & security
user adoption: emotions	Sustainability
user adoption: manned vs. autonomous%	reliability
user adoption: media	safery: entry barrier
user adoption: new tech awareness / familiarity%	safery: not differentiating factor
user adoption: on-demand	safety
user adoption: perceived benefits	pilot vs autonomous
user adoption: privacy&security	convenience and comfort
user adoption: reliability	convenience and comfort / cabin noise
user adoption: routing: land vs water	convenience and comfort / vibrations
user adoption: safety%	
user adoption: socio-demographic	
user adoption: sustainability%	
user adoption: total travel time%	
user adoption: travel cost%	
user adoption: trust	
user adoption: waiting time	
user adoption: weather%	
REGULATOR	
regulator: certification / STOL as entry solution	regulatory compliance
regulator: certification%	certification
regulator: market interventions	certification: / simple design faster

regulator: regulatory uncertainty	certification: noise and emissions
	certification: safety
	certification: safety / metric
	certification: safety / mission dependent
	certification: safety / redundant propulsion system
	certification: safety / redundant systems
	New regulations
	level of regulatory uncertainty
	opportunity: using current helicopter regulations

Appendix B

ID	Indicator code (scientific literature after third cycle coding)	ID	Indicator code (gray literature after second cycle coding)
S1	* definition UAM	G1	accessibility
S2	Aircraft flight altitude	G2	aircraft architecture
S3	Aircraft propulsion%	G3	aircraft design flexibility
S4	Aircraft range%	G4	Aircraft propulsion and lift
S5	Aircraft size and seating capacity%	G5	aircraft speed
S6	Aircraft speed & efficiency	G6	aircraft speed / metric
S7	Aircraft TOL V or S%	G7	aircraft: seating capacity
S8	Business model%	G8	alignment concept with use case
S9	Comfort and convenience	G9	ANS
S10	Demand size / constraining factors	G10	ATM & ATC systems
S11	Demand size / constraining factors * socio-cultural	G11	benefits
S12	Demand size / estimations%	G12	benefits: reduce urban pop density
S13	Demand size / Target and potential markets%	G13	business case attractive to investors
S14	Enablers of UAM / government support%	G14	business case: passengers per trip
S15	Enablers of UAM / tech%	G15	business case: useful lifetime & amortization / metric
S16	Equity & accessibility	G16	business model uncertainty
S17	Externalities / Congestion	G17	certification
S18	Externalities / Emissions & Sustainability%	G18	certification: / simple design faster
S19	Externalities / Noise%	G19	certification: noise and emissions
S20	Externalities / other	G20	certification: safety
S21	Familiarity&trust of new technology%	G21	certification: safety / metric
S22	Integration with existing infrastructure	G22	certification: safety / mission dependent
S23	Lessons learned / other innovations and transport modes%	G23	certification: safety / redundant propulsion system
S24	Lessons learned / simulation and testing%	G24	certification: safety / redundant systems
S25	Level of difficulty for certification%	G25	congestion
S26	Level of regulatory uncertainty%	G26	congestion in the air
S27	Market interventions	G27	convenience and comfort
S28	Market structure%	G28	convenience and comfort / cabin noise
S29	New infrastructure and technologies, investment%	G29	convenience and comfort / vibrations
S30	Operation costs%	G30	dominant design
S31	Pricing & WTP%	G31	enabler: 5G
S32	Privacy & Security	G32	enabler: autonomous flight tech
S33	Reliability	G33	enabler: electric propulsion
S34	Safety%	G34	enabler: other tech
S35	Total travel time%	G35	equity
S36	Weather%	G36	familiarity / trust of new tech
		G37	impact of external factors / trends

		G38	improving battery tech (enabler and challenge)
		G39	infrastructure charging
		G40	infrastructure investment
		G41	infrastructure investment / business model
		G42	infrastructure investment / low
		G43	infrastructure: integration / ATM
		G44	infrastructure: integration / existing transport systems
		G45	infrastructure: vertiport cost / metric
		G46	infrastructure: vertiport number / metric
		G47	integrated mobility
		G48	Investment hardware and supporting systems
		G49	lessons learned: ground taxis
		G50	lessons learned: helicopters
		G51	level of regulatory uncertainty
		G52	live pilot projects
		G53	market size forecasts
		G54	market size sensitivity & constraints
		G55	market structure
		G56	market: alternative applications
		G57	market: inter-city
		G58	market: intra-city
		G59	market: trip purposes
		G60	marketing
		G61	multi actor collaboration & partnerships
		G62	network neutrality
		G63	New regulations
		G64	new tech developments risk
		G65	Noise
		G66	operation cost / avoid complicated mechanisms
		G67	operation cost / battery
		G68	opportunity: using current helicopter regulations
		G69	pilot training
		G70	pilot vs autonomous
		G71	Price & WTP
		G72	price / metric
		G73	privacy & security
		G74	production & operation cost
		G75	range: inter-city / metric
		G76	range: intra-city / metric
		G77	regulatory compliance
		G78	reliability
		G79	safery: entry barrier

		G80	safery: not differentiating factor
		G81	safety
		G82	service providers
		G83	simulation and testing
		G84	Sustainability
		G85	synergy existing markets
		G86	synergy existing products
		G87	tesing locations
		G88	time savings
		G89	time savings metric
		G90	time to market
		G91	timing
		G92	timing / metric
		G93	Total cost of ownership
		G94	total travel time
		G95	total travel time / metric
		G96	use case airport shuttle
		G97	use case ambulance
		G98	use case cargo and parcel
		G99	use case congested city
		G100	use case inter-city
		G101	use case intra-city
		G102	UTM systems
		G103	value chain split
		G104	value proposition vs. other transport modes
		G105	vehicles per city / metric
		G106	visual pollution
		G107	weather

Appendix C

First cycle coding case studies
Accessibility
airspace navigation systems
availability
comfort
Competitive advantages
downwash
Familiarity & trust of new technology
Investment costs
Level of difficulty of integration
Level of government support
Level of ground congestion reduction
level of sustainability
level of sustainability: batteries
level of sustainability: energy efficiency
level of sustainability: energy efficiency / mission profile dependent
level of sustainability: recyclability
level of sustainability: vehicle manufacturing
maintenance costs and time
market size & segments
noise
noise: cabin
partnerships
partnerships: with government
passenger experience
physical infrastructure requirements
physical infrastructure requirements: charging
Pricing & affordability
privacy
Production & operation costs
reliability
reliability:; technical
Robustness of the business model
safety
selecting a target market with appropriate characteristics
Sensitivity to adverse weather
severity of risks
Strategies to cope with regulatory uncertainty
technology readiness
throughput constraint: vertiport capacity
Time to obtain certification
total travel time savings
Use case definition and alignment
vehicle communication technology
visual pollution

Second cycle coding case studies
F1 reliability
F10 Level of ground congestion reduction
F11 Level of sustainability
F12 total travel time savings
F13 Accessibility
F14 Passenger experience & comfort
F15 Time to obtain certification
F16 market size & segments
F17 Production & operation costs
F18 Pricing & affordability
F19 Definition of use case(s)
F2 privacy
F20 Robustness of the business model
F21 Strategies to cope with regulatory uncertainty
F22 level of government support
F23 partnerships
F24 competitive advantages
F26 physical infrastructure requirements
F27 digital infrastructure requirements
F28 Level of difficulty of integration
F29 investment costs
F30 Other negative effects: visual pollution and downwash
F4 safety
F5 Familiarity & trust of new technology
F7 Noise
F8 Sensitivity to adverse weather

Appendix D

Interview guide

Pre-interview Checklist

- Research interviewee background
- Wired internet
- Phone vibration mode
- Paper and pen: use red pen for follow up questions

Introduction

Good afternoon [name]

[ice breaker]

Thank you for taking the time for this conversation.

Introduction to interview topic

As you know from [previous email / Linkedin message], I am doing my master thesis at Delft University of Technology. My thesis is about urban air mobility.

Specifically, I want to obtain a set of indicators to assess the success potential of early-stage innovations in urban air mobility. So far I have obtained indicators from scientific and gray literature and case studies. Now I am interviewing experts.

The purpose of this interview is to better understand what indicators are relevant to assess the success potential of different configurations for early-stage innovations in urban air mobility.

Permission to Record

I would like to record this interview. Can I record?

With the recording I will transcribe the interview and then send you the interview transcripts by email, so that you can check that the transcript does not contain information that you would prefer not to be published.

I want to include the transcripts in the appendix of my thesis, which will be published and will be publicly available, that's why I will ask you for your approval.

Clarify terms

Before we start with the questions, I would like to clarify some terms that I will use:

- With indicator I refer to a metric that can be either hard (example: travel time) or soft (not measurable directly, example collaboration with other companies)
- With early stage I am referring to the concept stage of the innovation process, this is, before a working prototype (a real-life size aircraft) is manufactured.

[if permission given, start recording]

Thank you for letting me record. Now I will start with the questions.

Structured questions

1. **Supposing that you have two possible UAM configurations, for example a multirotor and a tilt-wing, how would you select which one to continue developing to create a working prototype and which one to discard?**
    a. Question objective: I want to know all indicators that they consider relevant.
    b. Alternative/follow-up question: What (other) indicators do you take into account to evaluate the success potential of an UAM project that is still in the early stage?

2. **Could you give examples of go / no go or knockout indicators for UAM aircraft at early-stages of the innovation process?**
    a. Question objective: elicit knock-out indicators
    b. If clarification is asked: Go / No go indicator means that if the UAM aircraft does not fulfill the knockout indicator, the UAM aircraft should be discarded

Follow up questions based on answers to structured questions

- You mentioned [indicator]. Could you elaborate on its importance?
- Could you elaborate why is [indicator] a knockout?

Optional questions (made from categories of Indicator Set V1)

- What is important for **user adoption** and how can this be used to make design decisions (at the early stage)?
- What are critical aspects to gain **public acceptance** that can be influenced at the early stage?
- What is the value proposition of UAM?
    - What elements of the **value proposition** could already present in an aircraft at the early stage of the innovation process?
- At the concept stage, what factors do you consider to assess whether there is **a business case** or not?
- What indicators related to **regulations** could be relevant at early stages?
- What is the importance of considering at the early stage the **infrastructure** that an UAM aircraft will require?

Optional questions about indicators mentioned by previous interviewees

- Examples: certifiability, handling adverse weather conditions, etc.

Closing interview

- Is there anything you would like to add?
- Thank interviewees for their time

Considerations while conducting interviews

Based on literature, the author gathered the following set of principles and techniques to be taken into account during the interviews.

- Use verbal and non-verbal clues to encourage the interviewee to talk. According to (Hove & Anda, 2005), during the interview it is important to show engagement and interest by nodding and asking follow up or clarification questions. This will encourage the expert to continue the conversation.
- The interviewer should avoid arguing with the interviewee in case of disagreement with the answers given (Hove & Anda, 2005). If the interviewer disagrees with what is being said, a question can be asked to better understand the expert's view.
- Make the interviewees feel comfortable with the conversation. To help create an atmosphere of comfort and trust the interviewer should ensure that questions are not formulated in a threatening or intruding way and should avoid expressing dismay when the interviewer disagrees or is surprised with the interviewees answers (Hove & Anda, 2005).
- Be careful when handling an answer that is (apparently) digressing from the interview's objective. In this thesis, the author is asking interviewees for one hour of their time. Since time is limited, it can be problematic when an interviewee is constantly digressing or talking too much about seemingly irrelevant topics. If this happens, (Hove & Anda, 2005) recommend that it is better to let the interviewee talk freely because it can be difficult to discern during the interview whether what is being said will be useful for further analysis or not. Only if it is obvious that the interview is going off-topic it is recommended to tactfully discourage the interviewee from keeping talking by using non-verbal cues like stop nodding the head or taking advantage of pauses in speech to intervene and ask another question to get back on topic (Hove & Anda, 2005).
- Pay attention to nuances in answers. Although after several interviews, interviewers might have the sense of hearing similar answers, interviewers should remain attentive to nuances that could be interesting to explore (Adams, 2015).
- Use follow-up questions connected to what the interviewee mentioned previously to elicit additional information. Sometimes, a question as simple as "Anything you want to add?" could be used for the same purpose.
- Be flexible to pursue unexpected but potentially valuable paths (Adams, 2015).
- Try to create a conversation, rather than a disconnected set of questions and answers. Interviewers should know the interview guide well so that they don't need to read it and formulate questions exactly as they are written (Adams, 2015). Instead, they should be able to incorporate them smoothly into the conversation.

