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PLATFORM SELECTION FOR COMPLEX SYSTEMS: BUILDING AUTOMATION SYSTEMS

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Abstract

Automation systems for buildings interconnect components and technologies from the information technology industry and the telecommunications industry. In these industries, existing platforms and new platforms (that are designed to make building automation systems work) compete for market acceptance and consequently several platform battles among suppliers for building automation networking are being waged. It is unclear what the outcome of these battles will be and also which factors are important in achieving platform dominance. Taking the fuzziness of decision makers' judgments into account, a fuzzy multi-criteria decision-making methodology called the Fuzzy Analytic Hierarchy Process is applied to investigate the importance of such factors in platform battles for building automation networking. We present the relative importance of the factors for three types of platforms (subsystem platforms, system platforms, and evolved subsystem platforms). The results provide a first indication that the set of important factors differs per type of platform. For example, when focusing on other stakeholders, for subsystem platforms, the previous installed base is of importance; for system platforms, the diversity of the network of stakeholders is essential; and for evolved subsystem platforms, the judiciary is an important factor.

Keywords: Building, automation system, complex system, platform, Fuzzy Analytic Hierarchy Process (AHP), multi-criteria decision-making (MCDM)

1. Introduction

Building automation systems are communication networks that interconnect the various technological components and subsystems in a building. Such systems become viable as various technological components may be combined into one system and may result in great advantages. It will become much easier to operate different subsystems in the building. These can include appliances, telecommunication devices, sensors, actuators, switches, controllers, and user interfaces to create novel applications and provide an infrastructure for multimedia distribution (Wacks 2002). Because subsystems can communicate with other subsystems inside and outside the building, the range of their possibilities increases. For instance, heating and energy properties, but also the lights in the building can be remotely controlled. Other examples include various forms of information distribution in buildings such as error logs or instruction codes for systems which can communicate with manufacturers.

Interestingly, the system sketched could already be implemented more than a decade ago and, at that time, a high demand for such systems existed (Wacks 2002). However, currently, they are not available yet on a large scale. A major reason is that generally accepted common platforms are lacking with which the distinct components of the building automation system can be connected (Frenzel 2009).

Platform technologies are products or services that act as a foundation upon which an array of complementary products (e.g. software, movies or music) can be offered (Gawer 2009a). Multiple technical standards may constitute such a platform (e.g. the GSM platform for mobile telecommunications is specified in a set of different standards of the European Telecommunications Standards Institute ETSI (Pelkmans 2001). Such platforms are a prerequisite for automation networks for buildings to emerge because the different subsystems must meet a common set of platforms in order to be able to communicate with each other.

Most subsystems have already been developed and most have their own set of platforms. Several of these platforms might also be used to interconnect subsystems in the building automation system (Rose 2001). Another option is to develop new platforms for this purpose. The problem is not a lack of platforms, on the contrary, there are too many (such as Konnex, COBA, BACnet, etc.). Therefore, it is difficult both for the manufacturers of products in which the platforms are applied and for the end customers of these products to make a choice: if others do not choose the same set of platforms, the system will be ‘an island’. As a result, users are reluctant to invest in such systems and companies think twice about introducing new products, inhibiting possible innovations. If a clear choice for a common set of platforms were made, users could evaluate and exchange products in the marketplace more easily (Garud et al. 2002). An example of such a platform is HDMI, which is the dominant platform for the interconnection of consumer electronics products. Thus, in a situation where multiple competing platforms exist next to each other, there is a need to be able to explain and predict which platform will have the highest chance of achieving dominance to mitigate the uncertainty attached to adopting a particular platform and thus investing in a complete system, in our case: a building automation system.

In this study, platform battles will be addressed from a market perspective (Farrell and Saloner 1988, Keil 2002), focusing on the process by which a platform becomes dominant in the market. Authors from the technology management discipline have identified various factors that may impact platform dominance

(Schilling 1998, 2002, Shapiro and Varian 1999b, Suarez 2004). We use these studies to create a framework with relevant factors for the case of complex systems. This paper aims to investigate whether the impact of these factors on platform dominance differs for various types of platforms. Confusingly, the term platform is used in different ways in literature. Tiwani et al. (2010) define a platform as: “the extensible codebase of a software-based system that provides core functionality shared by the modules that interoperate with it and the interfaces through which they operate”. Robertson and Ulrich (1998) define a platform as a collection of assets which are shared by a set of products. The assets can be divided into four categories: components, processes, knowledge and people. Sawhney (1998) describes a product platform as a collection of subsystems and interfaces that form a common structure on which a stream of derivative products can be developed and produced efficiently. He distinguishes between product, process, brand, customer and global platforms. Such a multi-dimensional perspective of platforms is also advocated by Halman, Hofer and Van Vuuren (2003). In many papers, however, the platform thinking has been focused on the physical product (Kotha 1995, Krishnan and Gupta 2001). Meyer and Utterback (1993) claim that the platform is the centre of the product family. Baldwin and Clark (1997) argue that the platform indicates which modules the system consists of and what their functionality is. In this paper we focus on physical systems that make use of digital technology and, more specifically, we focus on the interfaces between the modules that it consists of. These interfaces are at the centre of the product family and enable interoperability of the modules the system can consist of. Thus, we focus on digital product platforms (Yoo et al. 2010) which enable digital infrastructures (Tilson et al. 2010) whereby the focus lies on an infrastructure (or a system) which connects two or more subsystems that are already established and already have their own platforms.

