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# An AHP Approach toward Evaluating IoT Business Ecosystem in Korea<sup>a</sup>

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## ABSTRACT

The Internet of Things (IoT) has been a major buzz word and is accepted as a future direction of ICT. One of the market's challenges is the formation of healthy business ecosystems. As IoT business inherently encompasses convergence of distinct industries, forming a healthy business ecosystem is challenging. However, there is only limited amount of studies concerning the business ecosystem evaluation. Thus, the current study intends to develop a viable model for assessing the healthiness of IoT business ecosystems. Factors affecting the IoT business ecosystems are suggested in the form of hierarchical decision tree, of which the first layer consists of stability, productivity, and diversity. In the second layer, 7 sub-criteria were presented under each major evaluation factor. Consequently, the health of three Korean IoT business ecosystems were assessed. Using the AHP method, the perceptions of 51 IoT researchers were analyzed. The results showed that the service oriented IoT business ecosystem alternative was the healthiest. Telecom firm's ecosystem showed well distributed capabilities in every factor. Meanwhile, tech-oriented firm's technological strength did not compensate its lack of value creation. Detailed theoretical, practical implications, and limitations of this study are also discussed.

**Keyword:** Internet of things; IoT; business ecosystem; AHP; multi-criteria decision model; business ecosystem health

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## 1. Introduction

Internet of Things (IoT) is clearly one of the buzzwords proliferating in the ICT and media industry. This new paradigm envisions extending the benefits of computing to virtually all objects that are ubiquitous among us. Implementation of such concept is viewed as one of the key drivers that could innovate business processes, transform the competition and realize Industry 4.0 (Dutton, 2014). IoT's economic impact is also expected to be significant. Gartner Inc. estimated the total IoT endpoint spending to reach 1.41 trillion USD in 2016, which will reach approximately 3.01 trillion USD by 2020 (Gartner, 2015). It seems clear that IoT has gathered considerable interest from the industry for its huge economic potential.

Meanwhile, realization of IoT inherently requires convergence of corporations from different industries. For instance, smart home applications, which is one of the application domains of IoT, naturally invites myriads of home appliance companies to information technology (IT) industry. Such characteristic is one of the reasons why the perspective of business ecosystem is essential for understanding the IoT industry (Rong et al., 2014). As the IoT industry is in its nascent stage of development and yet to provision full-fledged IoT applications, establishing sound ecosystems around viable platforms should be one of key tasks for companies participating in the market. While academic discussions on this issue have been highly technological, there still remains wide arrays of issues of technology standardization, regulatory framework, and numerous other societal problems (e.g., privacy, data sovereignty, etc.). Considering that the regulatory body is also an important component in a business ecosystem, in depth examination of these issues is crucial for establishing firm foundation for market to grow, and academia recently started to engage in such endeavor (Dutton, 2014; van Kranenburg & Bassi, 2012; Weber, 2011, 2016). Furthermore, there were also efforts to conceptualize the IoT business ecosystem and viable business models from a more practical standpoint (Mazhelis et al., 2012; Rong et al., 2014; Westerlund et al., 2014). However, to our best knowledge, most of the current studies in both lines remain highly conceptual, lacking empirical studies with tangible data and framework. Thus, this study aims to provide more concrete and holistic sense of IoT business ecosystem supported by tangible data. Especially, determining which aspect of an IoT business ecosystem is relatively more important should be a critical process for prospective niche players in the market. What characteristics should be considered in order to assess the healthiness of an IoT business ecosystem? Which characteristic is relatively significant over others? Which IoT business ecosystem is then currently the healthiest? The current study intends to seek answers to these questions by creating an evaluation model of IoT business ecosystem and implementing it to specific cases of burgeoning Korean IoT industry.

The remaining parts of this article proceeds with a literature review on previous works regarding the IoT business ecosystem and business ecosystem evaluation. Inspired mainly by the previous work of Iansiti & Levien (2004a) on business ecosystem health measures, we suggest a more detailed sub-categories for business ecosystem evaluation particularly germane to the IoT context. Then we will discuss the analytic hierarchy process (AHP) methodology, which we consider appropriate when gauging the relative significances of each criteria. Three IoT business ecosystem building efforts in Korea were selected as case alternatives. Each case represents endeavors from different key domains of IoT: device, connectivity, and service. Analysis results from 51 AHP survey responses from IoT researchers will follow, as well as our discussions and the limitations of this study.

## **2. Literature Review**

### **2.1. IoT Business Ecosystem**

The concept of business ecosystem was coined by Moore (1993) as an extension of supply chain perspective to accommodate wider stakeholders. In a business ecosystem, diverse companies co-evolve by sharing and utilizing complementary resources of innovative platform. Generally, a business ecosystem consists of a keystone with core platform and multitude of niche players (Pussinen & Okkonen, 2013). Previous studies on business ecosystem have focused on identifying constructive elements of the ecosystem, how these elements are configured in a network, and the mechanisms taking place in the process of configuration (Rong et al., 2015). Such endeavors are also present in the subject of IoT business ecosystem. Mazhelis et al. (2012) took the first step to define the IoT business ecosystem as “a special type of business ecosystem which is comprised of the community of interacting companies and individuals along with their socio-economic environment, where the companies are competing and cooperating by utilizing a common set of core assets related to the interconnection of the physical world of things with the virtual world of Internet.” (Mazhelis et al., 2012, p. 5) The researchers provided comprehensive list of companies’ roles within IoT ecosystem. These roles can be grouped by IoT’s three technical domains: device, connectivity, and service (Borgia, 2014; Mazhelis et al., 2012). Although other researchers suggested additional roles and actors in follow up studies (e.g., Toivanen et al., 2015), they can be nested in the three core domains. These domains reflect the core process of IoT: connecting physical world of things to the virtual network. Which domain will become the keystone in an IoT business ecosystem is yet to be determined. However, there is a compelling speculation that the network operators (i.e., telecommunication companies) are striving to secure the role of key platform vendor in the ecosystem by being the ‘middle man’ connecting devices and consumers. A network analysis of IoT platform ecosystems found evidence of such trend, while showing that they were in the productization and standardization phase without a clear keystone platform leader (Toivanen et al., 2015). In fact, recent IoT-related initiatives from three major Korean telecommunication companies (i.e., SK Telecom, LG U+, and KT) consolidates such projection. Meanwhile, other players also seem to be seeking opportunities to become the keystone. For instance, IT companies from diverse origin recently started a fierce competition to secure the hub platform of smart home applications. Major IT corporates such as Amazon, Apple, Google, and Microsoft have aggressively entered the IoT business ecosystem through the smart home application domain, and their competition has been on the rise since early 2017 (Weinberger, 2017).