Appendix E

Interview transcripts and interview notes

Interview 1

Transcripts of interview

E: I will start with the questions. First one is: What indicators do you take into account to evaluate the success potential of an urban air mobility project that's still in an early stage?

L: Okay. Yeah, I'll try to dive into what I know. It's a bit broad, okay? And so, dependent on being over Urban Air Mobility I would say that it follows more or less this mindset for any kind of new air concept that is supposed to be entering in a possible future market. The first thing is to understand if there is a market for whatever we are looking for or developing and if we do have it, how is this market, what is the value proposition of the market? What are the main requirements for the market and specifically what translated into product? So, if there is a market, what are the product requirements and technologies linked to this product requirements? Then we had to see us as an OEM, if we do have the capabilities to consider a feasibility study in this regard. So, then we start a phase where we will, after finding a market, after understanding the product requirements, and understanding the knowledge capabilities and technologies required to manufacture this possible product, we do a feasibility study regarding what would be the investment and the return from the investment and if we would be able to launch this new program, develop a new possible product. And think, of course, in the return for this investment, but if it would fit also the timeline that we had foreseen for a nice suitable entry for the product. Otherwise if we lose this window, then game over. So it's very broad. When we go for Urban Air Mobility, I believe that we're in a, let's say in a slightly different from previous aircrafts. Additionally, when we think about product requirements, as we also have a lot of competition, for the aircraft we're pretty much talking about a very clear and regulated sector. And so, much of the variables are known from the certification basis, from the operation, from the public's acceptance. So, the passengers, as there is a market, airlines would be suitable for buying the aircrafts and to complete their fleets and thus things are fine. When I think about urban air mobility there is a big unknown regarding lots of things. So we're talking about citizens, cities, urban planning, and also sustainability, environmental impact. And also, let's say, the case for Urban Air Mobility in the markets, of course, they have a list of positive impact, they also have a list of negative impacts. And together with that, there are some certification challenges ahead, because there are some topics regarding noise, and even emissions, and even life cycle. But also, how will citizens perceive, and view and deal with sky pollution, noise pollution, or even safety aspects.

L: Also some topics that are still not very clear: when you compare to an aircraft, you have the airports that are relatively far from urban centers, you can also have small airports, more or less close to city centers, but for small aircraft. There might be also lots of points that have to be very coherent to the value proposition of urban air mobility. The point of trying and adopting an urban air mobility solution: if it doesn't bring really a benefit for the user. The question is, why should I, for instance, use it instead of other possibilities? And in order to do it, let's say there might be some benefits linked to infrastructure, linked to reliability. For example, I can take a train to go to the airport, and I can play myself and I can deal with train delays, but they're pretty much trustable. But if you if you go for a solution that is supposed to fly, even if you promise that you're going to be there in 15-20 minutes, the complexity about things that are supposed to fly and has a dependence on the weather conditions and other aspects like charging issues. It has really to be very well done. The customers will have to experience it in a very precise and, and good way. But in this regard, there are lots of questions because we are talking about a very complex ecosystem that has to come together to make it a good solution. So I don't know if I answered your question.

E: Yes. Yes. It's very interesting. I am very happy. And I have many questions now that came up with your answer.

L: I don't have all the answers. But I will address eventually some questions to other experts, because it's a new area for many people.

E: And as you say, it's really, really complex.

L: Yes.

E: One thing that you mentioned is certification, first the uncertainty regarding it. Do you think that there could be some concepts or some designs that would have less certification uncertainty, or that would take less time to be certified?

L: Yes, definitely. Perhaps I'm not able to go deep into this topic because of the lack of knowledge but I've heard already in different forums that some configurations are more suitable to be certified, they are more likely to be certified, because the certification basis that regulates helicopters, that would be the reference for EVTOLS, for configurations that have some similarity regarding helicopters, in a very broad way of speaking, they are more suitable to be certified. So the risk of not certifying is lower. But I think in some companies the decision making regarding the configuration is based on the certification. I would say that. I think it's one of the relevant topics when they decide from one to another configuration. And, of course, just bringing the complexity, the configuration will also respond for the mission of the EVTOL. In the end, the EVTOL is a sizing issue as any air vehicle, it's a sizing issue. So you the mission is: you want to move something, goods, whatever it is, from a certain distance, and then you want to add a payload and you have to have the propulsion system, and the vehicle itself, and an amount of passengers. But it has to be more efficient than a helicopter. And a helicopter is already a very optimized configuration. So then in order to do that there's new technology that allows these developments. But assume, if there is a compromise between the weight, the speed, the distance, the battery required, the time to charge, to recharge it, so that it's an optimization issue. We're not going to go very deep into technical details, but perhaps someone for a more technical background can put it into clusters and I think it can be interesting. So some configurations are more likely to be certified. But then there is another parameter that will be: when you want your urban air mobility to enter in the market. And some companies don't want to be the first. It's really very dynamic, very complex.

E: Okay. So this last point is related to what you mentioned that in general, the aviation industry has a timeline, right? The window?

L: Yes. And I think this brings really a huge complexity. But it still turns it very exciting. I think when you talk with [expert’s name removed for confidentiality reasons], that's not only responsible for this platform that Embraer is currently developing, but also, he comes from market intelligence. So I think he is someone that can join all aspects. And still t's a puzzle, very uncertain, very complex. But it's an opportunity. So I think it's possible.

E: Yes. We don't know when, yet. But yeah, for sure. My next question also comes from your first answer. Do you think that there could be some configurations that would be more robust against adverse weather so that they could be able to fly, let's say, even if the weather is not so good?

L: This is a very good question. And I don't know how to answer it, to be honest. I think it's possible. I think that everyone that is developing a platform, independent on the configuration, they are counting that it has to be certified, otherwise, it's not going to be allowed to fly in the market. So I believe that engineers are very focused in the certification issues. I think it's a good question to ask to someone more technical that can also bring some known configurations. And as they might know, something in these regards, they can give some examples. I think it's a good point. But in the other hand I believe that weather conditions will influence everyone.

L: Also something that I know: we have the climate change, so the temperature is increasing. So the systems that that that are present in aircrafts, and also in urban Air Mobility, and whatever is going to fly, they are designed to operate in a certain envelope. And this envelope is shifting to a higher temperature. I also think that this kind of climate change will also have an impact in the future. And I'm not sure if the current platforms are already considering this shift properly.

E: Interesting.

L: Yes. Yes. So in a way, the efficiencies that are being advertised today, they might not be so efficient in the future. It also just brings another uncertainty to the topic. I think it's a good point, but also perhaps noise would also be a point for attention regarding certification. Because for example, if the weather is a constraint, you might not be able to operate all the time, which is very bad for the user and also for the company, because when you're not flying you are not make making money. But the noise can be a no go anytime. So environmental emissions and noise are some things that, yeah, if you don't fulfill the current requirements, you are not going to be able to enter the markets and to operate. Of course, it might change slightly from the city and region, but in global terms I think it's a very standard market. I think either you get the noise emission and sustainability, environmental emissions as required. Otherwise, you are out of the game.

E: Yeah. Okay. Okay. And continuing with this line of thought, you guessed one of my next question, which is: What go / no go indicators are there? I think you just mentioned noise and environmental requirements?

L: Yeah, like, CO_2 emission, but also, I believe that environmental regulations are turning more concrete in all the industry. These zero emissions to fly in Europe in 2050, and things like that, and very connected to cities planning and goals. Of course, it will depend on the country. In some countries, it will probably start first. But I think theoretically, even in Europe, for instance, you're supposed to fly between cities as well. So I think it will be applied for every country or everywhere. And when you think about there will be, as there are already, some regulations regarding the site facility, so how is the manufacturing plant using the resources, what kind of waste they are generating, and how is the end of life of the product. So all these aspects, recyclability of components and systems and materials altogether, I think it is also an issue. And also the batteries. We can put it under the sustainability umbrella. All these aspects, I think they are a challenge ahead. Think about, let's say, the Netherlands decide that they are going to use an urban air mobility solution for specific segments, I don't know, to offer an option for trains accordingly. Perhaps the city will accept a few possible urban air mobility solutions. I believe they will need to follow the city requirements. So as I said before, different from aircrafts, I think the proximity with the user will be much more clear.

E: Okay,

L: For the city to accept. And of course then as for any other option for the user to adopt. As we are in this transformation moment when sustainability is more clear, people are getting aware and more conscious. I think it is a good thing when you think: Okay, if these OEMs, these EVTOL makers want to provide something they have to do it very well otherwise it will not be a success. So it's good for society and planet but for the for the OEMs it's very challenging.

E: Yes, I can imagine. Okay and are there more go no go indicators apart from environmental considerations and noise?

L: yeah, I'd say there are probably technical challenges too because I think otherwise we will already have UAM. I think we are close to see urban air mobility solutions certified first step, but even for certification, thinking about all the regulations and requirements is the first step to certify. But then there are a lot of ifs: if there is a market, if there is a clear use, and if the city is going to select it and allow it and then the users will see that value. And still, perhaps you can try once and then "okay nice but I prefer to use other things". There are so many things that we don't know for sure. I believe that the platforms that are still alive are aware about their risks. But there are other things that I believe it's not clear yet like for instance: I don't know exactly how is to fly in a helicopter, I heard and I could see from observing, and movies and things like that and even sometimes in real life that it's very noisy. It can be nice to have like a very nice view but it's not so comfortable. There are some additional things like for instance: if you want to go to the airport with urban air mobility solution you have your luggage and how is it going to be addressed? There are lots of things that are not very completely clear for the benefits. So I think besides certification, there might be something that could be a bit of user experience but also the value of the solution. User experience for example: some EVTOLs are supposed to have big windows and you can be seated not in the flight direction, but how is the feeling of flying: are you going to feel sick because some people feel this way when they are in a car. Things like that. There are small details that usually make a huge difference when you decide to adopt a solution that are still not completely clear I believe.

E: okay and what I am wondering is for example, this passenger comfort, how the people are going to feel when they're flying, do you think we can use that to make a difference between two concepts, to select which could be better?

