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Designing for the Internet of Things: a critical interrogation of IoT processes and principles

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Abstract: With the emergence of Internet of Things (IoT) as a new source of ‘big data’, businesses face new opportunities as well as emergent challenges. However, although academics and practitioners often critically debate the IoT, little attention has been focused on the design and development of IoT. Re-framing of New Product Development (NPD) for IoT is compulsory as the integration of software in physical products is radically challenging the innovation processes and practices. Thus, the aim of this paper is to contribute to a comprehensive understanding of IoT NPD. Based on a featured case study, a new approach towards IoT design and development process and their relevance against the characteristics of existing NPD processes are reviewed and critically debated. This paper summarizes how NPD processes and value creation could be improved and proposes guidelines with the conceptual framework for IoT NPD processes.

Keywords: digital innovation; internet of things; design process; development risk management

1. Introduction

Gartner (2014) forecasted noteworthy growth in the number of connected devices and areas of application. Cisco (Evans, 2011) estimated that by 2020, 50 billion devices around the world will be connected to the Internet. IoT is “a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols” (Vermesan et al., 2011). Amalgamating sensors, radiofrequency identification (RFID) tags, and cloud computing with non-digital products and services possibly gives products and services new properties (Yoo, Lyytinen, Boland, & Berente, 2010) and create vital opportunities for new innovation (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Radziwon, Bilberg, Bogers, & Madsen, 2014; Xu, 2012; Yoo, 2013). In this regard, it is estimated that the total global impact of IoT technologies could generate anywhere from \$ 2.7 trillion to \$ 14.4 trillion in value by 2025 (Cisco, 2013; McKinsey, 2013).

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With the emergence of Internet of Things as a new source of 'big data', businesses face new opportunities as well as new challenges (Porter & Heppelmann, 2014). The IoT remains a fertile field for commercial enterprises and so that one in every six businesses is planning to roll out an IoT-based product (Burkitt, 2014). These pervasive adoptions of digital technologies are radically changing the nature of products and services that affect not only how organisations develop new products and services (Yoo, Boland, Lyytinen, & Majchrzak, 2012) but also how they create meaningful value (Hui, 2014). It also opens new opportunities in terms of how organisations increase turnover. Consequently, the 'Internet of Things' (IoT) is becoming a popular theme of exploration amongst academics and industry practitioners, i.e. a new technological orientated paradigm regarded as a vision of connectivity, for anything, at anytime and anywhere, with an impact on everyday life more dramatic than the Internet had in the past twenty years (ITU, 2005).

However, although academics and practitioners often critically debate these emergent opportunities and challenges to the adoption of the IoT, little attention has been focused on the new product development (NPD) process of IoT; arguably one of the most critical marketing planning and implementation process activities undertaken within the organisation (Lee, Cooper, & Hands, 2018). Recent researchers claim how the unique properties of digital technology enable new kinds of innovation processes that are evidently distinctive from the innovation processes in 20th century (Henfridsson, Mathiassen, & Svahn, 2014; Yoo et al., 2012). However, there is a paucity of established academic theories and industry practices to support and re-think traditional processes of product design and development activities to meet current needs and potential commercial opportunities in the era of IoT and digital economy. Scholars from marketing and design argue that it is time to reframe traditional processes of product design and development to satisfy current needs and potential commercial opportunities in the era of IoT (Ng & Wakenshaw, 2017; Speed & Maxwell, 2015).

1.1 Research Aims

This paper offers initial results of current doctoral research, based on a comprehensive literature review, exploratory interviews, and case study in order to identify and debate how contemporary design and development process can be revised to embrace new market opportunities. It concludes by offering key insights and observations as to how design and development process for IoT products and services are reframed, which could then enable academics and industry practitioners to further understand the process of designing IoT products and services. The following research questions will be both offered and critically debated:

1. How the existing NPD processes could be related to their counterpart in the digital economy?
2. How IoT products and services are actually developed and what risks are inherent over the development process?
3. How design and development process for IoT could be reframed?