Formation of a healthy ecosystem is critical for industry development especially in such a nascent stage. However, how to determine which ecosystems are healthy has not been thoroughly examined yet. Instead, majority of the business ecosystem researches have so far defined the components (Mazhelis et al., 2012; Rong et al., 2014; Westerlund et al., 2014), or employed network theory to descriptively delineate the ecosystem dynamics (Toivanen et al., 2015). In this study, we intend to propose a framework that could be utilized to evaluate IoT business ecosystems. In the following section, we will build on few prior studies related to business ecosystem evaluation, especially focusing on the concept of business ecosystem health, and derive important criteria that we consider integral to be examined.

### **2.2. Business Ecosystem Evaluation Criteria**

Before earnestly discussing the business ecosystem, it would be meaningful to briefly mention the interfirm network studies. This is not only because the business ecosystem evaluation literature is scant, but for the fact that interfirm network can be considered as a preceding concept to business ecosystem. Prior to the accepted business ecosystem perspective, scholars' focal point was interfirm (or inter-organization) networks which consist of numerous interfirm relationships. Business ecosystem can be understood as a broadened version of interfirm network, in which embraces other industrial sectors or external organizations such as regulatory bodies, research centers, and universities. While pure economic metrics function as an important proxy for interfirm networks' performance measure, it has been addressed that network's structuration process, characteristic of network as a whole, and relational aspects should also be considered when evaluating interfirm networks (Palmatier et al., 2007; Provan et al., 2007; Sydow & Windeler, 1998). In addition to such network-level characteristics, the effect of broader societal, technological, economic, and regulatory context is also pertinent when it comes to understanding complex business ecosystem (Basole et al., 2015). Thus, an appropriate evaluation model for business ecosystem should also take such structural and relational aspects into account. To sum up, the interfirm network studies provide two themes for assessing a network's performance: (1) economic performance, and (2) network-level characteristics. While these themes are important foundations for business ecosystem evaluation, concepts that reflect unique ecosystemic characteristics are needed.

Studies exploring business ecosystem performance or evaluation are scant compared to the literature on interfirm network. One of the widely used approach to visualize and assess business ecosystem is network theory and analysis. For instance, business ecosystem can be assessed by incorporating social network analysis over time. Toivanen et al. (2015)'s comparison of IoT platform ecosystem over the two-year period provides insights of how the ecosystem has changed, from which we can infer the business ecosystem's evolution by growth. However, such network analysis remains in a descriptive level of explanation and relies on network variables, which mainly provides compositional and relational information of the network. More detailed categorization of variables underlying the change is not discussed in depth. On the other hand, a concept suggested by Iansiti & Levien (2004b) seems to provide better potential for understanding business ecosystems' performance or evaluation: the business ecosystem health. Based on ecological analogy, the researchers tried to define and measure the factors that make a healthy business ecosystem. Three aspects were presented: robustness, productivity, and niche creation. To elaborate, a healthy business ecosystem survives various exogenous threats (robustness) while effectively converting its resources to new value (productivity), and achieve meaningful diversity by creating valuable niches (niche creation or innovation) (Iansiti & Richards, 2006). Later, Den Hartigh et al. (2006) proposed alternative health measures from a more managerial point of view; namely partner health, and network health. Meanwhile, Berk et al. (2010) explicated a strategy assessment model for software ecosystem, which extensively elaborates specific roles of the keystone player in the ecosystem that affects the Iansiti & Levien (2004b)'s three health indicators. These ecosystem attributes and the hub's specific actions eventually seem to be related as determiners of the three overarching health indicators (Berk et al., 2010). <Appendix 1> summarizes the evaluation criteria mentioned by previous business ecosystem health studies.

Building on the prior efforts, current study tried to extrapolate common aspects of aforementioned factors to conceptualize an analytic hierarchy process (AHP) model. Although numbers of studies suggested meaningful addition and new evaluation criteria, the initial three factors suggested by Iansiti & Levien (2004a) seem viable umbrella concepts that could accommodate most of the factors proposed by follow-up studies. In

other words, the ecosystem attributes and the hub's specific actions eventually seem to be related as determiners of the three overarching health indicators (Berk et al., 2010). Using the three constructs as founding stones, we extend the depth of those constructs by proposing stability, productivity, and diversity as the three factors consisting the first layer of the AHP model. The significance of a stable platform has been constantly addressed when it comes to forming a successful business ecosystem, especially in IT industry (Zhang & Liang, 2011). For instance, success of Microsoft, Apple, and Google would not have been possible without Windows, iOS, and Android. Furthermore, stable network based on closely knit relationships around the platform is critical for the ecosystem's sustainability. Another important factor to consider should be productivity, how effective and efficient does a business ecosystem yield both financial and synergic outcomes. As we can see from several cases in mobile messenger platforms (e.g., Kakao Talk, Snapchat), platforms without viable business models pose high risk for potential niche players and cannot be considered as a healthy ecosystem. Finally, a business ecosystem's ability to foster value creation should be deemed pivotal for making the ecosystem healthy and sustainable, especially in IT business ecosystems such as software ecosystem (Jansen et al., 2009).

While business ecosystem health measures can be generated from available market data or accepted indicators (Zhang et al., 2017), nascence of the industry and lack of reliable market data prohibits us from conducting such analysis. Thus, current study will focus on suggesting more detailed evaluation criteria germane to IoT context and determining the relative significance of those indicators and assess the current health status of IoT business ecosystem alternatives. Aforementioned three business ecosystem aspects would also be critical for rapid adoption of IoT technologies (Mazhelis et al., 2012). Following section elaborates the three first level factors and proposes sub-criteria nested within each factor.

### **2.2.1. Stability**

The business ecosystem stability extends from the concept of robustness, which refers to the ecosystem's ability to effectively survive from, or make use of exogenous disruptions (Iansiti & Levien, 2004a). Under the broad stability concept, several sub-concepts can be additionally considered to evaluate robustness better in IoT context, namely structural, network, and technological stability.

*Structural Stability* – Structural stability refers to the general component characteristics of a business ecosystem. Emphasis on structural aspects has become more widely accepted as network theory surfaced as one of the major approaches when examining business networks (Provan et al., 2007). In order for an IoT ecosystem to function properly, it needs firms in every required stage of IoT service provision; for instance, key technology firms, data analytics services, platform players, and service providers. Acquiring balanced players in each essential part and sustaining their existence is crucial for stability.

*Network Stability* – As business ecosystems are generally formed in web-like networked structure, the relationships between firms, and component diversity are pivotal (Rong et al., 2015). Promoting network stability is one of the core tasks of the keystones to maintain the ecosystem's innovativeness. They could enhance long-term network stability by building higher reputation, increasing niche's expectations for future benefits from cooperative actions, and promoting relationship multiplexity (i.e., two or more types of relationships occurring simultaneously) (Dhanarai & Parkhe, 2006). The quality of business ecosystem network has also been emphasized by previous business ecosystem health studies, and it is assumed that healthier ecosystem consists of more relationships forming a tight knit structure that is not easily compromised (Den Hartigh et al., 2006; Iansiti & Levien, 2004b).