Various factors may explain platform dominance including the application of platform strategies (e.g. timing of entry strategies (Lieberman and Montgomery 1988, Lieberman and Montgomery 1998) and marketing strategies (Besen and Farrell 1994)), the possession of complementary assets (e.g. financial resources (Schilling 1999) or reputation (Axelrodm et al. 1995)), or the possession of a superior platform in terms of e.g. the extent to which it is backwards compatible (Lee et al. 2003). Also, a platform may achieve dominance when it is selected by a large amount of potential users or when system elements (in which the platform has been applied to enable interconnection) are selected by a large amount of potential users. Thus, the user’s selection of platforms can be approached and analysed as a decision-making problem. In our case, the decision maker is the manufacturer of the technological components that comprise the building automation system such as heaters and air coolers or the designer of a building automation system in which different components are being interconnected. Both decision makers need to make a choice for a platform for the interconnection of these components in the larger building automation system. The decision as to which platform should be supported is strategic for both categories of companies and necessitates fulfilling various (often conflicting) criteria (Steward 1992). Since the number of criteria in this study is large and it is difficult for decision makers to compare them, a multi-criteria decision-making methodology such as the Analytic Hierarchy Process (AHP) (Saaty 1980) which allows judgments to be systematically made would be suitable. The AHP has been used in many different studies related to economics, management, politics, society and technology (Vargas 1990). Within the area of management, the AHP has been applied in a diverse range of subfields including global supplier selection (Chan et al. 2008), supplier segmentation (Rezaei and Ortt 2013), facility layout (Singh and Singh 2011), supply chain risk measurement (Samvedi et al. 2013), and project managers selection (Varajão and Cruz-Cunha 2013). Recently, however, benefiting from the advantages of fuzzy set theory (Zadeh 1965), some fuzzy versions of AHP have been developed. As fuzzy AHP applies linguistic judgments (e.g. a is 'strongly' preferred over b) instead of crisp numbers, it is closer to real-world situations and more efficient for handling the vagueness of the human thinking and judgment. This is the reason for applying one of the most recent versions of fuzzy AHP (Wang and Chin 2011) to platform selection for complex systems.

The paper proceeds as follows. First, drawing upon several streams of literature including technology management, we present a framework for platform selection for complex systems. Next, we describe our methodology, and present and discuss our findings. Finally, we discuss our contributions and recommend areas for further research.

2. A Framework for Platform Selection for Complex Systems

We define a complex system as one in which there are multiple interactions between many different components (Mitchell and Singh 1996) that can be systems in their own right (Simon 1962, Soh and Roberts 2003) and that originate from multiple converging product markets (Baker et al. 2004, Duysters and Hagedoorn 1998). These sub systems can be both established and new. By established we mean that one or more platforms which enable communication in the subsystem have already become dominant. A building automation system is an example of a complex system which combines components and technologies that originate from the information technology and telecommunications industries (Baker et al. 2004). Figure 1 presents a model for the selection of platforms for complex systems. We explain the elements of the model in the following sections.

2.1 Platform Dominance

The terms 'platform' and 'standard' are sometimes used interchangeably in the literature on platform battles (Cusumano 2011, Shapiro and Varian 1999b) and they then both refer to interface formats that create a single network of compatible users (Gallagher 2007). In this paper, we distinguish between these terms and we prefer to use the term platform. In our context of automation networks, a platform is a technology upon which an array of complementary (sub) systems can be offered (modification of Gawer's (2009a) more general definition). The specification of this technology is laid down in one or more standards. These standards are the codified specifications which define the interrelations between entities, in order to enable them to function together (Garud and Kumaraswamy 1993). This distinction between the technology and its specification is a first reason to use the term platform. The second reason is that more than one standard may apply. Our third argument is that apart from the compatibility standards that apply for such platform technologies, other categories of standards also exist, for instance, minimum quality and safety standards, variety reducing standards, and information and measurement standards (Blind 2004). In line with Suarez (2004), dominance of platforms is defined in terms of market share. We consider platforms to be dominant when they "achieve the largest market share among new products sold […] in a certain product category for a certain amount of time" (Van de Kaa and De Vries 2014).

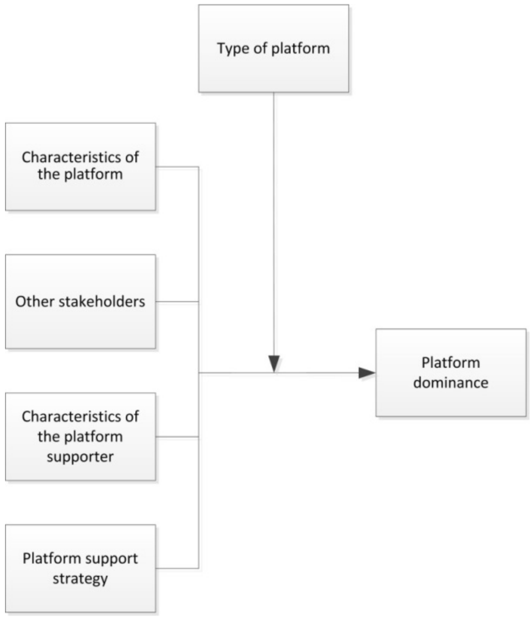

Figure 1 Research model

2.1 Platform Dominance

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2.2 Factors for Platform Dominance

Platforms are studied from multiple perspectives including engineering design, economics and strategy (Gawer 2014, Gawer and Cusumano 2013). Where engineering scholars focus on the effects of the existence of platforms on innovation in general (Langlois and Robertson 1992, Schilling 2000), economists and strategy scholars are especially interested in the question how platforms achieve market dominance given economic mechanisms (Shapiro and Varian 1999a). These scholars use the adjective two-sided for the term platform to indicate that two groups of users are involved and connected through the platform: users of core products and users of complementary products (e.g. hardware and software or video gaming consoles and video games) (Boudreau 2012). These scholars have endeavoured to explain and predict the outcome of platform wars. They have developed models consisting of factors that may affect dominance of platforms (Schilling 1998, Shapiro and Varian 1999b, Suarez 2004).