L: Yes, I think, but it's still also very dependent on what the company wants, what is the market the company is reaching. I think it's it can be comparable to a car manufacturing very luxurious and expensive cars or very popular cars. So you're talking about completely different users, different price and different experience. So what is the brand strategy. So if you put in a cluster, these EVTOLs have different configurations, some of them can cover similar missions, but some of them are clearly offering a service for different missions: the distance and the speed and the number of passengers, and some of them might provide a more comfortable, pleasant experience than others. So I think this is part of the value proposition that the company aims to bring. It has to be very coherent and consistent. The company has to address lots of topics, one of them is how is going to be the user experience? But the user experience is pretty much everything like, I want something that is easy to use. So the company is going to offer me many options. So I have the freedom to play with different times of availability, of different ways to get there. How far is from the place I live? The cost? And is it easy to board and deboard? to wait? Am I going to waste my time? And then it's comfortable? the fight is nice? Every time if I use it, I feel sick? Of course, you can also enjoy the finish and design. But I think that is for relatively short distance and very much time, I will go more for a more basic comfort. But still, it has to be attractive for the user in many ways, depending on the purpose. For the last mile user, it's a niche. Someone that's going to the airport, it's another niche. If you think about someone that would consider using it in a big city, it's another topic. But even the big city, for example, I'm from San Paolo: the perception I have is that we have a huge market there, but actually very limited to wealthy people. And also the amount of helicopters that can fly at the same time in the city is very small. So if we think about a possible future where it would be very useful to have EVTOLs in mega cities, instead of the congestion we have now. These are good drivers, good ideas, but how would that turn into reality? Will the price be accessible to everyone, will it be easy to access the vehicle? And it's going to take you to different options like a bus or a car? So the benefits that the user can get will be determinant on this acceptance as well. Or more adoption.

E: Yes, user adoption rate?

L: Yeah, yeah. Because when you certify, if it's accepted is another thing. You can have a wonderful solution there. But you can say, "well, nice, but I don't know. I don't want it".

E: Yes, then it's a failure for the company

L: Yes. Yeah, that's why I believe some companies don't need to be the first because from some that will enter in the markets, we will learn a lot, what is working, what's not working. But of course, they have the benefits that being the first perhaps they can get part of the market for them already. So it is very tough game.

E: Yes, this stuff is really interesting.

L: Yeah, it is really interesting. I agree.

E: Yes. Okay. And I have a question: In the beginning you described the process to check aircraft. So you said: is there a market? Then check product requirements and the technology. Will the evaluation process for urban air mobility, for several concepts, will it be more or less in the same steps?

L: Yeah, I think so. I think we evaluate the markets, the mission that fits in the possible markets, and what fits with our company backgrounds and capabilities in order to manufacture and certify the solution. And also, think about, linked to the mission, possible use for the vehicle is also an interesting topic to address when we are considering this platform. Because particularly for urban air mobility, especially for public acceptance. So coming to the human side, some people like innovation, but the nature of humans, we are very much keeping in our comfort zone. There has to be also some attractiveness regarding open the portfolio of users, can be helpful to convince the regulators and the cities. We want to make money from it. We want to provide another option regarding transport, air transport, that can contribute to congestion, and it's a more sustainable solution. So it's better regarding what? It's better regarding helicopters, but better regarding the train? So it's a good topic. But we can also think of some humanitarian cause and something that you can diversify the use. So, it can be similar to when you think about a business jet. So with Urban air mobility you can transport people, you can transport goods and you can transport medications and it can also be a mobile medical facility. So there are interesting things regarding technology to bring more good things and you know from the JIP project. You can do good things with the technology and can try to provide better things or increase the quality of life in different areas that are exclusive from transportation. Because we think usually about using the aircraft to go from one point to another, but then with urban Air Mobility, we are also thinking about that you can move easily to a facility that would be difficult to get there. You can take off and land in a small area because you have the vertical takeoff and landing. And so it can be very, very helpful and useful. But not necessarily for all types of use that people are considering for now. So well, let's see.

L: And also, depending on the region. So again, it can also be interesting in Los Angeles and Sao Paolo, where we don't have public infrastructure for trains. And the trains I think is interesting because it's a huge investment that was already done. So in a region where you do have a very nice public transport working it's very questionable, why you're going to introduce something that will perhaps ok you can get there 20 minutes compared to 15 minutes. But do you really need to do it as we are going to be using more raw material and producing more waste.

E: Yeah, again, comes the question of sustainability.

L: Before sustainability was just an ambition: in the future we will have to reduce the emissions, we will need to be worried about the end of life. But this is in the present now, it's not in the future anymore. So, I think for the industry, the regulation, it's super important, but it's very challenging, it's an additional challenge.

E: Okay. And about this topic of sustainability. To what extent do you think that some concepts could rank higher on sustainability than others?

L: Yeah, I think it will depend on how they are being designed, you can say you use the design for disassembly concept. I think depends on how it's being addressed in each platform. But also, I think the solutions that require let's say more material or the material itself they are considering I suppose composites. The whole thing about the batteries, the electric motors, so everything in the package: there is the end of life, the recyclability of the airframe and everything as a whole, the operations and during the operation, the emissions. And also in the manufacturing process, the waste that is generated. Think about the waste, whatever it is, they impact on the environment: so the plants and people, the toxicity of material. I think that some part of it will intrinsically be there because otherwise it is not going to be certified. you know way but Perhaps you can also show like, yeah, think about equal design for the concept, perhaps there are some concepts that that might be better regarding equal design. They will have a better impact in the environment. But I don't know, how relevant it would be will be for the adoption and acceptance.

E: Okay.

L: Because, let's say it's complex. Sometimes there is another aspect, that would be the brand. In Germany Lilium platform will be more likely to be accepted than EVE.

E: Hmm, interesting. Yeah.

L: Yeah. But not only there, even here in the Netherlands. Even for this PAM group, I believe that Lilium is also more suitable to have the attention from some people, from some users. So this is a bit of the brand itself. But Embraer also has, we have our followers, and our brands in the market can also be a good thing. So, we have an established brand in aviation, and we are diversifying our portfolio. We have known and recognized expertise in designing and manufacturing and certifying aircrafts. Good point for us. We are not an unknown company that suddenly decided to put in the market an EVTOL. But it depends a lot on lobbies and regions, you know, politicians, political aspects as well. It's really

E: complex? Yes?

L: Yes, but I think there isn't an assumption that any product that they aim to get in the market, it has to be certified. So I think for companies that decided for more complex configurations and solutions, they would be in a not so nice situation. But if they succeed depends on lots of factors. Also, we see in when, just a comment, when the technology can be very good, but it has, in order to happen, the benefits for the use of the technology, usually, lots of things have to come together. So let's say for the EVTOL, it has to be easily rechargeable and the end of life of the battery is something that will need to be solved and it has to be easy to access. And it's not solved yet. And, also perhaps you too will require a standard infrastructure. Think about the airport. The airport is something standard like you can take off and land everywhere. Of course, sometimes you have some particularities from some airports that are very close to city centers. So sometimes you have to climb a high altitude that is not so smoothly as others, sometimes you have to take off and do a turn. In Rio de Janeiro we have (inaudible, Portuguese?). So the aircraft has to be adapted to operate in some specific airports, but in broad terms, you can operate everywhere. You have to have a huge infrastructure that's already there, to fuel the aircraft and to do the catering or maintenance in repair parts. There is the whole thing around that is there to make it possible the operation to happen. And for urban mobility for example perhaps we will need also to have like to build the infrastructure but it's not simple like a car that you just find a place and you plug. You have to have people that will charge the urban air mobility and it's something in which there is not a very intense flux. For example, I have a flight today and then I decided to use it. of course there are lots of people. There might be a clear need that we require for instance to have some charging or vertiports decided to be at some places and there you have some people that will be working there. The whole logistics, everything has to come together to make the business running and alive

E: and now that we're talking about this, do you think that there are some, yeah, some concepts that will be easier to integrate into the city or into the existing infrastructure?

L: I think yes. I think like depending on the configuration. When I think about the configuration, I think there is a direct connection with noise. Perhaps in some configurations the user would feel more confident or somehow will perceive it in in a more safe manner. I'm not sure but I think yeah there is the human perception. For instance sometimes you can try a seat that looks like uncomfortable and it's super comfortable. But sometimes, think when you see something that is smooth and has a lot of material and it looks like comfortable and then you end up going for it. It's just a comparison but perhaps some people will end up naturally perceiving some configurations as being safer and reliable and whatever, this is a point, in case you have options. Even the price can be slightly different. When you think about Uber when you decide for the low costs or medium cost or higher costs perhaps depending on the reason you are using it and the place you are using. For example in brazil you think it's safer to pay a bit more because it's very dangerous but if you are here perhaps you don't think about this because you think you're safe here. So if you are the Uber provider with low cost and the other one, which one is better in the Netherlands? I think there is the aesthetic, it's linked to configuration, the noise and also the free area required to have the vertiport and infrastructure. I thought before that we could use the current helicopter infrastructure and it's not true. There might be built totally new infrastructure. Yeah. So perhaps the heliports can be adapted, but there might be an investment, it is not something that is easy. I think it has also to do with the topology of the city. So in mega cities we have on the top of buildings, some heliports because you don't have free space on grounds. But again, it depends on where you're talking. You see. So the vertiport logistics design in Munich, may be different from Mexico City or Amsterdam.

E: Yeah, then another question that I have is: if each city or target market would have different requirements regarding maybe infrastructure, how will companies decide which configuration to pursue?

L: Yeah, then it's linked to the first thing in the market analysis. That's why it's so important, I think when you end up managing a bit your risk, when you can set up okay, for this market here. And then when you define a markets and a product's requirements, you are immediately linking to some known possible markets. You're focusing on some specific regions, we'll see. I think mega cities are one of the interesting targets for some configurations and especially mega cities where there is no public infrastructure, where people use mainly cars and with a huge congestion, and growing population. It is going to be really difficult. On the other hand, there is these social and economic aspects. For instance, we can say there is a huge a helicopter market, but it is still limited to a size and for wealthy people and a specific use. But still, there is a niche, there is a market. But it doesn't solve the congestion issue in Sao Paolo. Is it going to contribute to congestion, an urban air mobility in Sao Paolo? Well, if you tell me that everyone that uses his bus (car?) will be allowed (able?) to use an EVTOL, then we're talking about decreasing the congestion, in my opinion.

E: But for that to happen...

L: Yeah, I don't believe really. So I don't know. But perhaps, hopefully, I'm wrong, you know, but let's see, but I think there are lots of unknowns, so let's see.

E: Yes,

L: On the other hand, there are also lots of car accidents. So if in the future, EVTOLs, autonomous EVTOLs are proven to be safer, absolutely, we are adding more value to the concept. Then it can be that even if it's not that sustainable, it can be more accepted. Of course it's very nice that people don't die more in car accidents.

E: Yes, yes, of course

E: Okay. And for the value proposition has a lot of aspects. Well, sorry. Just an interruption. I said one hour and it's one-hour interview already, so probably we would have to end, right?

L: Yeah, actually I have another meeting but how long would you need more?

E: It's fine because I asked everyone for one hour, so I think it's better that we stop.

L: Okay. Yes.

E: Thank you very much for your time.

L: My pleasure really nice

E: It was really interesting.

L: yeah, I hope I can help a bit, but we can talk more later.

Interview 2

Transcripts of interview

E: Yeah, so I have started the recording. Thank you for letting me record it

P: No worries.

E: Um, okay. So as you know, I'm doing my thesis and it's about urban air mobility. And more specifically…

P: I was going to ask more like, what's the exact area of your research?

E: Yeah, more specific. It's about finding indicators or metrics that could be used to assess the success potential of a concept for urban air mobility.

P: Who's your supervisor?

E: Luciana. She's my supervisor. And from TU Delft is Jan Anne. He's from TPM.

P: Okay. All right, because I actually wrote a research paper. It's not published. So it's just a piece of research done. About factors determining the like, if what will likely make urban Air Mobility format. So if it's like a drone or fixed wing, tilting wings, that kind of stuff? What kind of factors will make it likely that one of these formats dominates another one?

E: Okay, so dominant design?

P: Yeah, exactly. dominant design. And it is the best worst method. I don't know if you're familiar with that.

E: yes, from Jafar Rezaei

P: yeah, exactly. Him. So maybe, yeah, maybe I can send you my paper. Maybe that's

E: Oh, yeah. Interesting. Thank you. And Well, actually, and did you focus like in only in technical indicators, or in all sort of,

P: I focused on all sorts of indicators. Like range. But also, like, the size of the company, and that kind of stuff.