*Technological Stability* – For maximizing IoT value, interoperability from shared technological standard is commonly suggested as an essential issue (Manyika et al., 2015). Provision of acceptable standard is also closely related to acquiring internal and external legitimacy from the market, which is crucial to a business network's sustainability especially in its early stage of evolution (Provan et al., 2007). To certain extent, technological stability can be closely related to the business ecosystem networks to develop diversely (Berk et al., 2010), while promoting long-term network stability (Dhanarai & Parkhe, 2006). Furthermore, clear technological infrastructure and guideline is also deemed critical for kick-starting wider adoption of IoT (Dutton, 2014; Leminen et al., 2012). Recent efforts from prominent ICT firms to acquire the prime position as global IoT platform reflects aforementioned notions. Therefore, offering stable technological platforms with high level of compatibility and jointability should be taken into account when assessing the health of an IoT business ecosystem (Li et al., 2013).

### **2.2.2. Productivity**

Iansiti & Levien (2004a) defined the productivity of a business ecosystem as “effectiveness of an ecosystem in converting the raw materials of innovation into lowered costs and new products and functions”. In addition to stability, the financial productivity should also be considered since the ultimate goal of business ecosystem as a part of an industry is to maximize profit. Albeit the convenience of using monetary performance as a proxy, additional concept of productivity germane to value creation is also pivotal (Den Hartigh et al., 2006; Iansiti & Levien, 2004a). To accommodate this aspect, current study suggests ‘value productivity’ as a subcategory. This concept is assumed to be more important when it comes to IoT business ecosystem in such a nascent stage, where numerous startups are more prevalent than conspicuously large firms.

*Financial Productivity* – Financial productivity reflects the overall financial competencies of the ecosystem constituents. Monetary performance has been considered as one of the simplest and effective proxy reflecting the performance of interfirm network (Palmatier et al., 2007; Sydow & Windeler, 1998). Furthermore, financial measures (e.g., labor productivity, total factor productivity) have been commonly used as useful indices to fathom the overall productivity of IT ecosystem (Iansiti & Richards, 2006). Acquiring sound financial capabilities is also important for a business ecosystem since it could increase investments in research and development, which could initiate innovations.

*Value Productivity* – Despite the essentiality of financial productivity, it is not enough to fully reflect the characteristics of business ecosystem. The interorganizational relationship performance studies have typically examined cooperation and conflict (relational performance) hand-in-hand with moderating effect of environmental uncertainty (e.g., market diversity) to accommodate contextual effect (Palmatier et al., 2007). In the context of business ecosystem, this relational performance is commonly conceptualized as the ‘coopetition’ between the firms (Basole et al., 2015). The synergetic values of the ecosystem participants makes the ecosystem self-sustainable in a most ideal case (Li et al., 2013). Moreover, there are often participants other than private companies such as universities, research centers, or public-sector organizations included in the ecosystem. Forming complex relationships by self-organization process, the consisting entities of a business ecosystem creates synergetic values (e.g., innovation, entrepreneurship), which makes it self-sustainable in a most ideal case (Li et al., 2013; Peltoniemi & Vuori, 2004). Thus, an ecosystem is more than a mere addition of constituents, rather it is a whole network creating additional value as an independent unit (Peltoniemi, 2005; Provan et al.,

2007). Thus, to which extent does a business ecosystem is perceived to be capable of creating meaningful value other than financial profit should be considered when assessing the ecosystem health.

### **2.2.3. Diversity**

Diversity aspect was conceptualized as ‘niche creation’ in the business ecosystem health (Iansiti & Levien, 2004a). However, the term is less intuitive and potentially ambiguous. Thus, current study suggests ‘diversity’ as a more appropriate concept. From a business perspective, the concept of diversity indicates an ecosystem’s potential for productive innovation (Iansiti & Levien, 2004b). Firstly, the innovation could be technology-oriented. However, more technologies do not promise more value. Only technologies with viable business model and services reaching end-users can generate value. Therefore, we suggest ‘service diversity’ as a subcategory.

*Technological Diversity* – An IoT ecosystem’s ability to innovate is related to the technological capability. In fact, number of newly adopted technologies has been suggested as an index to measure niche creation ability of a business ecosystem (Iansiti & Levien, 2004b; Li et al., 2013). To elaborate, an ecosystem with RFID, WSN, and bio-sensor would potentially create more innovative niche than those who only have RFID. Thus, it could be said that healthier ecosystems are those capable of more technological solutions and those who have faster technology adoption rate.

*Service Diversity* – Besides technological diversity, the locus of higher value creation is in the service level rather than technological infrastructure. As mentioned above, simply having wide library of available technology does not guarantee diversity of service. Business ecosystems that offer wide array of services with innovative business models from limited technological variety should be considered just as healthy. In fact, the ability to create value with viable business models is considered one of the major challenges for IoT’s wide dissemination (Manyika et al., 2015; Westerlund et al., 2014). Therefore, an ecosystem’s diversity of service, which partially indicates the level of innovation of the ecosystem, should be an integral factor representing its healthiness.

## **3. Methodology**

### **3.1. Korean IoT Business Ecosystem Alternatives**

The current study suggests three Korean IoT business ecosystem alternatives for the AHP model. Despite its immaturity, several meaningful Korean IoT ecosystem building initiatives by major firms are surfacing. For instance, prominent telecommunication companies, device manufacturers, and Internet service providers are actively engaged in the IoT platform competition.