In prior research, we conducted an extensive search for factors which impact platform dominance. Our starting point was a review paper by Suarez (2004). The relevant factors were derived from that article and were arranged in a list. We conducted a backward search of publications that were quoted in the initial paper. This was followed by a forward search of publications that quoted the article. We then repeated this process for all new publications found. Both the backward and forward search was made using the ISI Web of Knowledge. When we discovered new factors, these were examined and included in the list. The factors were then classified in order to identify those factors that were closely related or overlapping in meaning. This procedure resulted in a shorter list of 29 unique factors. Based on similarities, we grouped the factors into five categories resulting in a model for platform dominance. We examined both the completeness and relevance of the model by applying it to three historical platform battles. This resulted in the model we will use for our analysis. Scholars tend to distinguish between factors that directly affect platform dominance and are defined at the 'firm level' and factors that indirectly affect platform dominance and are defined at the 'environmental level' (Suarez, 2004). In this paper, we focus on the 20 factors for platform dominance that firms can directly influence. These are listed in Table 1. In the remainder of this section we will elaborate on the underlying assumptions.

Table 1 Factors for platform dominance (based on (Van de Kaa and De Vries 2014, Van de Kaa et al. 2011))

Category / factor		Description
Characteristics of the platform		
1	Technological superiority	A platform is technologically superior when it has features that make the platform outperform other platforms (Schumpeter 1934).
2	Compatibility	Compatibility concerns the fitting of interrelated entities with each other in order to enable them to function together.
3	Complementary goods	Those "other" goods needed to successfully commercialize a certain platform (Teece 1986). When more complementary goods are available for the platform, this has a positive effect on the installed base of that platform (Schilling 2002). Firms can also diversify into providing their own complementary goods.
4	Flexibility	The extent to which the platform can be changed to suit new conditions or situations (Hornby 2000).
Other stakeholders		
5	Current installed base	Collection of users of a certain platform.
6	Previous installed base	Users that might upgrade to the new platform (Farrell and Saloner 1986).
7	Big fish	A player that can exercise a lot of influence by either promoting or financially supporting a platform or by exercising buying power that is so great that it contributes strongly to the market position of the platform (Suarez and Utterback 1995).
8	Regulator	The actor that can prescribe a certain platform in the market (Suarez and Utterback 1995, Van de Kaa, et al. 2013).
9	Judiciary	The judges of a country or state when considered as a group (Hornby 2000) which can prohibit certain platforms from becoming dominant for reasons of anti-trust policy.
10	Suppliers	Companies that produce complementary goods or services (Teece 1986).
11	Effectiveness of the platform development process	The stakeholders participating in the (further) development of the platform affects that process (for instance, in terms of duration). This influences the potential of the platform becoming dominant (Lehr 1992).
12	Diversity of the network	The extent to which different stakeholders are represented in the group of platform supporters. A platform that is supported by stakeholders that represent each relevant product market for which the platform serves a defining role will have a higher chance of achieving dominance (Gomes-Casseras 1994, Keil 2002). For instance, in the digital video disc platform war, hardware manufacturers worked together with movie studios to establish the DVD format (Dranove and Gandal 2003, Lint and Pennings 2003).
Characteristics of platform supporter		
13	Financial strength	Current and future financial condition of the group of platform supporters (based on Willard and Cooper 1985).
14	Brand reputation and credibility	The opinion that people have about a group of platform supporters, based on past performance (based on Hornby 2000).
15	Learning orientation	The extent to which the group of platform supporters expand their knowledge and skills base and improve their ability to assimilate and utilize future information (based on Schilling 1998).
Platform support strategy		
16	Pricing strategy	The technique of offering low prices for products implementing a platform to early customers so as to build up an installed base and influence the choices of later adopters (Besen and Farrell 1994).
17	Appropriability strategy	All actions that are undertaken by firms to protect a platform from imitation by competitors (Lee et al. 1995).
18	Timing of entry	The point in time at which the platform is introduced in the market (based on Suarez 2004).
19	Marketing communications	Actions taken to impact customer expectations (based on Suarez 2004).
20	Commitment	Obligation or pledge to carry out some action or policy or to give support to some policy or person (Webster 2000). A platform has a higher chance of achieving dominance when it is supported by an actor that is committed to the platform.