E: Okay. Good. And I think we will have an interesting conversation today. Because Yeah, that's also my aim to have like a holistic set of indicators to see which concept would be likely to succeed.

P: And I my focus was on the, like, the area of Sao Paolo, I thought it would be a bit difficult to like generalize the entire market, because like, the needs for the Brazilian region is going to be very different from the European based on, like, purchasing power, and also distances and why people use helicopters, for example, nowadays is different in different regions.

E: Yes, true. So then there will be kind of one of the first criteria like selecting a market or something like that?

P: I think I think it could play a role. Maybe that's something that you can also investigate. Like, what is the difference in consumer needs? In North America, South America and Europe? I think there's the biggest markets, maybe China is over. I don't think you get a lot of data from them. So maybe, maybe that's also interesting to see if it if it three different markets actually behave differently, or not.

E: Yeah, true. Okay. And for example, that's a that's if we focus on Sao Paolo. Yeah. And you have, as you mentioned, like, for example, a multi rotor configuration versus the tilt wing. How would you select which one?

P: Yeah, so in my research, I interviewed several people, including a company in San Paolo called [company name], which they do leasing of helicopters. So it's like a subscription service. And I asked the, the CEO, like, what was his like, what were the ranges that, that people go like? Where do people go when they use their helicopters? And he said, 80% of the time they go on holidays, so that's to the mountains or to the beach, and that's a range of about, like, between 300-400 kilometers. So most of these EVTOL systems that don't have wings, they can't reach that distances. So that knocks them out already as, as possible contenders. But then he said for the 20% that use it to go to the airport or in like, just city hub, you could use these. Yeah. He does without wings, basically. But then again, like, does that even make sense in, in the [company name] case, like for their business? Well, the ones without wings can do this flight path as well. There's only 40 kilometers. Yeah. It's just they're not as efficient within 10 kilometers. That's the, like the transition? I think it's, that's what it heats up. I think it heats up like something between zero, like, if you're within five kilometers, transitional vehicles are not efficient. But if you're anything further than five kilometers, the transitional vehicles are already good.

E: Yeah. Okay. So then, okay, one indicator they like, the range that is needed for the range needed for the target market or for the for the need or use case, however we want to call it right.

P: That's, that's what my research found that range was number one priority.

E: Okay. What other thing you think is important?

P: I think I wrote this a while ago, but I think then, if it's autonomous or not, that might be important. Especially with rollout and rollout strategies, like, because a lot of these companies are investing heavily in this autonomous market, but I think they will have trouble succeeding if they don't make a first version, which takes a pilot and is commercially viable, because, like cars, it's going to take a while for it to become autonomous. There's a lot of regulations. Yeah, regulations an important factor. But I can try to pull up my research. I think I just have to, there's a table, which has everything. But ask away

E: Okay, okay. Okay, good. What you mentioned about being autonomous? Um, I was wondering, how important do you think that it's that people are, like, familiar with the new features? For example, this autonomous, it might be the case that people don't trust it.

P: Yeah, yeah, I think that's Yeah, I think that's it's an important like, public opinion is very important. But I think for my researcher, it turned out that it was not going to be so important people are quite like, okay with it. They just, they just have to assimilate it between a, like a helicopter. Most people think a helicopter is like, relatively, like, on the dangerous side of the spectrum. And so they will put EVTOLs close to there, until they are proven to be safer or otherwise. So I think people would just assimilate into helicopters, because that's basically what they are. They just modern helicopters.

E: Yes. Just smaller and hopefully more efficient.

P: Yeah, faster and more efficient.

E: And do you think that there are some we could call it go no/go or knockout indicators or something that if the concept does not meet this indicator, then it's out of the game?

P: Yeah, I think if, if, if a concept does not take, lift more than two people, or like two people or more, and does not have a range of more than 30 kilometers, it's not useful at all for urban air mobility. And so the idea that a lot of like the volume of people that are going to use these things is going to be high. is also a fallacy like this technology, I believe it will take over the helicopter industry possibly be a bit more accessible due to cheaper technology? But I don't think it can grow the market much faster or than what the market is growing at currently, for helicopters, I mean. You just have to think helicopters use combustion engines, which are currently much better performing than an electrical configuration. So, and a big helicopter, I think, an H109? has a range of, like 650 kilometers. The best EVTOL, Electric vertical takeoff landing vehicle, is expecting to do 300 kilometers, so half the range of this helicopter. And I think also like, two thirds of the speed. So it's still not competing. It's still not as competitive as helicopter in many scenarios. But again, the technology is new, and many new developments in rotor quality. Also, the noise is also something that EVTOLs plan to tackle, so, they have like that they have other things going for them.

E: And do you think for this last point, noise, do you think that some little configurations would be better at handling noise than others?

P: Yeah, so I don't know. Do you? Do you have any background in aerospace engineering?

E: No, just what I have read so far for my thesis, that's it,

P: okay. So, basically, the noises generated by the rotors and is how they cut through the air. And so, the longer the rotor, the slower it needs to spin to create lift. And also, so, the smaller so, the smaller the rotor the faster has to spin and the faster has to spin, the faster the tip velocity, which cracks the air like a whip. So, so you get more noise. So the bigger the rotors the less noise created by the fan. the propeller basically,

E: okay. Then, what about multi rotor configuration? It will have probably small blades, right?

P: Yes. Yeah, multi rotor systems are probably noisier than larger rotor systems. But again, like if you use ducted ducts, and that kind of stuff, you can eliminate parts of you can eliminate, eliminate noise as well. Not entirely, of course, you're just limiting it.

E: And going back to the another point, that you were mentioning about, like, the market, that might overtake Helicopters, Do you think that they are also, could take a part of market share from let's say, trains or public transportation?

P: I think, yeah, I think it all comes down to the cost, like, cost and time. So the tradeoff is always between the price and time of things. So if the train Yeah, if the, if it cuts the time of the train in half, and at twice the cost, then it Yeah. It's it breaks even so there's no point you can just choose whatever, it'll be the same unless you value time more than money. So it really is that function like try to solve a cost and time and you can make this calculation. It's good to use some real-life examples, such as illustrates the points to people. If you say, I want to go from Amsterdam to London, how long does it take by all the methods and how long would it take by an EVTOL? I can tell an EVTOL will take it will be much faster. Because you can just take off from any rooftop. You don't need to go to the airport. And so like, that's kind of what I see as the future dream scenario is a, like a hotel in Amsterdam has an affiliate hotel in London, both with a EVTOL station on the top floor, and then you can just shuttle between the two cities in in a matter of an hour. And that is something that is a service that is really worth it. Yeah, I think that is where the future of urban air mobility lies. Because the whole system of going checking through an airport, that's what takes time. Yeah, if you go, if you fly from Amsterdam to London, it's a, I think it's a 30-minute flight. But you have to get at the airport an hour ahead. It takes you an hour to leave the airport. And then you have to because the airports are far away from the city centers, you have to get a train for half an hour and another train for... The flight is 30 minutes, but just to get to the airports, to get to the airport and away from the airport is two and a half hours. Yeah. So an EVTOL could probably cut those two and a half hours to maybe half an hour. Because it is smaller, because it's less noisy. It can be closer to the city center. Or even rooftops are like the prime locations.

E: Yeah. And do you think that some configurations will be, let's say faster, considering the whole trip?

P: Yeah. So also in a, there is a technical limit to how fast helicopters can go. Again, I haven't studied aerospace. But I know this briefly from discussions with the Talaria team. Because when you're moving forward, what you can't do at a helicopter is have the tip velocity of the blade go faster than the speed of sound, then you break it apart. So when you're moving in the helicopter at an angle, and to think that the advancing blade is moving at the speed that it's turning as a vector, and at the speed that the helicopter is moving forward. So there's a limit in those two velocities, they cannot equal the speed of sound. Like I would say, like fact check this thing that I'm saying about these, these physical limitations because I'm not totally sure. So, I would say that EVTOLs with wings have a likelier chance of being successful in places that you want high velocity and like larger range. Multi fans without wings, those things in some specialized cases have potential but not really, for mass transit, I would say.

E: Okay. And what do you think about short takeoff and landing configurations?

P: I think that they're a bit more energy efficient. Because you don't need so much energy to take off. That, that really, I think people from Lilium told us, I think that 20% of the energy of a flight or even higher goes into taking off and landing just like, you know, I don't know, 10 seconds of 20 seconds of takeoff or 20 seconds of landing in an hour flight is 20%. Because you have to use so much power to take it off. So there it is, I think it's a bit more energy efficient, but it does not benefit from the ease of or the lack of needed infrastructure, which is, I think, a huge selling point for urban air mobility or for an EVTOL. Oh, just VTOL. It doesn't need to be electric, by the way. To be honest, I think nonelectric ones are more likely to succeed due to range, but I think there needs to be a sustainability aspect. So I think the EVTOLs will probably do better in the long term.

E: Okay, and what about hybrid configurations?

P: Yeah, hybrid, I think that's probably the best way now, because the battery technology is not up to, up to what we need it to be for the duration, range element. So yeah, hybrid. Normally it's electric motors with combustion generator. Which I think benefits from the fact that you can have relatively quiet vehicles because the generator, just hidden inside the helicopter units, or the machine itself wouldn't be too loud. And you can also benefit from the fact that electric motors are smaller and simpler as well. But you have the drawback that you have a generator and a stack of batteries. So the weight becomes an issue. And that would impact the range. But again, because you have a combustion, you should get the range back from higher energy density fuel.

E: Do you see other problems maybe regarding I don't know, infrastructure, if you have a hybrid configuration?

P: To be honest, I think it might be easier because rooftops cannot have refueling stations. And that at least that's the legislation in Sao Paolo, but I think it should be quite standard around the world that you cannot have huge batteries or huge fuel tanks on top of buildings, because fires on top of buildings are very difficult to get rid of. Buildings are designed not to have fires by any chance. So there's legislation in place that doesn't allow refueling, and depending on location and time of day, you can also not land

P: I talked to the people from San Paolo, who, who know more about the stuff, some helicopter pilots as well. And yeah, for me the fact the most important factors in my research was like the purpose of the vehicle, like what is it being designed for. And, when I say vehicle, I mean, the format of the vehicle, and what kind of purposes it can fulfill. Like a fixed wing it probably can't go in, it can't do a few things. If it doesn't have wings, it doesn't have the range. So it cannot serve so many purposes. So the more purposes format can

E: serve?

P: exactly serve, the more likely that format is will dominate the field of urban air mobility. And then also the company's ability to rapidly innovate. And that's was also voted very important. The location of development... Yeah, because it's just like it's a globalized world, it doesn't matter so much. And the pricing strategy didn't matter at all practically. The range like the most important were purpose, range, accessibility, flexibility, and regulation and noise. And then user experience as well as important.

E: For example, what I'm wondering in my work is there are many indicators that are relevant, but I see that many of them for example, user experience, you can only know how it will really be in later stages but not at the point where the development is now. So I am wondering then how do you make decisions on the best configuration?

P: like the user experience includes quite a lot of things, right? Like if your user experience intends to be like a rapid, like this example that I gave from Amsterdam to London, right? It has the vehicle has to be capable of taking off from a rooftop inside a city. So that kind of determines already, that knocks out the formats that need the runway, that knocks out formats that are noisy. And also in this in this case, which is like an intercity use case you need a range of over 300 kilometers. So that already knocks most of them out. And then you're just left with fixed wing or tilt wing aircraft.

E: Yeah. True. So part of it could be used to knock out some configurations. But let's say another part of user experience could be the actual way that passengers feel, right?