Given the abundance of the cases, it is integral that we choose valuable cases. Two possible schemes were: (1) evaluating different business ecosystems from the same industrial background; (2) evaluating business ecosystems from different industrial origins. Although both are valuable comparisons, evaluating IoT ecosystems from a certain industry could yield more homogeneous assessment due to the firms’ similar sets of resources, which might also lead to similar strategic approaches towards IoT ecosystem building. Thus, the current study selected IoT business ecosystem alternatives based on the latter scheme. In specific, we selected ecosystem building efforts from three core aspects of IoT service: device, connectivity, and service (Mazhelis et al., 2012). Three representative firms from each dimension were selected; Samsung (‘ARTIK’), SK Telecom



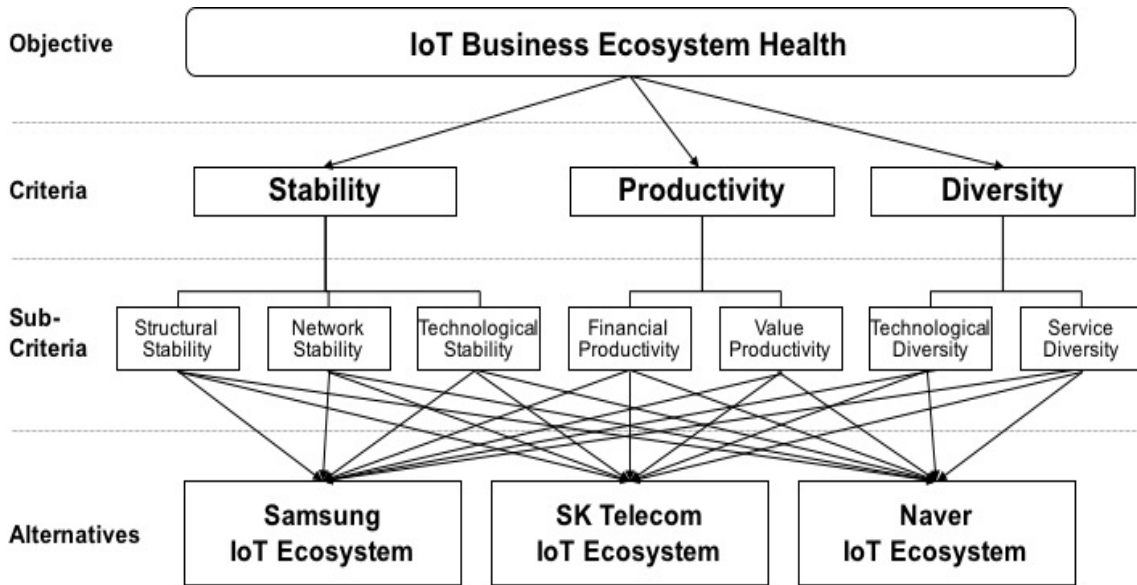
(‘ThingPlug’), and Naver. Explicitly declaring specific company names could cause biased responses. Nevertheless, not only does such aspects of keystone firms play a significant role in overall ecosystem’s value, but the specificity could enhance the respondents’ general understanding of IoT business ecosystem in such an early stage. Moreover, identifying representative companies’ efforts could draw more accurate map of current Korean IoT industry and let us yield more practical implications.

### **3.2. AHP Method**

First proposed by T. L. Saaty, the analytic hierarchy process (AHP) is a widely used theoretical modeling technique for complex decision making process (Saaty, 1990). Generally, the researcher sets the decision objective and underlying categories that affects the decision in a hierarchical tree. Consequently, numerical data is collected through expert survey, which is compared pairwise for AHP weight score calculation. While AHP is a useful methods for the decision makers in the real world problems, researchers have also utilized for conceptualizing decision models and gauging relative importance of the factors affecting the decision goal in question. (Saaty, 1990; Yang et al., 2007) The method has also recently been adopted in several business ecosystem health studies for analyzing the weights of the health evaluation criteria (Li et al., 2013; Zhang et al., 2017).

The goal of the current AHP model is preliminary evaluation of the healthiness of IoT business ecosystems. The categories for IoT business ecosystem health evaluation were laid out into two layers. The first layer consists of three major aspects for ecosystem health; namely, stability, productivity, and diversity. The second layer comprises total of seven subcategories: structural stability, network stability, technological stability, financial productivity, value productivity, technological diversity, and service diversity. In the third layer, the three aforementioned alternatives exist for evaluation; namely, Samsung, SK Telecom, and Naver. <Figure 1> visualizes the hierarchical AHP model.

For data collection, this study conducted an expert survey. To elaborate, survey participants are asked to compare each factor from the same hierarchical level and numerically indicate the relative importance between the factors that are being compared. Pairwise comparison matrixes for each level, which consists of the importance ratings and their reciprocals, are constructed to calculate priority vector for each factor. As a result, the AHP analysis will provide relative weights for each criterion. AHP has been utilized to explore the potential killer application for IoT (Kim & Kim, 2016), and was also found useful for developing a health evaluation model for business ecosystem (Li et al., 2013).



**Figure 1.** AHP model for IoT business ecosystem health assessment

### 3.3. Data Collection

The survey questionnaire consisted of two parts: (1) pairwise comparisons of health factors, and (2) pairwise comparisons of alternatives. The respondents numerically indicated the relevant importance on the 9 point comparison scale, which is the most commonly used scale (Kim & Kim, 2016; Saaty, 1990, 2008).

Due to the fact that our alternatives include specific names of private companies (i.e., Samsung or Naver), the sample could not embrace practitioners from the industry for potential bias. Assuming that scholarly experts would possess the most objective stance to the subject, the present study limited the scope of the sample to academia. In specific, researchers who have been studying and interested in the emerging IoT industry were selected. The sample consists of 51 participants who have been conducting academic researches on IoT related convergence at three nationally funded research teams; namely two Communication Policy Research Center (CPRC) teams, and Social Science Korea (SSK) research team. 12 among them are full time professors in major universities in Korea, and others are graduate students. The questionnaire was distributed in the form of an online questionnaire and a word document from June 1<sup>st</sup> to June 29<sup>th</sup>, 2016. General demographics of the sample is delineated in the <Table 2>.

**Table 1.** Respondents' demographic and background information as experts (N = 51)

Measures	Frequency	Measures	Frequency
<i>Gender</i>		<i>Major (graduate level)</i>	
Male	33	Media / Mass Communication	10
Female	18	Law	4
<i>Age</i>		Engineering / Computer Science	10
20 ~ 29	28	Business / Management	14
30 ~ 39	12	Economics	1

40 ~ 49	6	Policy	2
50 ~ 59	4	Information Security	8
More than 60	1	Sociology	2
<i>Education (final degree)</i>		<i>Field of interest (related to IoT)</i>	
Bachelor	16	Policy	17
Master	16	Social Issues	8
Doctor	19	B2C Service	11
<i>Experience</i>		B2B Service	0
Less than 1 year	12	B2G Service	3
1 ~ 2 years	12	Technical Solutions	12
2 ~ 3 years	5		
3 ~ 4 years	3		
4 ~ 5 years	3		
More than 5 years	16		

### 3.4. Data Analysis

For data analysis, MATLAB, a technical computing language software, was used. The code used for computation was borrowed from Kim & Nam (2014), where the researchers analyzed news publishers' contribution to the inflow of web portal site visitors via AHP method. Specifically, the MATLAB code (1) calculates CI (consistency index), (2) calculates CR (consistency ratio), (3) choose eligible cases (CR above 0.2), and (4) calculates final AHP weight scores.