Factors that indirectly affect platform dominance are called 'external conditions' (Lee 1995). These factors may also be viewed as underlying assumptions of factors for format dominance and they moderate the effect of firm level factors on platform dominance. Many of the factors mentioned in Table 1 are relevant because of the fact that market mechanisms such as network effects are apparent in these markets. Network effects refer to the conception that technology increases in value the more it is adopted (Farrell and Saloner 1985, Katz and Shapiro 1985). Such effects moderate the influence of many factors including installed base, the availability of complementary goods and timing of entry (Schilling 1998). Also, given the existence of network effects, reinforcing effects between the installed base and the availability of complementary goods arise (Schilling 1999). This reinforcing effect is apparent in the home video gaming industry amongst others (Gallagher and Park 2002). As more users adopt a certain platform such as a video game console, manufacturers of complementary goods in the form of games are more reluctant to develop more of such games. In turn, as more games are available for a certain gaming platform, more users will adopt that platform. Likewise, network effects lead to bandwagon behaviour (De Vries 1999, De Vries and Hendrikse 2001) which further increases the installed base of platforms. Additionally, the rate of technological change and the sheer number of platforms that competes in the market has an effect on market uncertainty. As a result of market uncertainty, stakeholders might not invest in platforms in the first place and may e.g. delay their decision to adopt a platform (Leiponen 2008, Schmidt and Werle 1998). When many platforms exist simultaneously, and thus market uncertainty is high, actors may be less committed to platforms and they may spread their chances by promoting multiple, possibly competing, platforms. We assume that these mechanisms are equal for each platform that competes in the market. Thus, for example, a certain level of network effects applies for each of the platforms that compete. Another assumption is that actors have access to the required complementary assets. For example, entrepreneurs will lack important resources including funds and reputation and may thus not have the possibility to choose a point in time to enter the market or apply marketing campaigns. However, such marketing campaigns may be necessary to e.g. influence customers' perceived or expected installed base (Schilling 2013). In this research we assume that competitors have access to such resources. Another assumption is that the platforms that compete for dominance are comparable in terms of the functionality that these platforms offer.

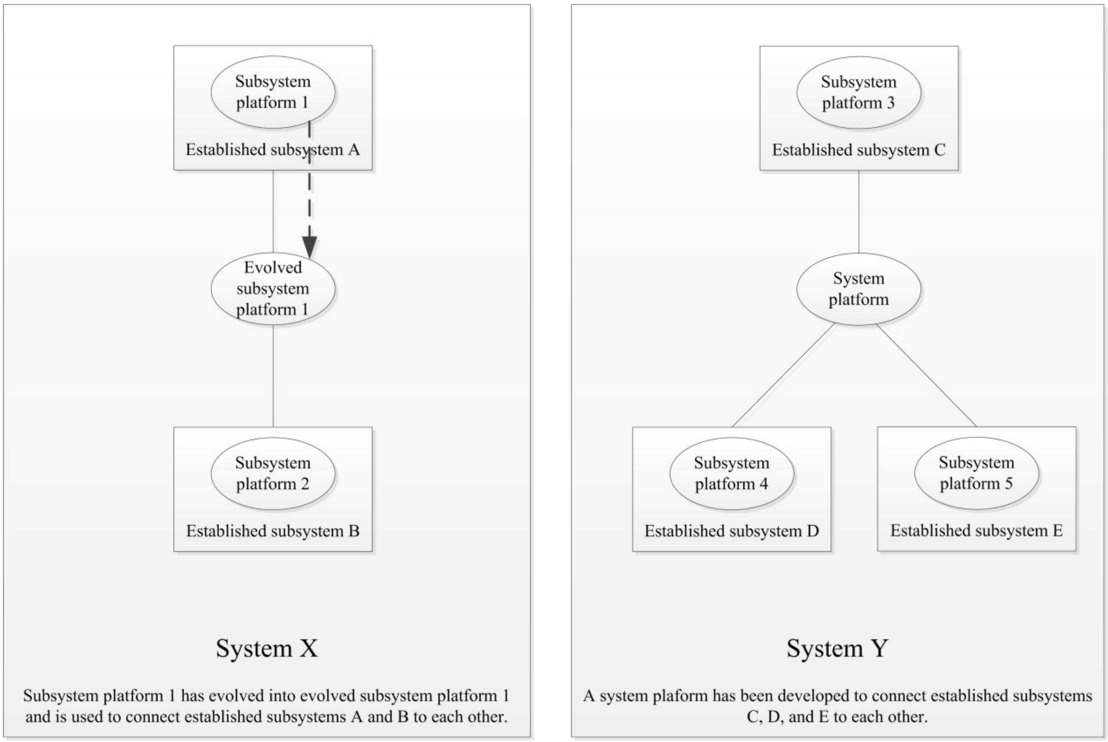

Figure 2 Subsystem platforms vs. Evolved subsystem platforms vs. System platforms(based on (Van de Kaa et al. 2009)).

2.3 Type of Platform

Complex systems consist of established subsystems that originate from converging industries and are thus a result of digital innovation which is defined by Yoo et al. (2010) as: 'the carrying out of new combinations of digital and physical components to produce novel products'. The components are the subsystems and the novel product is the complex system as a whole. The components may include pervasive digital technologies (Yoo et al. 2012) such as smart cloths and regular (physical) technologies. A building automation system may have a layered modular architecture in the sense that its constituent components do not have a 'fixed boundary' (Yoo et al. 2010). For example a tablet can be used on a stand-alone basis but it may also be bundled with other devices (e.g. to facilitate energy usage control in buildings). The functionality of the tablet depends on the applications that are developed for it (mostly by third parties). Characteristically, such layered modular architectures involve digital product platforms (Yoo et al. 2010) that enable digital infrastructures (Tilson et al. 2010) and that consist of a mixture of physical and digital elements. Whereas physical platforms are characterized by an underlying design hierarchy (Clark 1985), the digital product platforms on which our focus lies are less predictable as the layered modular architectures that they enable involve: "heterogeneous layers following multiple design hierarchies" (Yoo et al. 2010).