P: Yeah, yeah. And but that's also, kind of each company, you know, will design to whatever market they're trying to reach. So yeah, [expert name] gave me like, an interesting point, which was that, private jets that are designed by Embraer, they are designed to consumers in Brazil, and designed for consumers in the United States are different because the American consumer desires different things in his private jet, and the Brazilian consumer also desires different things. So this UX will depend on region basically. And also on the purchasing power you are targeting. Because if you know, yeah, you got to get just make a super fancy aircraft, but it's too expensive. And yeah, there's no point to having such a cool user experience. The market is two people: Jeff Bezos and Elon Musk.

E: And probably they already created their own. So

P: yeah, the last podcast with Elon Musk, like (name, inaudible) asked him if he was going to make an airplane. But he said like, I think that would like collapse me because he has too much on his plate. But I think the guy said, I think like companies like Lilium, and I think it's called vertical flight in the UK, they're doing a good job. And you can see like, they all have winged devices. The most promising concepts are all with wings, because I think they recognize that this range issue can only be really solved with wings.

E: Yeah, now, I am... Have you heard of Volocopter?

P: Yeah. The new the new Volocopter is also wings, right?

E: I thought that they only have multi rotor, but maybe I'm maybe I'm wrong.

P: There's one benefit of having multi rotors: is that most of the time, like you have all the motors. And so the system is really easy to make. With wings it makes it a bit harder. Yeah, it's they only have multi copters. You're right. But again, like Volocopter is targeting this kind of inter big city travel, which I think is a niche market. But again, like, I don't think I've done as much market research as Volocopter, so I'll trust them they are right. Yeah, but that's also something that the CEO of [company name] told me that it makes no sense to travel within a city like even... Where are you from in Mexico?

E: Aguascalientes, it's a... Well, let's say Mexico City.

P: Yeah, well, yeah, Mexico City is huge city, right? massive. And Sao Paolo as well, that's where I'm from, you know, that both have more than 20 million people, and traffic is a huge issue, right? There, you will see, oh, like, of course, it makes sense to get a helicopter to go, you know, from one business meeting to a factory or one business meeting to another in the city. And I mean, factories close to the city, right, we're talking about, this is the use case for Volocopter: short range intercity flights. But he said, like the time, it's not so easy to book a helicopter currently. So if you want to use a helicopter from [company A name], you have to call in at least one hour in advance to say that you want a helicopter, you have to say exactly what time you want, and what building and your building has to have helipad. And then the helicopter can stay on top of that building for 15 minutes before it has to take off again, so you can't be late. And then it has to organize the flight plan to the next building. And so like, the logistics of it is not super easy. And like you have to call him one hour in advance. And so it's not as on demand as getting an Uber, which is what the future is claiming to be because there's a lot of regulations behind flight plans and that kind of stuff, especially in busy places, busy cities like Sao Paolo and Mexico City where you have like, maybe even up to hundreds of flights of helicopters and planes a day over the city. So I think there is a technology that really needs to catch up with the momentum, which is air traffic control. So it's, it's much faster just to get a car, like if you're going to hop between a city, like between a building and another building, let's say, by car it's going to take 45 minutes, right? That's pretty bad. But if you go by a helicopter, you probably take five minutes, but you have to wait for 15 minutes of landing, 15 minutes to take off. So at the end, you only got 10 minutes, but you paid like 100 times what you paid for taxis. And nowadays, I think work in normal life with Zoom and stuff. So I don't think it will matter that much. But if you want to visit a factory, that's already different, you know, you have to actually be on the floor, you can't just do a Zoom call or whatever. Again, like if the factory is within the city limits. First, it has to have a location where you can land either on the factory or next to the factory. And so again, you're a bit dependent on this infrastructure. And in this short range, it might not make sense. It might just make sense to get a car, because that's still an efficient mode of transport. So, like, what I see, like shuttle services to airports, that makes sense. I think that's a niche market, like, and the amount of people utilizing the service is not so much.

E: Yeah. Yeah. Especially if the airport is well connected the city, then. Yeah. Why would they use it?

P: Exactly. So that's, that's my dot on the short-range vehicles. But the long range, yeah, they can do better.

E: Yeah, they have a better competitive advantage there, I think. Yeah. Okay. And I want to come back a bit to a previous question, which was about, like knockout indicators. I think we mentioned the range, noise, cost, time. Do you think there are more?

P: Regulation can be a big problem. So regulation wants to avoid single points of failures. And they too have to be super safe, like I mean, safety factors of actual devices. So like very complicated vehicles are probably going to struggle with regulations. Also vehicles that don't have like an inherent safety. So either that they are like these winged ones, they, some of them have a gliding ratio, so if all the engines cut off, they can still, they won't freefall over the sky like multirotors will. Helicopters having a safety factor, if the engine breaks down, they can use the rotor blades to fall softly, it's out of rotation. But with shorter blades, like you have in multi rotors, you can't use it, you can't use that for your benefit. So that's a problem. So if people have ballistic parachutes and that kind of stuff, they'll probably make consumers more eager to or more willing to use their devices, I think. So some sort of safety assurance or something like that. I think that that could be a potential knock out factor. Basically, like cars and airbags, like you don't want to get into a car without an airbag It's not that you're think you're going to crash. A good example is like a small plane, I think it’s called... anyway, a single engine, has a parachute installed in it on the roof, like it's just for emergency, if the engine breaks, you can just pull that and you have a parachute.

E: makes people feel safer.

P: Yeah, yeah. It's one of the best small, best-selling small aircrafts because yeah, aircraft if the engine breaks, you can just glide down, it's really not a problem. But there's knowing you have a second option makes people feel a lot more comfortable as well. So, this safety aspects of, of a design of a concept, I think is really important. It could be a potential knockout factor, especially like in the later stages of development. So if there are three or four matured concepts and designs that have been proven in the field and possibly been running some use cases. I think one could dominate over another depending on this added safety features.

E: Yeah. Okay. And yeah, what about, I was wondering, weather, because weather could have an impact, also in safety. Do you think it's possible that some configurations would be more, let's say robust, against adverse weather?

P: Yeah, any small aircraft in bad weather is really like tossed around, doesn't matter if it's a helicopter or an airplane. You really are tossed around the wind and it's actually like a problem in cities because all these tall buildings they channel and circulate the air differently. So for these futuristic movies, the cars going at like skyscraper level, you know? But that is super windy. I don't know if you ever been on a windy day at Delft between the EWI faculty really, it's just... exactly imagine trying to fly like a helicopter there you know, in a very bad day. It will just smash you along the other building. So I don't know. I don't know if technically speaking, if there is an aircraft configuration that would be more effective at combating bad weather. But my opinion is small aircraft have difficulties anyways.

E: Yeah. So in general, any configuration will be subject to more or less the same. Yeah. And what about certification. Would some configurations be easier to certify, or quicker?

P: There's regulation in place for aircraft, and there's regulation for helicopters. If the device is very similar to one or the other, it's going to have an easier time getting through regulation. But they are doing new regulations now for urban air mobility so I don't think it would affect any design of concept significantly. But regulation that could stifle the industry would be pertaining flying over cities because that would erase the benefit of having these things which is a lack of needed infrastructure or proximity to the customer. So these are more like local regulations, environmental regulations.

E: About this last point, environmental… sustainability, let's call it. Do you think it matters at an early stage of development?

P: My opinion is that if anyone tells you that it is more sustainable to fly somewhere, it's not true. The amount of energy… it makes no sense energy wise speaking to put people in the air. It's not sustainable, even if it is electric. It's more CO2 expensive to fly. If your grid is CO2 intensive. But I think it's an important aspect. It kind of help with selling the products.

E: And you still have batteries. How to dispose of them could be an issue.

P: Yeah, recyclability. Quite a lot of resources are needed for batteries. To be honest I think the urban air mobility market is quite small. It wouldn't demand too much material. But it's not contributing. But I think the benefits outweigh the drawbacks especially in case of first responders, air ambulance, that kind of stuff, you can really help society because you don't need the infrastructure. If I were the CEO of these companies first thing I would do is to make an air ambulance because that's how you can sell it to consumers. Systems for ambulances and firefighting they are all easy to justify in regulations, they skip a few things, like you could land on a road. So get people accustomed to the technology.

E: That's an interesting point. So kind of using these use cases to enter the market and get acceptance from the public and the regulator.

P: Yeah, I have said this publicly at the Amsterdam drone Week. It's a big event on urban air mobility and drone technology and how to make good use of them. I had the chance to speak. This is what I said: just roll it out as an ambulance, make people comfortable with technology, show them it can be used for good. It's not an annoying loud thing that flies. Because that's what people think, not in my backyard. So I hope they listened to what I said.

E: Ok, did you hear any comments from them?

P: Yeah, they said it was nice.

E: Ok… so the last question will be, if a company has 2 or 3 different configurations, do you think it is important they consider their capabilities and current markets?

P: I think it kind of depends. For example Lilium developed a four-seater version and a 7-seater. The 7-seater is like a ride sharing, and the 4-seater more like a private. It's difficult to say how they consider the different configurations. I think it really depends on the company and what their long-term strategy is. If Lilium wants an even larger one… They can reach even larger audiences. I wouldn't really know if it matters so much.

E: Ok, well, thank you very much

P: You're welcome

E: It was very interesting. I wanted to know if you can think of another person that I could interview?

P: Like what kind of questions you want to ask?

E: I am interested in certification… yeah mostly certification.

P: Yeah, I have a friend from [organization], he did a lot of research in certification, he talked to the guys in EASA. They do the legislation. His name is [name], I will text him and let you know. I will also send my research paper to you

E: Yes, thank you very much. One last point, with other interviewees, for example with [expert name], I created the whole transcript and then sent it to her because she had to check that she had not said anything that was confidential or whatever.

P: There is no need. I don't have anything confidential

E: Ok, good. Alright!

P: Thanks for the meeting

E: Ok, thank you very much

Interview 3

Summary of interview

If a company is trying to decide between two different configurations, what aspects or indicators will they take into account?

- How good a configuration is depends on the mission. Example: missions with long range (e.g. inter-city missions) require wings.
- In simple terms: the less noisy an UAM design is, the better. And the best it blends into its surroundings
- Would you feel comfortable flying in capsule that is autonomous? Many people will not feel comfortable. Possibly only some enthusiasts will be willing to fly in it. EHang has pilotless aircraft that are remotely controlled by humans who are on ground. This might get more acceptance than completely autonomous and pilotless.
- Community acceptance is critical: and noise is very important for it.
- PAL-V: to get to market as quick as possible: make it as close as possible to existing regulations to minimize certification time.
- From what companies are doing, it seems that features of dominant designs will be being electric and having VTOL capabilities. If UAM aircraft needs a runway, even if it is STOL: you are losing the advantages of proximity to the customer. And of almost no additional infrastructure (except for places to land, take-off, recharge)
- Consider missions / scenarios where UAM can offer unique advantages: islands, mountains, unsafe ground transportation. In some cities (example JFK-Manhattan): airport shuttle.
- Possible process: Market analysis, then choose mission(s) to serve, then choose the configuration that's best suited to this mission.
- Alternatively: First you have the hammer. Then: what can you do with the hammer? Leverage/use the company’s technological capabilities.

Regarding using UAM for emergency services: I read that using electric aircraft could be problematic given that they might not be available when needed (if they are not charged, for example). What do you think?

- I don’t see a problem there. I think that eVTOLs could easily become air ambulances.
- Availability of the vehicle is a logistics issue, not a technological one. Take that into account when calculating number of aircraft in your emergency fleet. You can have back up terrestrial vehicles. Use swappable batteries.
- Moreover, currently you can’t have helicopters at night because of the noise. If you can have eVTOLs as air ambulances, being less noisy than helicopters, they might be accepted as for flight during night emergency services.