During the analysis, 30 answers out of 51 were valid in terms of composite CR. When put into a more rigorous threshold, 0.1, only 12 answers were useful. Although 0.1 is considered as a given standard for CR score, there are also arguments where those with 0.2 or less could also be tolerable in social science since its ambiguity of constructs could compromise the consistency of the responses (Kim & Kim, 2016; Yang et al., 2007).

## 4. Results

### 4.1. Criteria Weights

First, local weight scores for the first and second layer of the AHP model were calculated. Consequently, global weight scores were yielded by multiplying the first layer weights and the second layer weight scores. All local and global weight scores for the evaluation criteria and the rankings are provided in the <Table 3>.

The results indicated that stability (.358) was the most important evaluation factor for IoT business ecosystem health. Productivity followed stability with the weight score of .332, and diversity (.310) came the last.

**Table 2.** AHP criteria weights and ranks

Criteria (1 <sup>st</sup> layer)	Weight ( $W_C$ )	Sub-Criteria (2 <sup>nd</sup> layer)	Local Score ( $W_L$ )	Global Weight ( $W_C * W_L$ )	Rank
Stability	<b>.358</b>	Structural Stability	.327	<b>.117</b>	5
		Network Stability	.301	<b>.108</b>	6
		Technological Stability	.372	<b>.133</b>	3
Productivity	<b>.332</b>	Financial Productivity	.236	<b>.078</b>	7
		Value Productivity	.764	<b>.254</b>	1
Diversity	<b>.310</b>	Technological Diversity	.396	<b>.123</b>	4
		Service Diversity	.604	<b>.187</b>	2

Concerning the sub-criteria under the umbrella of stability criterion, the local score of technological stability (.372) was found to be the highest. Structural stability (.327) followed next, and network stability (.301) came last with marginal difference. Under the productivity criterion, value productivity (.764) was considered far more important than financial productivity (.236) when evaluating IoT business ecosystem's health. In terms of diversity, service diversity (.604) significantly outweighed technological diversity (.396).

The global weight scores show the ultimate relative importance weights of the seven criteria. The final results indicated that the most influential criterion for IoT business ecosystem health is its value productivity (.254). Although stability as a whole was the most important factor in the first layer, service diversity (.187) came second place in the ultimate weight score ranking. Such findings imply that ecosystem's ability to promote innovation and create value is the foremost requirement for becoming a healthy ecosystem.

Technological stability (.133) ranked third, followed by technological diversity (.123). The relative status of technological criteria represents that the technological aspects are still important factors for retaining ecosystem health. Meanwhile, the network characteristics of IoT business ecosystem obtained relatively low gross weight ranking. Specifically, structural stability (.117) and network stability (.108) ranked fifth and sixth among the seven factors. Surprisingly, financial productivity (.078) was found to be the least important factor. This is a striking results considering that financial performance has been accepted as the proxy for ecosystem's productivity when measuring its health (Iansiti & Levien, 2004b; Zhang & Liang, 2011).

#### 4.2. Alternative Priority

The priority among the alternatives is computed by using the global criteria weights ( $W_C$ ) of each factor obtained from above and the three alternatives' local weight scores ( $W_L$ ) for seven sub-criteria. Eventually, the sum of the product index becomes the final weight of an alternative.

The local scores for each alternative's healthiness in terms of the seven evaluation factors are presented in <Table 4>.

**Table 3.** AHP alternatives' local scores and ranks

Criteria		Samsung IoT Ecosystem		SK Telecom IoT Ecosystem		Naver IoT Ecosystem	
		Local Score ( $W_L$ )	Rank	Local Score ( $W_L$ )	Rank	Local Score ( $W_L$ )	Rank
		Stability	SS	.374	4	<b>.385</b>	1
	NS	.210	6	.374	2	<b>.415</b>	3
	TS	<b>.583</b>	1	.240	7	.177	7
Productivity	FP	<b>.419</b>	2	.261	6	.320	5
	VP	.225	5	.325	4	<b>.450</b>	2
Diversity	TD	<b>.377</b>	3	.284	5	.340	4
	SD	.186	7	.326	3	<b>.488</b>	1

*Note:* SS (structural stability), NS (network stability), TS (technological stability), FP (financial productivity), VP (value productivity), TD (technological diversity), SD (service diversity); Boldfaced elements indicate the highest local score within each criteria (i.e., row)

When we look at the local weight scores for each alternative Korean IoT ecosystem, Samsung's IoT ecosystem was found prominent in technological stability (.583), technological diversity (.377), and financial productivity (.419). However, this could be compromised by its lack of service diversity (.186), network stability (.210) or value productivity (.225). Overall, Samsung's ecosystem had significant advantages in terms of technological aspects and financial capability, but was not perceived to be innovative in terms of service innovation.

On the other hand, some of the most important factors affecting SK Telecom's IoT ecosystem's health were its structural stability (.385), network stability (.374), and service diversity (.326). Meanwhile, the Korean telecom giant did not show noticeable edge in technology and financial performances considering the low local weight scores in technological stability (.240), financial productivity (.261), and technological diversity (.284).

Naver's IoT ecosystem showed high local scores in service diversity (.488), value productivity (.450), and network stability (.415). Such results seem to stem from Naver's wide user base and their diverse service portfolio. Similar to SK Telecom, Naver did not show advantages in technological aspects, scoring only .177 and .340 for technological stability and technological diversity, respectively. In addition, Naver's local weight score for structural stability (.241) was significantly lower than other two alternatives. This can be explained by Naver's relative lack of explicit connections with IoT related firms. The portal company is currently recruiting promising partners to outline its plan for ecosystem development; thus, this score could change in the future.

In order to determine each ecosystem's health scores with consideration of the first and second criteria layers of the AHP model, global weight scores were calculated and summed up to yield single health proxy for each alternative (<Table 5>).

The results showed that the healthiest IoT business ecosystem in Korea is Naver's ecosystem, scoring total weight score of .369. The second healthiest IoT ecosystem in the Korean market was SK Telecom's (.316).

Samsung's IoT ecosystem (.315) was the least healthy ecosystem. However, the numerical difference between the latter two was almost negligible.

Albeit its strong local scores in the technological stability and diversity, evaluation on Samsung's service diversity and value productivity were significantly lower than the other two. Meanwhile, Naver and SK Telecom's high scores were due to their relative strength in non-technological aspects such as value productivity, service diversity, or network stability rather than technological edges.