Also, we argue that such systems consist of two levels: the system level and the subsystem level. Then, three types of platforms can be distinguished: subsystem platforms, evolved subsystem platforms and system platforms. Subsystem platforms are platforms that have been developed at the subsystem level (and that are thus used to enable communication within that level) and which may also be used to realize communication between subsystems (at the system level). Evolved subsystem platforms are platforms that have initially been developed at the subsystem level and that have evolved to realize communication between subsystems. System platforms are platforms that have been specifically developed to realize communication between subsystems. This distinction is demonstrated in Figure 2.

3. Methodology

Social scientists often use a statistical approach to find the relationship between different constructs of a model. A relatively large number of data is needed to find reliable results. A multi-criteria decision analysis approach fits better in our case because of its potential to assist decision makers to find the best alternatives also when the model is too complex for statistical analysis. MCDM methods can handle complex systems (e.g. by structuring a hierarchy of the problem by Analytic Hierarchy Process (AHP)), and also to incorporate the decision maker's opinion. A second advantage is that MCDM methods can be used when having the opinion of a limited number of experts only. One may wonder if relying on the judgment of one or a limited number of experts only does not affect the validity of the results of the MCDM methods. Several researchers (e.g. Mitra 2010, Saaty 2005, Whitaker 2007) studied the validity of AHP for investigating several real-world problems and showed that AHP is able to produce very reliable results even based on the opinion of two experts. They compared the predicted results obtained by AHP and the actual things that happened afterwards in the real-world. For example, Saaty and Khouja (1976), as two experts used their professional knowledge to find the relative influence and standing of seven different countries in the world without looking at their GNP. The relative influence they found using AHP was very close to the relative GNP values. Others have found the same robustness for fuzzy AHP using analytical and statistical tests (e.g. Dağdeviren and Yüksel 2008, Rezaei et al. 2013).

We therefore use a multi-criteria decision-making methodology to explore whether the influence of factors for platform dominance is modified by the type of platform. The AHP is suitable when decision making is affected by criteria that are both intangible and tangible (Badri 2001). In this respect, this method is appropriate for our topic since the selection of a platform is contingent upon by both tangible and intangible criteria. In the following sections, we explain the method and apply it to our decision problem.

3.1 Fuzzy AHP

AHP (Saaty 1980) is a method used to determine the relative importance of a set of decision elements in a multi-criteria decision-making problem. The method is based on three principles. First a structure is established for the decision problem, subsequently, decision elements are compared pair-wise and finally, priorities for the decision elements are synthesized.

The first step in an AHP analysis is to break up the decision problem into a decision hierarchy of objective, (sub) criteria, and alternatives. To determine the relative importance of each element, at each level of the hierarchy, one or more experts are asked to pair-wise compare each of the elements based on the element in the higher level. A ratio scale from 1 (*a* is equal to *b*) to 9 (*a* has extreme preference over *b*) is used to compare the elements.

Let $D=\{D_i \mid i=1,2,\ldots,n\}$ be the set of decision elements. The result of the pairwise comparisons on n criteria can be summarized in a pairwise comparison matrix A in which every element corresponds to the priority of criterion i over criterion j as follows.

$$A=(a_{ij})=\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}$$

$$a_{ji}=\frac{1}{a_{ij}}, \qquad i,j=1,\ldots,n.$$

There are several ways to obtain the weights of the criteria (w_i). For example, as one of the most common way, the reciprocal matrix is first normalized; the elements in each column of the reciprocal matrices are divided by the sum of the elements in that column. The relative weights are given by the right eigenvector which corresponds to the largest Eigen value.

In traditional AHP, crisp numbers are used to make the comparison. However in practice, it is more convenient for experts to express their judgment using linguistic variables such as “very important” instead of using crisp numbers. Linguistic variables are then converted to fuzzy numbers to be used in mathematical calculations. One of the most common fuzzy numbers used for this purpose is triangular fuzzy numbers (TFN) which is defined as follows:

Definition 1. (van Laarhoven and Pedrycz 1983) Triangular fuzzy number (TFN): A fuzzy number K on $\Re$ is defined to be a TFN if its membership function $\mu_K(x):\Re\rightarrow[0,1]$ be:

$$\mu_K(x)=\begin{cases} \dfrac{x-l}{m-l}, & l\le x\le m, \\ \dfrac{u-x}{u-m}, & m\le x\le u, \\ 0, & \text{otherwise}, \end{cases} \qquad (1)$$

where l, and u are the lower and upper bound of the support K respectively and m is the modal value. This triangular fuzzy number can be noted by the triple (l,m,u). Table 2 shows the TFNs used for our purpose in this paper.

Therefore the comparison matrix would be as follows.

$$\tilde{A}=(l_{ij},m_{ij},u_{ij}) = \begin{pmatrix} (1,1,1) & \cdots & (l_{1n},m_{1n},u_{1n}) \\ \vdots & \ddots & \vdots \\ (l_{n1},m_{n1},u_{n1}) & \cdots & (1,1,1) \end{pmatrix} \qquad (2)$$

where $l_{ji}=1/u_{ij}$, $m_{ji}=1/m_{ij}$, $u_{ji}=1/l_{ij}$.