What knockout indicators are there. What would make configuration a no go?

- Noise, because of public acceptance
- Having to modify the current certification and if the certification agency acts stiff, for instance as a result of an accident over a populated region. Then…
- Safety: if accident happen, regulations will tighten

- Consider if people are ready to accept the unfamiliar features of UAM (autonomous, for example).

Do you think that there are some configurations that will be quicker to certify?

- Yes, simple configurations will be quicker to certify. And configurations that are close to existing vehicles (e.g. helicopter). Also certifications that don't have single points of failure.
- Safety redundancies: if multi rotors configurations can prove that they can safely land after losing one or more rotors, this could speed up their certification.

How can the noise level be reduced by the configuration chosen, apart from reducing rotor tip speed?

- Some concepts are indeed better at reducing noise. Example: Lilium concept: uses ducted fans.
- Think: an UAM OEM will be able to sell aircraft to Uber only if it has a noise level low enough to operate anywhere in the city.

Do you think that there are some configurations that will be more robust against adverse weather?

- Some configurations could be more resistant to adverse weather. Multi-rotors better at maneuvering, for example.
- Weather conditions also have impact on passenger comfort but given short duration of trips it is probably not so important.

Interview 4

Transcripts of interview

E: Okay, I have started the audio recording. I asked you for permission, because then I will create like transcripts and send them to you. My first question is: **Supposing that you have two concept aircraft, two different configurations, how would you select which one to continue developing and which to discard?**

R: Okay, so, the first condition is: two concepts that have been designed for the same top level requirements, I suppose that both concepts comply with the top level requirements that I'm talking about: passengers, payload, range that it can fly, performance or how fast or slow you can do vertical take-off and landings. So before answering that question, these are my assumptions: that you have two concepts, which both have shown that they can comply with the top-level requirements. Then, what is the design objective of this aircraft? That could be costs, could be weight, could be environmental impact or a combination thereof. And then assess each concept on those metrics: what is the cost to operate? How heavy is the airplane? How heavy is it empty? How heavy is it with its maximum take-off weight? What is the environmental impact? So, during operations is it emitting anything into the atmosphere? So, I want to really get down to quantifying my objective. And then maybe the final thing that might be important here is the comfort level of the passengers. How comfortable are the passengers going to be inside this machine? Because there's usually a trade off between, you know, economy on one side (or costs) and emissions, but on the other side, how roomy or how spacious your cabin is going to be. So that will be another factor that I would put into that trade-off mix. Does that answer your question?

E: Yes, yes, it does. Okay, and now, **regarding range, why is it important?** You mentioned range in the beginning, that's one of the top-level requirements, right?

R: Yeah, I would assume that you would design for a certain requirement on the range that you need to fly. So, you would say, as starting point, I want to transport six people over 100 kilometers, for example. For me, it will be top level requirement. You could also make range an objective, but then that will impact the concept that you can choose. For electric airplanes, let's say range is the main killer. So, if you go over 300 kilometers, you start to have issues. I mean, your weight is going to snowball into something extremely heavy and at some point, it's just not converging anymore to a feasible design. So range is really your electric airplane killer. If you specify the range too high, then you cannot really do that with the electric airplane anymore. So you have to go to an aeroplane that uses fossil fuels or at least combust something. So its weight is reduced during the during the trip. So if you want to go for an electric airplane, range is really the prime requirement. If you set the range too high, then it's not possible to make a feasible airplane out of that. Given assumptions on battery technology, of course. So if you look at battery technology, what is currently certified in Europe, it has energy density of about 140 watt hours per kilogram.

E: Ok. You mentioned that the range might be a killer for an electric airplane. **What other killer or knockout indicators can you see?** Not specifically for electric airplanes. But **what would make an Urban Air Mobility concept infeasible?**

R: Very important requirements come from the regulations, I think. So, what regulations are put in place for Urban Air Mobility? So are the safety levels going to be as high as for large transport aeroplanes? Or is it more in the range of light sport aircraft or the very light aircraft category that we have in Europe, let's say. The latter has much less harsh performance requirements, safety standards, and the former has very tough safety requirements. Only looking at the physical books, you can already see that. I mean, the number of pages, it may be five, six times more for the regulation for large aeroplanes. So I do suspect that while it's not going to be necessarily a killer requirement, there are going to be driving requirements from those regulations that might force you to have more redundancy in your systems, for example, that drive up the weight of the airplane, that in turn drive up the cost or the energy consumption. I think that is something not to overlook.

E: Okay. So, safety because of certification…

R: Yes

E: Do you see another killer or very important indicator?

R: Let's see... for urban Air Mobility. Yeah, the other thing for urban Air Mobility is probably the noise levels that you must stay under, let's say, particularly for vertical take-off and landing vehicles with multiple rotors interacting with the airframe, usually close proximity to the airframe. That might be another challenge, let's put it that way.

E: You can influence the level of noise generated depending on your configuration, right?

R: Yeah, indeed. To some extent, you can. But probably, we also know that say these rotors need to be connected to the vehicle, right? Otherwise they don't work. So there's always going to be some kind of interaction, aerodynamic, aeroacoustics interaction between what the propeller or the rotor is producing and how the airframe is responding to that and vice versa. So the impact of the airframe on the propulsor, on the rotor and the resulting change in aerodynamics and aeroacoustics. So, to some extent, yes, you can influence that by for example, making low noise propellers. I suppose there are design methods that can do that. I am not familiar with them myself. But the second part is, of course, the interacting noise with the airframe. So I suspect there's definitely things to optimize there aerodynamically, acoustically. But I also think that it will be a driving requirement. If you have a requirement on the noise level of the airplane from a certain distance, then that will probably be an important one for the design.

E: okay. Okay, so far noise and safety. **Do you see another one?**

R: Another driving requirement?

E: Yes.

R: You know, let's say if you look at the requirements and not the objective, there can be there can be multiple driving requirements. You have to do an assessment of that: if it's a fixed wing airplane, the driving requirements are usually the take-off length, the landing distance, the climb gradient, the climb rate, the service ceiling, the cruise speed, And then there is the range and the endurance condition that drive the design, and all of the point performance requirements: size, the wing and propulsion system. And it depends which one is actually active, that depends on the mission, depends on the actual requirements that you specify. So if you have an airplane for which you specify that the climb rate should be very high, then the climb rate is probably going to be the driving requirement. On the other hand, if you have a very short field on which you want to take off and land, then probably the field length is going to drive the size of the (inaudible...) size the propulsion system or how much thrust you need from your engines. So that is something that you can very easily do with simple performance charts. I teach this in the first year to students: how to find out which requirement is your driving requirement, or which usually two or three requirements that together drive the design. In an iterative design loop, sometimes you switch, so sometimes the cruise speed is driving in one iteration. In the next iteration, you change: turns out that your take off distance is driving. Ideally, you design an airplane, where multiple requirements are driving the airplane very close together, right? So there's not one requirement, but they're all pretty close together. So it's that the airplane is not over designed to meet all of the other requirements, but one. That's, of course, a little bit challenging, sometimes. Getting the right requirements and balancing the requirement is also an exercise in itself that is usually overlooked. So people just take requirements for granted. But a requirements analysis, so with simple tools to find out which are the driving requirements. And if there is one driving requirement that might actually lead to a very much overpowered or oversized airplane for all of the other requirements, that might be also something to worth looking into. Because then you might go and say, is this requirement really necessary? Or where does it stem from? Can we do it in another way?

E: Okay. Good. Now, I want to switch into soft requirements we could say. So my question would be: **what do you think is important for user adoption of a new aircraft or for urban air mobility? And how can you reflect this into design decisions?**

R: Right, so from a user, I think there's a couple of things that are important: one is if it is safe. So you have to trust it, let's say, because you are basically trusting your life to this machine. Two, it doesn't necessarily need to be as cheap as the train, let's put it that way. But there should be a good balance between the additional price that you pay for the ticket, and the value that you get for that additional fare. So you will probably be trading speed, or time, for money. I think that is an important aspect. Otherwise, it's not economically viable. And then there might be also be the environmental footprint. If you know ahead of time that urban Air Mobility, being electric, or whatever, will have a higher environmental footprint. For example, it is nice that we have all electric airplane with zero emissions, but if it consumes three times the amount of energy that the train does, and that energy has got to come from somewhere. So that might also come into the decision. And then finally, but this is not for the person taking or deciding on taking the air taxi, but more the people that have to put up with the system: so the social acceptance of vertiports or small airports in a community: Are you going to allow us a small airport to reside in an urban environment where there's a lot of housing close by to the airport that might be influenced by at least the noise pollution of this airport. Maybe also the fact that you continue to see vehicles ascending and descending in the sky, that might be another thing. So adoption by the by the people that not necessarily benefit from this new air taxi service.

E: Okay. Okay. **We were talking about the value of time, let's call it like that, the price compared to how much time you can save. How could that be reflected in a design decision of the aircraft?**

R: Let's see. Yeah, so then basically, what you need to do is you need to compute what the cost of a ticket will roughly be, what the cost of a trip would be taking everything into consideration. So the whole lifecycle cost of the airplane, and bring it back to the single ride, think about what the cost would be. Think about what the profit margin you want to make and come up with the sort of fare for this trip. So that's what you can do on the airplane design, or the aircraft design side. And then on the value side, you have to put a price on the time, I suppose. Right? So you also have to look at the alternative. I think we did a study like that at some point where you say, Okay, you go from A to B, you take the cab, you take the train, or you take an urban air vehicle or an air taxi, let's say. What is the additional time that you gain and then you say, per unit of time I put a value to that and then we see if that value outweighs the cost? Something along these lines?

E: Okay, yes. Thank you. **What do you think would be the main value proposition of, let's say, an air taxi?**

R: Yeah, it's probably what we just talked about, the fact that you spend less time traveling from point A to point B, that you can use that time to work I suppose. I think that's the main value. Less time in traffic.

E: Okay, good. And another question is, **do you think that some designs or configurations can be more robust against adverse weather conditions?**

R: That's a good one. Because you want all weather capability, I suppose with this UAM. Right?

E: Yes, hopefully.

R: Then I can't say that I know of a configuration that would a priori perform better than another configuration. For example, gusty environment. I guess that's the main thing that we're talking about here. I don't know.

E: Okay. Probably no one knows…

R: Well, we know for example, fighter airplanes that have all weather capability. Right. So it would be terrible if you're attacked on a very windy day, and your whole fleet is grounded because they cannot take off because of the crosswind is beyond 25 knots. So you have the enemy evade, let's say, you can't have that. So many fighter airplanes are designed to have all weather capability, which essentially means that you can always operate them regardless of the weather, and you can effectively determine deter the enemy. So it is not an unheard-of requirement, let's say. The question is, what does it cost you, right to have an all-weather capability? So practically speaking, it probably comes down to overpowering your airplane, over controlling your airplane, increasing the control power on your airplane in order to make sure that you can adequately handle the airplane in such situations. And then there's the other things like snowing and so you have de-icing systems on board in order to make sure you can also work with snow and ice conditions, for example. And a good air conditioning system if it's like 50 degrees Celsius...

E: Okay, thank you. We have five more minutes, I guess. **Which configurations would likely take less time to be certified?**

R: The ones that can already be certified right now

E: with the existing regulations?

R: With existing regulations, yes. So either under CS-27, I think that is, for small helicopters. CS-29 I think is large helicopters or CS-23. For small, fixed wing airplanes, those are probably the ones that can go fastest, I would. But I really have no experience with the in between. Because we're also talking about sort of these tilt rotor airplanes, right?