**Table 4.** Alternatives' priority ranks due to criteria weights

Criteria	Criteria Weight ( $W_C$ )	Samsung IoT Ecosystem		SK Telecom IoT Ecosystem		Naver IoT Ecosystem	
		Global Weight ( $W_C * W_L$ )	Rank	Global Weight ( $W_C * W_L$ )	Rank	Global Weight ( $W_C * W_L$ )	Rank
		Stability	SS	.117	4	.045	3
	NS	.108	7	.040	4	.045	3
	TS	.133	1	.032	6	.023	7
Productivity	FP	.078	6	.020	7	.025	6
	VP	.254	2	.082	1	.114	1
Diversity	TD	.123	3	.035	5	.042	4
	SD	.187	5	.061	2	.091	2
Total Weight [ $\sum(W_C * W_L)$ ]		<b>.315</b>		<b>.316</b>		<b>.369</b>	
Alternative Ranking		<b>3</b>		<b>2</b>		<b>1</b>	

Note: Criteria weight ( $W_C$ ) refers to the global weights in <Table 3>

Specifically, the two criteria with highest criteria scores were identical to Naver and SK Telecom's ecosystem's two highest local scores; namely, value productivity, and service diversity. Value productivity was also ranked second within Samsung ecosystem's weight scores of evaluation criteria. Such results betray the significance of creating and capturing viable values in the context of IoT.

The criteria that took the least share in the total health evaluation weight score of Samsung's ecosystem were network stability (.023), financial productivity (.033), and service diversity (.035). For SK Telecom's IoT ecosystem, financial productivity (.020), technological stability (.032), and technological diversity (.035) gave marginal contribution to its general health. Similarly, some of the lowest criteria scores of Naver ecosystem are technological stability (.023), financial productivity (.025), and structural stability (.028). Generally, the latter two IoT ecosystems' local weight scores and criteria weight scores were proportional. In other words, the SK Telecom and Naver's IoT ecosystem scored high local weights in the criteria that showed high criteria weights.

On the other hand, Samsung showed high local scores in the criteria with low criteria weights, causing Samsung's lowest overall health score. The AHP model with the weight scores is depicted in the <Figure 3>.

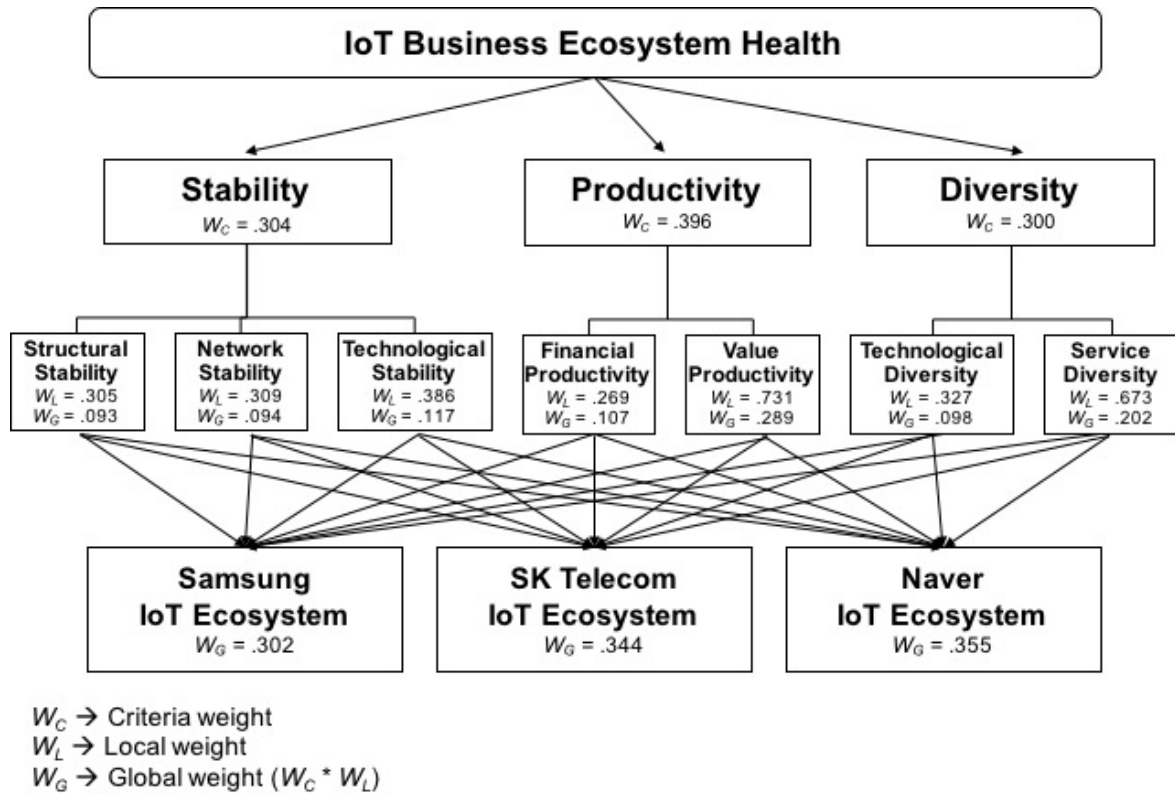


Figure 2. AHP decision model with weight scores

### 4.3. Discussions

According to the AHP analysis, the Korean IoT scholars, although limited, considered stability, productivity, and diversity as almost equivalently important when assessing IoT business ecosystem's health. Nonetheless, stability was found the most important factor among the three criteria with marginal difference. It was surprising that the network stability is perceived not as pivotal as technological stability. This could be explained by relative emphasis on the openness of the platforms and ease of relationship building between partner firms in the IoT context. On the other hand, solid technological foundation of the platform should be pivotal since it should guarantee compatibility and interoperability.

Besides stability, productivity was found slightly more important than diversity when evaluating IoT business ecosystem's health. Particularly, value productivity significantly outweighed financial productivity of the ecosystem, showing weight score of more than double. As the IoT industry is still in its nascent stage, there are lots of uncertainties concerning the concrete blueprint of values that IoT service and infrastructure could deliver. Moreover, as firms from diverse industries tend to converge in the IoT business ecosystem, clear evidence of their ability to create value could be more critical than mere financial outcomes.

Despite the low criteria weight in the first layer of the model, the importance of IoT business ecosystem's diversity was evident in the sub-criteria section. In particular, service diversity was found crucial aspect, scoring

second highest weight score among the seven. Such result is in line with the high score of value productivity. In a nutshell, the most critical element for an IoT business ecosystem to be healthy should be its ability to produce meaningful values and successfully converting them into innovative services. This is also consistent with the argument regarding the need for constant business model development and renovation in the IoT era (Dutton, 2014; Westerlund et al., 2014).

Nevertheless, the technological infrastructure should not be degraded. Technological stability and diversity closely follow the importance of the value or service aspects. Currently, there are neither *de jure* nor *de facto* technological standard for IoT services. Two of the proposed alternatives in this study are putting effort to establish their platform's status as the *de facto* standard in the market. Such uncertainty in the industry's early development could have inflated the significance of the technology in IoT business ecosystem health. Although technological aspects' importance may decrease as they become more taken for granted, currently it definitely is crucial factor for IoT ecosystem health evaluation.