In order to answer these primary questions, this paper commences with a common understanding of; traditional product development and innovation, digital innovation, design process for IoT, and fundamentals of IoT business success. The term IoT business used within this study is referred to the business, running B2B or B2C business based on sensor embedded smart products, while having a payment system which is oriented toward services rather than physical goods. The primary questions will be explored through case study research of the SPHERE (Sensor Platform for Health in a Residential Environment) project which is to design healthcare technology for the home environment for five years, from 2013 to 2018. A new approach toward IoT products and services development is presented based on findings arising from the SPHERE project.

1.2 Methodology

The research study currently involves three qualitative research methods, including an extensive examination of current literatures, exploratory interviews and a comprehensive case study. As part of the literature review, books, articles and academic texts which are broadly selected through searching through electronic databases such as Springer Journals Archive, Wiley Online Library Journals, ProQuest Business Premium Collection, and Google Scholar. Search terms used, included 1) “NPD”, “NSD”, “design and development process”, and “Innovation process”, 2) “IoT”, “Digital innovation”, “Digital artefact” and, “Digital economies”. These are then supported by a manual investigation of abstracts and articles published in select journals- Proceedings of CHI, Journal of Product Innovation Management, Journal of Information Technology, and European Journal of Innovation Management. Each text was critically examined for their relevance to the primary question(s) of the main research study.

The case study design is selected as a method, which is particularly appropriate for an exploration of why and how the phenomenon (Yin, 2009) of IoT systems are developed in the context of the case for the study. Case study research is identified as an ‘empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2009).’ The SPHERE project was selected as a primary case study prior to subsequent multiple case-study activities. In line with an exploratory approach, the SPHERE project was selected for the following reasons: 1) easiness of recruitment of potential participants; and 2) its aim which is to develop IoT products and services in the residential environment is aligned to the central area of focus for the research study.

The case study was conducted through a series of semi-structured interviews and engagement tools lasting up to two hours in July 2018. The recruitment criteria for participants for the case study featured experts who have knowledge and practical experience over 10 years; who understand the whole system of IoT products and services development; and who hold the authority to drive the project and make strategic decisions. The interviews were recorded, transcribed, coded and analysed for themes that were then clustered into defined categories and then compared across interviews, and the literature

review. The internal validity in the case studies was enhanced by member checks. The case was reviewed by the original informant asking them to confirm whether there is any incorrect information or missing point.

2. Design and development processes in the manufacturing economy

2.1 New Product Development (NPD) process

As pace of technological change and contemporary competitive pressure increases, companies face the challenges of creating breakthroughs, increasing efficiency, and pre-empting competitors (Meyer & Utterback, 1995; Kessler & Bierly, 2002). In this context, the continuous development of new products is commonly regarded as a requirement for corporations' growth and long-term prosperity. As a consequence, the subject of New Product Development (NPD) has received extensive attention from product development professionals and researchers over the decade (Durisin, Calabretta, & Parmeggiani, 2010; Marcelo, 2013). Its contribution to the growth of the organisations, its role as a key factor in business planning, and its influence on profit performance have been proved (Booz, Allen, and, 1982; Crawford, 1987; Urban & Hauser, 1993; Cooper, 2001; Ulrich & Eppinger, 2011). For example, a number of leading high-tech companies have identified that more than 50% of their current sales come from new products (Balbontin, Yazdani, Cooper, & Souder, 2000).

The term has been defined by a large number of academics, such as the transformation of a market opportunity and a set of assumptions about product technology into a product available for sale (Krishnan & Ulrich, 2001). Bruce and Cooper (2000) identify that NPD is to capture a range of different types of innovative activities leading to the production of a new service or product from radical innovations to simple modification and adaptations to existing products. Moreover, there is no single design and development model, which is agreed to provide a satisfactory description of the design process despite numerous research efforts conducted (Bahrami & Dagli, 1993).