E: Yes,

R: I suppose they sort of fall in between those categories. So I don't know if they would fall into the helicopter category or more into the fixed wing category, or that you actually need to certify to both categories at the same time. I'm not sure. There might be military requirements for these types of airplanes that can be adhered to. But I'm guessing that you have to come up with this certification regulations as you come up with the airplane. And also the acceptable means of compliance, basically saying, how do demonstrate that you comply with that regulation? That'll probably slow down the process, I would imagine.

E: Okay. Great. My last question, because I have no more time, **what indicators would you use to compare, a fully electric configuration versus a hybrid one?**

R: I would look at the payload-range energy efficiency. So that's the payload weight multiplied by the range divided by the energy that you need in order to perform that mission. That's a very important one. I would look at the maximum takeaway of the airplane, so just the bare number, the weight. And I would also look at the complexity of such a hybrid system compared to electric system. Hybrid systems probably need a little bit more infrastructure on the airplane because you are dealing with both a fuel system and an electric system. So some sort of complexity metric should be in there. I would probably also look quite carefully at the one engine out condition. And what kinds of scenarios, you can think about one engine out. For example, if you have a hybrid system with only one internal combustion engine. If that fails, then how does that work? If you have for example, six electric engines powering props. One of them fails, what happens? So that is also something that I would maybe look a little bit more closely at. So basically, the failure scenarios for the hybrid power train compared to the full electric power train.

E: Safety redundancies and avoiding single points of failures as well, I guess?

R: Yes. But also the impact it would have on the design, right. So you better over design for failure cases. So again, it's something that I would take into account.

E: Okay, good. Well, my time is over.

R: I hope I've helped you a little bit.

E: Yes, yes, it was quite interesting. And you, you brought up points that I had not heard before. So yeah that's valuable. Thank you very much.

R: You're welcome. Oh, good luck with the rest of the interviews and the rest of your studies.

E: Thank you.

R: And let me know if you need any clarification to any of my answers, then I can also do that through email. Okay, good.

E: Thank you very much. Have a good day.

R: Likewise

Interview 5

Transcripts of interview

E: Yes, I have started the recording, and thank you for letting me record. I will create a transcript of our conversation and then send them to you. **So my first question is a bit broad. And it is, supposing that you have two different configurations, let's say, multi rotor one and a lift and cruise, how would you select which one to continue developing?**

F: It's actually a quite technical question. I think each type of vehicle has a different purpose. And so I don't think that there will be one or the other. So we can discuss the hypothetical, that one will not be developed and the other will, but I don't think that's going to be the case. If we, for instance, look at parcels that are delivered at Rotterdam, I foresee that there will be larger unmanned planes, aircraft actually taking off from actual runways that will deliver those parcels to cities. So they deliver with unmanned aeroplanes from runways to other runways somewhere in Europe. From there, the parcel will be transported with a different vehicle, a lift and cruise, for instance, to get to the regions, you know, to get to local regions, and that might be a grass strip or whatever. And then the final part of the transport will be with a drone, you basically have an individual package, or maybe three combined to an individual vehicle, would be delivered to your house. So I think that all vehicles will be developed in conjunction, you know, next to each other for different purposes. Why do you question if one could not be developed? what's the idea behind the question?

E: Yeah, my idea was, let's say there's a company, but they will only develop one vehicle, and they had to choose between several configurations. But then I think I have my answer. If they can only develop one vehicle, then first they have to choose what purpose they want to serve, and then choose the configuration that's more adequate for that purpose.

F: Yeah, I mean, the first most important thing of any conversation, everything has to do with money. Money is the driving factor. If a company finds money in a configuration that they are good at, or that they can provide or that the market has not provided yet, and they can, you know, then they will go into that niche of the market. I don't think a company will have to choose because one configuration will not be useful. I think they will all be useful and it's money that drives eventually what's the best configuration for a specific company to develop.

E: Yes. Okay. So, then if we have multi rotor configuration for passenger applications, what go / no go indicators are there? So things that if the design does not fulfill or comply, then it will be a failure.

F: Safety. Yeah, safety is the primary driving factor. Because every vehicle, especially manned vehicles have to be approved, have to be certified. This certification process will be for a manned flight operation very strict. That is the reason why in aviation development is very, very slow. If you would understand that airplanes nowadays look very modern, but they are in fact, very old fashioned. I mean, your iPhone is more powerful than a computer in an Airbus. And that has everything to do with safety, because you have to certify and prove that your vehicle meets all the safety standards. For a multi rotor vehicle to carry passengers, the prime concern that everybody has is how safe it is. And you can understand that if you have 12 small rotors on your vehicle, and one breaks down, you still have 11, that can carry you. That's much better than if you have for instance an Osprey, a tilt rotor, lift and cruise that already flies with the US Air Force. If you have only two tilt rotors, if one of the tilt rotors dies, you are dead, the thing crashes, but the safety standards for military operations are different then for civil operations. But for passenger operations, it’s not. So there's only one clear answer to that question: safety. Then, secondary, is it economically viable? I mean, if it makes no sense for the company to build it or to operate, I mean, if it's too expensive with for instance, with the gas prices, now, you understand that all these vehicles we are talking about will be electric. But if there's an economic reason not to do it, then nothing will happen. Other reasons like social and others they are all secondary to safety. Because you need to solve the safety issue first, however they may in the end prohibit operation.

E: Ok. You mentioned certification. Do you think that some configurations will be easier or quicker to certify than others?

F: Yeah, configurations that are closer to current day operations are easier to certify. So, for instance, what we just talked about, you know, lift and cruise. I think, but that's my guess, you can't use that as "Frank said that", but that's my personal guess: I think that lift and cruise is closer to what we have currently, because the moment the aircraft configures to a cruise configuration, you basically have an aircraft. And that whole concept of changing the configuration, there are already aircraft out there, even though it's in the military, that can do that. So that is easier to certify. A multicopter is in that sense new. Even though Volocopter, I think is already certified in Germany. I'm not sure if it's by now also certified in all of Europe. But that just takes more time. But I mean, eventually it will be certified. Yeah, it might take some time. But eventually it will be certified, as long as the companies can prove redundancy, failsafe, basically safety in general. But my answer to this question would be: the closer it is to current regulation, so if the regulator can match it with current regulation, then the certification will be easier. If it's too far away, it will be more difficult, but not undoable, it can be done.

E: Yes. Okay. Good. What about noise? Would you consider it also a knockout indicator?

F: Now we're talking about switching into the operations itself, when the operation is acceptable. I think this is the biggest issue with drones. I think that noise and social acceptance is the biggest issue in drone operation, UAV operation. Everybody is talking about, you know, what I just did as well, safety, economics and all that stuff. But social acceptance is the one thing, I think, that will hold this whole operation back. Because people will not accept all these drones, flying over their house, over their gardens, peeking their windows, have this noise going through the streets. So I think that noise in that sense is going to be one of the determining factors of whether we can in the future really use drones. Does that apply the same way to UAM? So to passenger operations, like the Volocopter. The Volocopter, I'm not sure if I wrote it down in the paper, but I think it's about 10 times less noisy than a helicopter. And that's a huge difference. So the question now becomes, if a Volocopter or any equivalent vehicle can operate more economically friendly, safer, and 10 times quieter than a helicopter, then it might become possible to use this as a replacement for helicopter operations. And you might be thinking: "well, I don't see many helicopter operations here". That's true. That's why we concluded also in that paper that for that type of operation, the Netherlands will not be among the first ones because we don't have that many helicopter operations. In the major cities like Rio de Janeiro, New York, Paris, major cities congested with traffic, they might be able to use these kind of operations. Noise will still be a determining factor. So even though it's 10 times less noisy than a helicopter, it still will be the driving factor determining whether people that live there will accept those operations. Because for instance, you live right next to landing spot and you get a vehicle like that every five minutes. It's like living right next to a train track and getting a train every five minutes. I mean, you're not going to be happy, if that happens all day long. So noise will be the determining factor there as well. So yeah, my answer on your question here is social acceptance. So I take it a little bit broader than just noise, because there's also visual, that people don't like having vehicles up to their window level, don't like them flying over their garden. Don't like the noise. Social acceptance might be the biggest factor, why these operations will have problems. So even if you solve the safety issue, if you have convinced everybody that you have a business plan, so that it is economical viable, then you still have to solve the social issue. And how do you solve that? Operationally, for instance, you can't fly through the streets, you have to fly over buildings, you have to fly higher, but then you get into the path of other aircraft.

Anyway, that's a conceptual problem. But, but yeah, take the social issue as one of the primary factors, if you do not take that into account, you're going to fail. Because people will just not accept those operations even though you have a fantastic product. People would not accept it.

E: Okay. Okay, so for acceptance we mentioned noise. We also mentioned, just very briefly, the visual pollution we can call it

F: Yeah. Privacy. People call it privacy as well. You don't want that thing over your garden where you're sitting there with your girlfriend or wife. You don't want it.

E: Yeah, of course. Okay, good. What do you think is important so that people adopt or use the aircraft?

F: So let's play this game and ask yourself what has to be done so that you will get into a Volocopter?

E: safe and reasonably cheap

F: Yeah safety first and secondary be economical. Money wise it has to be within the ballpark of you know, a taxi drive or whatever, because that's what they're competing with. Yeah, I mean, you and I, I'm not sure how rich you are, but we will not get into a helicopter to get from Delft University to Schiphol. You will take the train and if you're in a hurry, you might take a taxi. So you already answered your own question. The primary thing for people to get into is the confidence that it's safe. I mean, look at what happened with the Boeing 737 max. Now the 737 is one of the oldest aircraft in existence that's currently still flying. And still, due to one change, people have lost trust in the safety of the vehicle, and they don't want to fly it anymore. So safety in aviation is the prime factor. And then secondary is what you said, money. If you know it's absolutely unsafe, it can be dirt cheap, you're still not going to get in it.

E: Do you see anything else? Because I don't. For me, that will be the only two reasons

F: For me as well. So yeah, you know, sometimes these questions are simple, you just have to answer it yourself. Because I don't think that other people are different than you and me. I mean, it's the question, would I get into it? Yes, I will get into it. I fully trust the Volocopter. But that also has to do with the fact that I've technically looked at it, what they have done, so I trust them. But I think that my friends who are not in aviation probably would not, they would be doubtful. And so the first years of operations will be tricky, because, you know, that's the same as when aviation started. People have to gain trust in in the safety of the operation. What is even worse, and we haven't even spoken about it, but you read it in our paper, we've concluded that for the operation to be viable, so to make money at all, you should not have a pilot. It should be completely autonomous. Now, the question is, would you get into a vehicle where there is no pilot?

E: I don't know.

F: Think about it for a while. Because it's very important to understand that these operations make no sense if you put it the pilot in there, because you have to pay the pilot.

E: Yeah. And you're taking 25% of the space.

F: So first, I mean, everything goes in stages, of course, first, you have to start an operation with a pilot, of course. Then you have a time where the pilot is still there, but is not in control. So basically, the vehicle is autonomous, but the pilot is there just in case. And after many years of flying that way, you will transition into an autonomous operation. I think it's going to take many years, maybe even decades, but you hope in the meantime, that society, people have accepted that kind of operation and have confidence that it can be done safely. But yeah, the primary factor of these operations to succeed is first and outmost, safety. Secondary, economics, because you can make it safe as hell. But if have to pay 1000 euros per minute, you're still not going to use it.

E: Yeah, yeah. Then you take the helicopter.

F: Yeah. Then the helicopter is cheaper again.

E: Yeah. Okay. And now I want to switch into integration into airspace, which I think is your area of expertise. So I want to know if there could be design decisions at the aircraft level that will make it easier to integrate with airspace? Or is integration of airspace more a regulatory and systemic issue?