The assessment of Korea alternatives showed Naver's ecosystem as the healthiest IoT business ecosystem. Naver's ecosystem showed prominent local weight scores for service diversity, value productivity, and network stability. Although the local scores for other criteria were not significantly larger than other two alternatives, the portal giant showed highest global weight after taking criteria weights into account. The advantages in the service aspect might come from its recent expansion in service portfolio. To elaborate, the online portal site's endeavors on promoting payment solution 'Naver Pay' and navigation service reflect the firm's intention to become a comprehensive service platform.

Meanwhile, SK Telecom's ecosystem showed the most evenly distributed scores, and had slight advantages in structural and network stabilities. This seems to reflect the fact that SK Telecom is a telecommunication company providing connectivity, which is essential to any IoT service provision. On the other hand, Samsung resulted in the lowest health rating among the three, despite its distinguishable local weights in technological stability, technological diversity, and financial productivity. This is due to its significantly low ability of service diversification and value production. It seems that Samsung's prolonged inability to deliver viable service or software as a technology-oriented firm is affecting the ecosystem health evaluation.

Looking at the results, notable implications can be also discussed concerning the alternatives' industrial origin. According to the current analysis, Internet service providers, although being late starters, have considerable potential of becoming keystone ecosystem organizer in IoT industry. This seems to stem from their perceived advantage in value producing ability and service diversity. Telecommunication firms also are highly likely to become a major platform provider. Based on their inherent roles of connecting diverse actors of IoT ecosystem, connectivity-oriented companies have well-balanced capabilities of forming healthy ecosystem. On the other hand, technology-oriented device makers are expected to face major challenges regarding their ability to create additional values and services despite their evident technological superiority. Without significant investments in advancing value production, technology-oriented platform providers will face hard time nurturing a healthy IoT ecosystem.

## **5. Conclusions & Implications**



This study intended to build IoT business ecosystem health evaluation model by utilizing AHP model. Based on the previous literatures, the current study proposed stability, productivity, and diversity as the first layer criteria for ecosystem health evaluation model. Under the umbrella of the three concepts, total of seven sub-criteria were suggested: structural stability, network stability, technological stability, financial productivity, value productivity, technological diversity, and service diversity. Three Korean IoT business ecosystems were selected as the alternatives: Samsung, SK Telecom, and Naver's IoT ecosystems. An expert survey on 51 Korean scholars was conducted to collect input data for AHP analysis. The results indicated that value productivity and service diversity were the prominently important factors when evaluating IoT business ecosystem's health. Taking the pairwise comparison of the alternatives and the individual weights of each criteria into consideration, Naver's IoT ecosystem, although it is not yet fully realized, was the healthiest ecosystem alternative. SK Telecom and Samsung's ecosystems ranked second and third.

### **5.1. Theoretical implications**

The current study poses several theoretical implications to the business ecosystem and IoT literatures. As discussed earlier, studies concerning IoT remained highly conceptual or technical. This study will contribute to the IoT literature for being based on an empirical data, albeit limited, with viable analytical framework of AHP.

Furthermore, the literature regarding evaluation of the business ecosystem have been limited to few studies. After the introduction of the concept by Iansiti & Levien (2004a), several researchers have endeavored to develop the model by either elaborating its measurement models (Den Hartigh et al., 2006), or reconstructing the health attributes (Li et al., 2013). In addition to the fact that this study is the first attempt to assess the business ecosystem health of IoT industry in particular, we intended to fill in some untouched parts of the prior researches. To elaborate, the former study by Den Hartigh et al. (2006) proposed more simplified model and measurement for ecosystem health evaluation with industry data from Dutch IT industry, however it did not specify relative importance between the evaluation factors. On the other hand, the latter study by Li et al. (2013) analyzed the relative significance, however the model was overly complex and did not conduct in depth evaluation of alternatives. The current study contributed by filling in such gaps by proposing relatively simple hierarchical framework, calculating relative importance via AHP analysis, and evaluating cases of Korean IoT ecosystems.

### **5.2. Practical implications**

The results of the current study also present several practical implications. As constantly delineated in the previous sections, the foremost task for IoT ecosystem builders should be acquiring value productivity via developing IoT business model and diversifying service. This is due to the global weight scores for the value productivity and service diversity factors, which were significantly higher than other criteria. Such results are consistent with other IoT literatures addressing the importance of business model development and value realization (Dutton, 2014; Kim & Kim, 2016).

Among the three alternatives, only SK Telecom's 'ThingPlug' platform explicitly mentions the values delivered to the participating partners; 'MOCA (Monitor, Optimize, Control, Automation)'. In addition to the platform's proposed values, actual value to the end-users is delivered through individual services. Therefore, it is integral for platform providers to educate partners with appropriate ways to maximize the platform's capabilities. A good example from the selected alternatives would be Samsung's 'Certified ARTIK Partner

Program (CAPP)'. Moreover, constant investments to the partners' innovative ideas or developer conferences could maximize not only the ecosystem's stability but also the value productivity from intercommunication between partners. The epitome for such an endeavor would be Google's I/O; an annual developer-focused conference introducing Google's platform, software development kit (SDK), etc.

The technological aspects were found slightly less important than the value attributes. However, their significance should not be overlooked. Especially, in such an early development stage, acquiring market status of *de facto* technological standard could dramatically influence the future of the industry. While maintaining technological development efforts, companies should prepare their capabilities regarding service innovation since technological aspects would eventually become obsolete as it was the case for most of the IT devices.

Although the three alternatives were considered independent ecosystems in this study, significant overlap or interrelationship among them is plausible. Such scenario seems even more preferable looking at the local weight scores of the three alternatives. To elaborate, Naver's lack of technological advantages can be complemented by Samsung's technological edges, vice versa. In order to achieve such cooperative synergy, firms should actively cooperate and perceive each other as advantageous partners rather than competitors in the converging IoT market. In particular, niche players should constantly endeavor to develop novel business models uniquely applicable in IoT context since most of the ecosystem's value production and service diversity are generated by these innovative niche players. Meanwhile, keystone leaders of the ecosystem should provide effective environment where niche players can maximize their value creation. For instance, technology-oriented keystone players can focus on forming active community around their platform to boost value production rather than focusing on maximizing the sales of the device platform. Leading connectivity firms' IoT ecosystem could constantly improve their capability and efficiency in terms of data transmission, while also investing on technological aspects. Internet service companies can take advantage of their already existing edge on service diversity and value production, while reinforcing the technological capabilities via either cooperating with prominent tech firms or investing on in-house hardware development. The aforementioned tasks for the three major potential leaders of IoT ecosystem can be achieved by either cooperation or individual efforts. Although there is no single answer, it would be better for them to lean towards active cooperation. The cooperation between the three core sectors can complement each other's weaknesses; thus forming a healthier IoT industry. Moreover, cooperation will result in higher compatibility and interoperability between diverse IoT services, which could maximize customers' value indeed.