Table 2 TFNs used for pair-wise comparisons

Intensity of importance (TFN)	Definition (in italics: linguistic variables)
$\tilde{9}$=(8,9,9)	*An extreme importance* of element A over element B exists. The evidence of favoring element A over element B is of the highest order of affirmation.
$\tilde{7}$=(6,7,8)	*A very strong importance* of element A over element B exists. Element A is strongly favored and its dominance is demonstrated in practice.
$\tilde{5}$=(4,5,6)	*A strong importance* of element A over element B exists. Experience and judgment strongly favor element A over element B.
$\tilde{3}$=(2,3,4)	*A moderate importance* of element A over element B exists. Experience and judgment slightly favor element A over element B.
$\tilde{1}$=(1,1,1)	The two elements are *equally important*, meaning that the two elements contribute equally to the property.
$\tilde{2}$=(1,2,3)	Intermediate values.
$\tilde{4}$=(3,4,5)	
$\tilde{6}$=(5,6,7)	
$\tilde{8}$=(7,8,9)	

The final goal is to find the optimal priority vector w*=(w_1, …,w_n), $w_i \geq 0, \sum w_i = 1$. In the literature, there are several ways to find the optimal priority vector (e.g. Buckley, 1985; Chang, 1996; van Laarhoven and Pedrycz, 1983; Wang et al., 2008). The recent methodologies consider maximizing the decision maker's satisfaction to find such an optimal vector. In this paper, we apply one of the most recent advanced fuzzy AHP proposed by Mikhailov (2003), and extended by Wang and Chin (2011). The proposed methodology is able to overcome one of the most challenging issues in AHP and fuzzy AHP -inability to preserve the order of the preference intensities (Çakır, 2008). They formulated the following model to find the optimal crisp priority vector w*=(w_1, …,w_n), $w_i \geq 0,\ \sum w_i = 1$, such that the decision maker's satisfaction (λ) would be maximized.

$$Minimize\ J = (1-\lambda)^2 + M\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(\delta_{ij}^2 + \eta_{ij}^2\right)$$

s.t.

$$x_i - x_j - \lambda \ln\left(m_{ij}/l_{ij}\right) + \delta_{ij} \geq \ln l_{ij},\ \ i = 1,\dots,n-1; j = i+1,\dots,n,$$

$$-x_i + x_j - \lambda \ln\left(u_{ij}/m_{ij}\right) + \eta_{ij} \geq -\ln u_{ij},\ \ i = 1,\dots,n-1; j = i+1,\dots,n,$$

$$\lambda, x_i \geq 0, i = 1,\dots,n, \delta_{ij}, \eta_{ij} \geq 0, i = 1,\dots,n-1; j = i+1,\dots,n,$$

where x_i = ln(w_i), and M is a large constant such as 10^3. $\delta_{ij} + \eta_{ij}$ are non-negative deviation variables to avoid λ from tacking negative values. As x_i = ln(w_i), having x_i^*, we can simply calculate the optimal weights as follows.

$$w_i^* = \frac{\exp(x_i^*)}{\sum_{j=1}^{n}\exp(x_j^*)}, i = 1,\dots,n. \qquad (4)$$

3.2 Application of Fuzzy AHP to Platform Selection for Complex Systems

Using the elements presented in Section 2, a decision hierarchy was developed (see Figure 3) consisting of four levels. The first level, the objective, is to choose the platform that is expected to achieve dominance in the market. The second, third and fourth levels consist of the criteria; categories and factors for platform dominance and type of platform. The fifth level, the alternatives, comprises the platforms from which a choice has to be made. To preserve space, this level has not been included in the decision hierarchy