No, there's a couple of things that are technical. These are technical issues that are being worked, so maybe they've already solved it. I mean, I've not been in the project for a while. But, for instance, this is a technical discussion. Airplanes nowadays fly with an airspeed indicator and an altitude indicator based on pressure differences, you know, so the higher you go, the lower the pressure is. So the indicator will say, Oh, you went up. And if you go down to pressure becomes higher, and the indicator says, Oh, you went down. And that's the same with air speeds, you know, you have pressure indicator that the faster you go, the higher the air pressure is and then the indicator says, oh, you're going faster, and the slower you go, so lower pressure. But these kinds of vehicles that we're talking about right now, they hover and they have no forward movement sometimes. Also, they don't use the normal pressure-based instruments to indicate altitude, vertical speed. UAM vehicles do that more based on GPS. So, GPS altitude, GPS speed. And that's not currently compatible with normal Aircraft Operations. So that is a field that has been worked on to basically match that up. And I honestly don't know where they are with that. I know that there have been projects that looked at that, but I don't really know where they are. That does not mean that it requires a different design of the vehicle or whatever, because the design of the vehicle doesn't really change, but the way the vehicle is operated with the instrumentation on board does. It is different and it has to basically match with other standard operations that we have right now.

E: Okay, just to clarify, the GPS technology is not compatible with the existing air traffic management systems?

F: The GPS information is currently being used in a different system to for instance, provide positioning. Positioning is of course, latitude and longitude, you know, where are you. But GPS information is not used to indicate speed or indicate altitude. For instance, in a car, the speedometer is not a GPS speed. So if you put your GPS phone or whatever right next to your speedometer of your car, you will see a difference in speed. Normally, it's around 10 kilometers an hour. So that's basically the same thing. In aircraft this speedometer, you know, is used by pressure gauge. And that indicator is different from the GPS speed. The GPS speed is ground speed. The aircraft uses an airspeed and that's different depending on the wind, but the whole ATM system, so the air traffic controller, is using airspeeds. When they tell you to fly 200 knots, that's an airspeed. That's not a GPS speed. So if you don't have an airspeed gauge on board of your Volocopter you have a problem because then the air traffic control will say “fly this speed” and your vehicle will not know what that speed is because it only uses GPS speeds. The same for altitude. So I think that a Volocopter will probably also have pressure indicator speeds just to be able to operate that way. So they have to basically match the old fashioned way. That's what I told you, a few minutes ago, that aviation is still very old. They have to match the old fashioned way of doing operations that is currently in place, because we never changed. I mean, this pressure-based systems are all coming from the 1940s or 1950s. It's never changed. They're reliable, and it works and it's safe. And that's why they don't change. But it's very old. So in short, to answer your question, the design of the vehicle itself doesn't have to change. I mean, for the Volocopter, the instrumentation and the operational means of how to operate that vehicle in the current ATM system requires that it uses systems that are basically applicable to the ATM system. And that will still be the case for some while until they have basically also resolved it for the whole system. And our view at the time was that eventually we think that aviation, the general aviation, you know, the normal ATM will also move towards the UAM operations, so that in the future, you will have an airspace in which these UAM operations and drone operations take place. And the bigger airplanes go above it, they do not enter this airspace. But in this airspace, where the drones operate, you can also have helicopters, you can also have general aviation like Cessnas. We think that eventually these helicopters and Cessnas will also move over to the UAM kind of operation. But for now, the UAM vehicles have to adapt to ATM and not the other way around.

E: Okay, good. And another related question. I saw a TED talk by an executive from Airbus. And he said that decentralized traffic management systems will be needed, while today we have centralized systems. Could you maybe elaborate on this? Or do you agree?

F: Yes, I agree. Because I am one of the pioneers of decentralized ATM, that's my profession, that's my heritage. So you're talking to somebody who is all in favor of decentralized. I've done decentralized ATM for over 20 years. And for the first 15 years I only did decentralized ATM. I had nothing to do with drones, nothing to do with UAM. I talk about the big airplanes, the Airbus, the Boeing's. And our goal was to decentralize ATM. So basically, give the separation responsibility to the aircraft instead of the air traffic controller. And we've developed concepts of operations, we have developed technologies, we have developed human factors. All the stuff has been developed to make it possible and we've also proven it to be safe, even safer than the current ATM system. It's not weird because if you understand that the current ATM system works in a way that every aircraft flies on the same route towards the same waypoint at the same altitude, and 20 aircraft are controlled by one person on the ground, that combination is not safe. I mean, the airspace is so big that you do not have to fly in that same route, everybody can fly somewhere different. Everybody can fly on their preferred altitude, that means that everybody is on different altitudes. Nobody wants to fly to a specific waypoint, they all want to go direct to their destination, nobody wants to fly certain waypoints. And if all the 20 aircraft would separate from each other, then you have 20 people looking at separation instead of one. And not just these 20 people that do that, but also supported by computers, that make sure that nothing happens. It is by far a safer operations. But aviation doesn't change, because they know what they have. And they know that what they currently have is safe. So change is something scary. So that's why they don't change until the moment comes that the airspace becomes so crowded, that they can't do it anymore. And then they eventually will go over to this decentralized ATM system. However, you know, we had the 2008 economical crisis and aviation dropped. And now we have the corona crisis and aviation drops. And all the airlines will not spend anything on changing, they will only spend money on survival. So we will not in the foreseeable future see any major changes in the ATM system, because they just don't have the capacity problem right now. And they also have an economical crisis to deal with. But now we're switching back to drone operations and UAM. But let's especially talk about drone operations. Imagine that we can do it safely. And we can solve the social problems, the problems we talked about: noise, and visual, and acceptance. And we end up with thousands of these little drones. Do you think it's a smart idea to have a one person on the ground or one computer on the ground controlling the safety of separation of all these vehicles?

E: No.

F: You can convince me with a very good computer on the ground that does have a good communication or maybe a redundant computer if one fails, and another will take over. But it's always a single point of failure. If the computer crashes or if the communication for whatever reason, doesn't work, imagine that that happens, with two vehicles coming, So you do not, in my eyes, want to have a centralized system controlling the safety of your operations.

Keep in mind that developing and testing the end system is not too hard. The difficulty is in how to get there. The transition. How do we come from where we are to where we want to be.

[part not included for privacy reasons]

F: My advice would be: design the vehicle with a decentralized control system in mind, so that it is ready for it, it is designed to do that, but make sure that it can still operate in ATM so that it can transition from current day to the future vision.

F: So two things are important to keep in mind, one thing is the safety aspect of the vehicle, so the autonomous operation. That has to gradually transition. It transitions through 3 steps. First step is you will have a pilot, second step is you still have a pilot but it does not have to do anything, third step is you do not have a pilot anymore. The same thing applies to the operation. First step is the vehicle will have to operate in ATM, then the vehicle will operate in ATM but will do the separation itself, basically do self-separation but inform the controller. Then those self-separating aircraft will be removed from the ATC so you can't even see them anymore. Then the aircraft will be self-separating, autonomous and the traffic controller will only handle the normal aircraft.

[part not included for privacy reasons]

F: Ok, good luck with your thesis then. So then send me your notes or your report. I will look at it, then I can give you the go ahead.

E: Ok

F: Good luck with your thesis

E: Thank you. Have a good day.

Interview 6

Interview notes not included since interviewee did not grant written permission.

Interview 7

Interview transcript not included per request of interviewee.

Interview 8

Written answers by interviewee 8

1. **Supposing that you have to choose between a lift and cruise and a tilt-wing configuration, what indicators would you use to compare them? Please elaborate on each of the indicators that you mention.**

The choice of the configuration is driven by the foreseen mission profile (range, payload, cruise speed, etc.), certification requirements (meeting safety targets) and development risks. Both of the above configurations have their own advantages and drawbacks. Lift+cruise aircraft are less complex, the only moving parts are the rotors. The lift and cruise engines can be optimized separately for cruise and hover condition. On the other hand the lift engines are a dead weight during cruise (mass penalty), and the propellers increase the drag. Tilt-wing aircraft usually have a better performance, but are mechanically complex, might have stability issues in hover in windy conditions and might have a heavy wing structure. In general a lift+cruise might be preferable for shorter missions or in case of a short development timeline, and a tiltwing might be a better choice if cruise performance is important.

2. **What is important for the user adoption of UAM and how can this be used to make design decisions?**

UAM needs to bring some added value compared to other transportation modes. This can be time saving (shorter travel time door-to-door), more enjoyable travel, increased safety and comfort. The design needs to be centered around the user experience. This includes passenger comfort, reliability of the service and many other aspects.

3. **What are critical aspects related to public acceptance that can be influenced at the early stage of the innovation process?**

Critical aspects are safety (both passenger safety and the safety of people on the ground) and noise emissions. Safety can be influenced in the early stage of design by choosing an architecture, that is inherently redundant and robust against failure.

4. **In your opinion, which are the knockout indicators for UAM? (knockout indicator = something that if the configuration does not fulfill, then it will be a failure).**

A lot of aspects of a design can be continuously improved over time, including manufacturing cost, operation cost and reliability of an aircraft, therefore I would not include these as knockout indicator. A knockout indicator could be an inherently unsafe feature of the design or a major shortcoming in performance, so that the aircraft cannot fulfill the envisioned mission. This can be a very short range, insufficient power to take off or excessively large noise emissions.

5. **Is it possible that even if your aircraft is certified (by EASA and FAA), you still face challenges related to compliance with city regulations? If yes, how do you think that companies will cope with this?**

City regulations might be more strict in some cases than certification requirements. For example a too noisy aircraft might be restricted to fewer operations per hour to protect the city-dwellers living nearby the vertiport from noise emissions. This can make a design economically unviable.

6. **Could some configurations be more robust against adverse weather conditions? If yes, please elaborate what characteristics of the configuration can make it more robust.**

This depends more on the detail design of the aircraft, such as systems for instrument meteorological conditions, lightning protection, etc. The aircraft needs to have good handling qualities to fly it in turbulent weather.

7. **What aircraft design decisions have the greatest impact on certification time? For each design decision you mention, please explain how does it impact certification time.**

The most important is to consider the full set of certification requirements early on in the design process, and to choose technical solutions that satisfy these requirements. Including more complex systems or the use of novel materials or manufacturing techniques can increase the certification time.

8. **Which design decisions have an impact on the level of noise generated? For each design decision you mention, please explain how does it impact the noise generated.**

A combination of low disc loading and low tip speed is advantageous for propeller aircraft. At the same time, at low RPM the noise is not attenuated that well by the atmosphere and it propagates further. Carefully designed ducted fans can reduce the noise, especially if acoustic liners are installed inside the engine duct.

9. **What design decisions have a considerable impact on maintenance costs?**

Planned lifetime and reliability of components. Maintenance costs can be significantly reduced if the assembly sequence of the main systems is considered carefully. It is important to select carefully what is a line-replaceable unit (which can be quickly replaced at the vertiport).

10. **What design decisions have a considerable impact on operation costs?**

One of the biggest considerations is to have a pilot or to operate the aircraft remotely or autonomously. This can be a promising prospect for the future to lower operation costs, if there will be a clear path to certification and all technical challenges can be solved. Landing fees in some cities might depend on the noise emission of the aircraft, so the acoustic design of the aircraft can also influence the operating costs.

11. What infrastructure-related challenges do you see for eVTOLs in general?

One of the advantages of eVTOL aircraft is a relatively low infrastructure cost compared to other high-speed transportation modes, e.g. high speed rail. This combined with the advantages of eVTOLs (low noise, no operational emissions) already sparked interest in many cities to consider building an infrastructure for flying taxis. Of course each landing site needs to be developed by involving all stakeholders, including city councils, citizens, etc. which can be a major effort. The electricity should come from a sustainable source to make eVTOLs truly environment-friendly, which can a challenge in countries with high portion of fossil fuels in their energy mix.