## **6. Limitation & Future Research**

This study is not without limitations. Firstly, the size of the sample and its level of expertise can be improved in the future studies. Qualitatively, the sample could be expanded to more experienced scholars or those from international university or institutes. Another potential drawback is the alternative IoT ecosystems' scope and different level of development. Not only did we limit the alternative cases within Korea, Naver's IoT ecosystem is relatively less defined than others. If the alternatives had similar level of development, the final weight scores would have been more robust. Moreover, explicitly mentioning the corporate names could have affected the survey respondents' answers. For instance, it is possible that the respondents evaluated the 'firm' and its reputations rather than its 'IoT business ecosystems'. Nonetheless, the fact that Naver scored the highest score

despite its low development status gives important implication. Moreover, some methodological limitation also exists. For instance, AHP model's weights are not definitive. Thus, it should be noted that the results are subject to change according to sample characteristics or market dynamics.

Taking these limitations into account, numbers of important aspects can be improved by future researches. To start with, the current study did not go as far to collect industry data for the limited availability. Numbers of previous business ecosystem health studies incorporated both AHP weight analysis and consecutive data collection that could represent the AHP criteria (Iansiti & Richards, 2006; Li et al., 2013; Zhang et al., 2017). While several industry indices on the IT sector such as S&P North American Technology Sector Index or productivity index can be used, it is hard to argue that the indices accurately represent the IoT business ecosystem. Narrowing down the scope resulted in harsh dearth of appropriate data. It is expected the data availability might increase as the IoT ecosystems grow, which will call for follow studies implementing the data set. Secondly, studies seeking potential causal relationships between the health factors are possible (e.g., Can service diversity be acquired by improving technological diversity or stability?). Finally, researchers could also put effort to figure out relative importance of the sections of IoT service provision (i.e., device, connectivity, and service). Pursuing such inquiry could potentially affect some of the critical tasks for future IoT industry building such as revenue sharing scheme. While technological standard and platform is integral, eventually the battlefield for IoT companies will be the general consumer market, where technological platform is likely mean much less than service platform. We've witnessed this throughout the development of IT industry after Internet (e.g., Google, and the resurrection of Apple after iPhone with App Store, etc.). In this sense, it should be noted that some of major international IT conglomerates such as Apple, Google, or Amazon weren't considered in the current study, and still needs closer examination.

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## Appendix

### Appendix 1. Business ecosystem evaluation criteria from previous literatures

Evaluation Criteria	Description	Factors/Measures	References
<b>Robustness (Stability)</b>	How an ecosystem can effectively survive from, or make use of disruptions from outside	<ul style="list-style-type: none"> <li>• Survival rates</li> <li>• Persistence of ecosystem structure</li> <li>• Predictability</li> <li>• Limited obsolescence</li> <li>• Continuity of use experience and use cases</li> </ul>	<ul style="list-style-type: none"> <li>• Iansiti &amp; Levien (2004a)</li> <li>• Mazhelis et al. (2012) - 'Stability'</li> <li>• Berk et al. (2010)</li> </ul>
<b>Productivity</b>	Effectiveness of an ecosystem in converting the raw materials of innovation into lowered costs and new products and functions	<ul style="list-style-type: none"> <li>• Total factor productivity</li> <li>• Productivity improvement over time</li> <li>• Delivery of innovations</li> </ul>	<ul style="list-style-type: none"> <li>• Iansiti &amp; Levien (2004a)</li> <li>• Mazhelis et al. (2012) - 'Productivity'</li> <li>• Berk et al. (2010)</li> </ul>
<b>Niche creation (Diversity)</b>	Capacity to increase meaningful diversity over time through the creation of new valuable functions: the capacity to create new valuable niches	<ul style="list-style-type: none"> <li>• Variety</li> <li>• Value creation</li> </ul>	<ul style="list-style-type: none"> <li>• Iansiti &amp; Levien (2004a)</li> <li>• Mazhelis et al. (2012) - 'Diversity'</li> <li>• Berk et al. (2010)</li> </ul>
<b>Partner health</b>	Long-term financially-based representation of a partner's strength of management and of its competencies to exploit opportunities that arise within the ecosystem	<ul style="list-style-type: none"> <li>• Solvency index</li> <li>• Liquidity</li> <li>• Total asset growth</li> <li>• Working capital over total assets</li> <li>• Retained earnings over total assets</li> <li>• EBIT over total assets</li> <li>• Company revenue over total assets</li> </ul>	<ul style="list-style-type: none"> <li>• Den Hartigh et al. (2006)</li> </ul>
<b>Network health</b>	Representation of how well a partner is embedded in the ecosystem as well as the impact the partner has in its local network	<ul style="list-style-type: none"> <li>• Number of partnerships</li> <li>• Visibility in the market</li> <li>• Covariance of partner variety with the market</li> </ul>	<ul style="list-style-type: none"> <li>• Den Hartigh et al. (2006)</li> </ul>

<b>Ecological attributes</b>	Based on ecology and complex system adaptive theories	<ul style="list-style-type: none"> <li>• Emergence</li> <li>• Synergetic evolution</li> <li>• Self-organization</li> <li>• Adaptability</li> </ul>	• Li et al. (2013)
<b>Structure attributes</b>	Components of business ecosystem	<ul style="list-style-type: none"> <li>• Basic enterprises</li> <li>• Expanded enterprises</li> <li>• Supporting mechanism</li> <li>• Complementary mechanism</li> <li>• Correlative environment</li> </ul>	• Li et al. (2013)
<b>Functional attributes</b>	Creating a value-sharing platform which produces strong financial performance; reinforces its foundation and increases profitability with productivity, vitality and creativity as its measure	<ul style="list-style-type: none"> <li>• Productivity</li> <li>• Vitality</li> <li>• Creativity</li> </ul>	• Li et al. (2013)
<b>Operation attributes</b>	Function node in which the system develops and realizes its functions through reasonable operations	<ul style="list-style-type: none"> <li>• Strategic clarity</li> <li>• Platform compatibility</li> <li>• Platform jointability</li> <li>• Contract stability</li> <li>• Conflict coordination</li> </ul>	• Li et al. (2013)
<b>Lifecycle attributes</b>	Four phases of lifecycle development	<ul style="list-style-type: none"> <li>• Exploiting phase</li> <li>• Expanding phase</li> <li>• Authority phase</li> <li>• Rallying phase</li> <li>• National economy and technical level current phase of business ecosystem</li> </ul>	• Li et al. (2013)