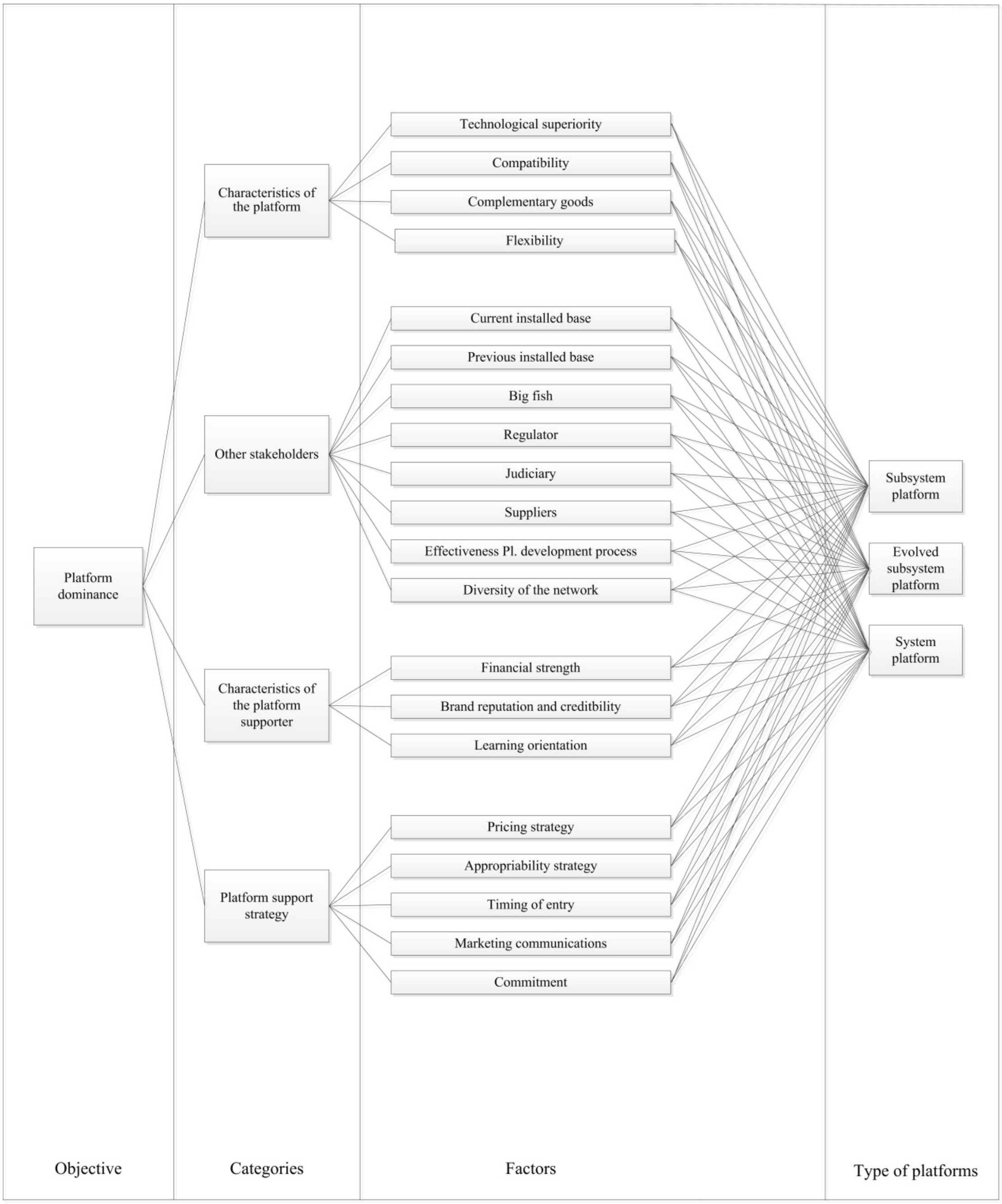

Figure 3 Decision hierarchy of the AHP model for selecting a platform for building automation systems

When decision makers compare two decision elements, they automatically think of the properties of (a set of) all the alternatives and question which of the decision elements are more important in expressing a preference among the alternatives (Saaty 1990). Also, because they are asked to compare only two elements, they assess the relative importance of the decision elements in a context-free sense. Thus, people will essentially express the same ratio of importance for one element relative to another, irrespective of the context of the specific decision problem (Belton and Stewart 2003). So, each level in the hierarchy can be analyzed independently of the elements in the levels below it. In this study, we focus on the fourth level of the hierarchy, the type of platform.

A questionnaire was developed in which the respondents were asked to compare the three types of platforms and to evaluate the importance of each factor for the dominance of that type of platform. In this way, we could evaluate whether the importance of each factor differed for the three types of platforms. One of the questions at this level was: "How much more important is it for the group of platform supporters that support subsystem platforms to have a high reputation and credibility compared to the group of platform supporters that support system platforms?" Four experts were consulted. The experts were standards managers and experts working at companies that manufacture (different technological components for) building automation systems. These experts are involved in the decision as to which platform to support in the products and systems that their company manufactures. The first expert was a senior manager at a US telecommunications company. The second expert was a scientist at a Dutch telecommunications company. The third was a standards manager at a large Dutch consumer electronics company and the fourth expert was a standards manager at a large US Information Technology firm. The experts were selected based on their knowledge of platforms for building automation systems. To arrive at average weights, the weighted arithmetic mean method was applied where the individual priority vectors are combined into one group priority vector.

4. Results

In this section, we present the results of the empirical study. We explore whether the influence of factors for platform dominance differs between three types of platforms. The results are presented in Table 3. Each number in Table 3 can be interpreted as the importance of a particular factor for a particular type of platform. For instance, on average, the compatibility factor has a value of 0.46 for subsystem platforms. Thus, it appears that it is more important to guarantee compatibility for actors that support subsystem platforms than for those who support system platforms or evolved subsystem platforms. The results also show that within the category characteristics of the platform, compatibility is the most important factor contributing to a subsystem platform achieving dominance.

Table 3 AHP Results at level 4 of the hierarchy (type of platform)

	Average		
	subsystem platform	system platform	evolved subsystem platform
Characteristics of the platform			
Technological superiority	0.40	**0.34**	0.26
Compatibility	**0.46**	0.18	0.35
Complementary goods	0.38	0.30	0.33
Flexibility	0.22	0.24	**0.54**
Other stakeholders			
Current installed base	0.43	0.23	0.34
Previous installed base	**0.49**	0.24	0.27
Big fish	0.32	0.40	0.28
Regulator	0.37	0.37	0.26
Judiciary	0.39	0.23	**0.39**
Suppliers	0.28	0.48	0.25
Effectiveness of the platform development process	0.25	0.37	0.38
Diversity of the network	0.29	**0.50**	0.21
Characteristics of the platform supporter			
Financial strength	0.25	0.41	**0.34**
Brand reputation and credibility	**0.39**	0.35	0.26
Learning orientation	0.27	**0.46**	0.27
Platform support strategy			
Pricing strategy	**0.53**	0.28	0.19
Appropriability strategy	0.28	0.37 (0.365)	0.35
Timing of entry	0.39	**0.37 (0.373)**	0.24
Marketing communications	0.40	0.33	0.27
Commitment	0.32	0.29	**0.39**

We determined which factor was rated as the most important in influencing platform dominance within each category and for each type of platform. The values of these factors are indicated in bold in the table. Consider the category other stakeholders. The previous installed base is the most important factor for subsystem platforms (weight: 0.49). The diversity of the network is the most important factor for system platforms (weight: 0.50), and the judiciary is the most important factor for evolved subsystem platforms (weight: 0.39). The data clearly show a different factor is rated as the most important factor influencing platform dominance for each type of platform and within each category. This leads us to believe that the influence of factors for building automation system platform dominance is modified by the type of platform.

5. Discussion

Our results are difficult to explain with the available literature since the moderating role of platform types has not been studied before. However, we make an attempt. Within the category characteristics of the platform, compatibility is the most important factor for subsystem platforms, while it is the least important for system platforms. A possible explanation could be that subsystem platforms enable communication in one subsystem and actors that support these platforms focus on increasing the compatibility that the platforms enable to other subsystems that are part of the complex system. In contrast, system platforms are newly developed and already enable communication between two or more subsystems that are part of the complex system. Furthermore, backward compatibility is less important for system platforms since these are usually newly developed and do not have a previous generation. Therefore, it can be argued that the importance of this factor is low for system platforms.

Within the category other stakeholders, diversity of the network is the most important factor for system platforms, while the installed base is the most important for subsystem platforms. The major strength of a subsystem platform is that it can have an installed base whereas system platforms lack a previous installed base of users. By definition, system platforms define communication between subsystems that represent two or more product markets. It is possible that these system platforms have been developed by groups of platform supporters from these different product markets. In contrast, subsystem platforms are supported by groups of platform supporters that represent fewer different product markets. This diversity is the major strength of system platforms. Through these diverse actors, these platforms can make use of the potential installed base in these product markets, which gives them an advantage over subsystem platforms.

A similar observation can be made about the characteristics of the platform supporter. Subsystem platforms may have already proven themselves in the single product markets from which they originate and they may be supported by major firms that have a high reputation. This is their strength. However, system platforms can be supported by diverse members who can learn from each other and incorporate changes in the platform that satisfy the needs of everyone involved. This could be their major strength. The results in the platform support strategy category are more difficult to explain.

This research may be relevant both for theory development in the area of platform battles and for managerial practice. We contribute to the literature on platforms (Gawer 2009b, 2014, Gawer and Cusumano 2002, Rochet and Tirole 2003) in several ways. Scholars in the area of platform battles argue that the outcome of such battles cannot easily be explained as random actions may occur that cannot be foreseen (David and Greenstein 1990). Path dependency theory may be used to explain the outcome of the battles

(Arthur 1989, David 1985). However, other researchers have argued that such occasions are actually precedents to acknowledged factors for platform dominance (Schilling 2002, Suarez 2004, Van de Kaa et al. 2014). Indeed, scholars have proven that the outcome of battles for platforms may be modelled and that weights may even be established for individual factors (Van de Kaa et al. 2014, Van de Kaa et al. 2014). We add to this literature by providing more evidence. Specifically, scholars in the area of platform wars have not yet studied the moderating role of the type of platform. Our data show that a different factor is rated as the most important factor influencing platform dominance for each type of platform and within each category. This provides a first indication that the influence of factors for building automation system platform dominance is modified by the type of platform. However, we do want to stress that we provide a first indication of weights for factors for platform dominance depending upon type of platform. Hence a recommendation for further research is to study other types of complex systems such as smart grids, the e-ticket system, and the inland transportation system for maritime containers possibly also utilizing other methodological approaches including the case study method or surveys of platform designers. By doing so, the generalizability of our findings can be explored. Finally, although the (fuzzy) AHP method has been applied in many research fields (Bozdağ et al. 2003, Kuo et al. 2002, Rezaei and Ortt 2013, Shim 1989, Vaidya and Kumar 2006, Vargas 1990), it has only scarcely been applied to platform battles (Van de Kaa et al. 2014, Van de Kaa et al. 2014). We apply a fuzzy AHP method to platform selection for complex systems.

The managerial contribution of this research lies in reducing the uncertainty for companies when deciding which platform should be supported in building automation systems. Firms can first determine the type of competing platforms. Then, they can use our results to assess which factors are especially important for that type of platform to become dominant. By taking these factors into account, the practitioner can come to a better understanding of the case and make a better informed choice as to which platform should be supported.

A limitation inherent in our research is that the list of factors for platform dominance that were used in this paper may not contain all possible relevant factors. Other factors may exist that are not taken into account. Through studying more cases of platform wars these factors may be found and may be included in a future similar analysis.

6. Conclusion

In this paper, we investigate the importance of factors that influence the process and outcome of platform battles in the building automation systems industry. In prior research, we performed a literature review and developed a framework with relevant factors for platform dominance. Here we analyse the relative importance of these factors for three types of platforms (subsystem platforms, system platforms, and evolved subsystem platforms) by applying a fuzzy multi-criteria decision-making methodology; a fuzzy AHP. We provide a first indication that the influence of factors for building automation system platform dominance is modified by the type of platform.

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