Over the past fifty years, NPD processes have progressed from 'tried and tested' ways of problem solving and are constantly refined by the practitioners applying them to 'real' client projects (Best, 2006). As a result, a number of factors have widened the designer's horizon and working methods in design process (Jacobs & Cooper, 2018). By reviewing design and development process including highly cited NPD process models, such as 'over the wall' process (Trott, 2012), a 'stage gate' system (Cooper, 1990), a 'rugby' approach, a 'double diamond design process mode' (Design council, 2007), and a 'service design' process (Johnson et al, 2000), this paper will review the trajectory of progress of design and development process.

2.2 Traditional NPD processes

Within manufacturing economies, NPD processes are close to conventional sequential

approaches such as 'over the wall process' or 'departmental-stage models' which represent the early form of new product development model (Trott, 2012). This is particularly accepted by large manufacturers in which the insular departmental view of the process hinders developing products (Jacobs & Cooper, 2018); different functions are responsible for completing each phase so that projects are transferred from one functional area to another during the development cycle, thus increasing time and cost of product development.

In correspondence with the growing literature on the significance of, considering the project as a whole, and integration between functions such as marketing, R&D and manufacturing (Crawford, 1980; Gupta, Raj, & Wilemon, 1986; Hauser & Clausing, 1988; Souder, 1988; (Clark, 1989; Gomory, 1989; and Narver & Slater, 1990), different approaches have emerged which are deemed as 'simultaneous approach' or 'rugby approach' such as parallel processing models (Takeuchi & Nonaka, 1986) (Figure 1). This way of approach not only increases the speed of the development process but also enables it to be accompanied by new philosophies of design, such as market-led design, implementing flexible manufacturing in order to respond to the flow of new information on customer demand and preferences, allowing products to be more tailored, adaptable and desirable to the customers (B. Evans, 1985).

Figure 1 Left, a Stage-Gate System. Right, sequential (A) vs. Overlapping (B&C) Phases of development

Double diamond design process model (Design council, 2007) and Chesbrough's (2004) open innovation model are not presented as a model of NPD process per se; however, they have many commonalities with generic NPD processes. Although double diamond design process does not illustrate the full scale of the NPD process, it matters significantly among organisations since they require their designers to get involved in creating value from initial idea to final recycling (Design council, 2007). The open innovation approach emphasises the significance of having open mind for ideas and suggestions driven from outside a firm in relation to design and development activities (Chesbrough, 2004) (Figure 2).

Figure 2 Left, double Diamond Design Process Model. Right, Chesbrough's Open Innovation Model

As manufacturing economies in the late 20th centuries started to be replaced by service and digital economies, diverse approaches towards NPD are considered eminent method to create value for customers in industries, such as service design process (Johnson, Menor, Roth, & Chase, 2000) or agile development method (Beck et al., 2001). One of the representative service model is developed by Johnson, Menor, Chase, and Roth (2000) and the rationale is the changeover in focus, from product-orientation to understanding why customers buy a particular service (i.e., a focus on value creation) (Andreassen et al., 2016).

In addition, as flexible product development is becoming a critical aspect, agile development method, which is for software development based on iterative and incremental process consists of a number of short cycles, known as 'sprints', begins to attract interest from designers and developers of physical products (Cooper, 2014; Ovesen & Sommer, 2015) who experienced the challenges and limitations of existing NPD processes. Although it is argued that these 'short cycles' improve communication and coordination activities, speed to market, and faster responses to changing customer requirements (Begel & Nagappan, 2007), a series of challenges for manufacturers adopting agile practices have been identified, i.e. a lack of scalability and a lack of management (Cooper, 2017) (Figure 3).

Figure 3 Left, New Service Development Process. Right, Agile Software Development adapted from Mistral

To summarise, existing NPD models are continuously evolving and supported by emergent trends of increasing particular significance in product development, such as a) the models illustrate linear processes involving sequential phases; b) the NPD process

runs simultaneously; c) recent approaches are more likely to work with customers, and competitors; d) in certain industry fields, such as electronics, the sprint approach becomes more suitable within NPD processes. However, existing models are regarded as obsolete in order to create value for the IoT products and services. This is because they do not reflect the characteristics of digital technologies (Yoo et al., 2012), the dimensions of data (McAfee & Brynjolfsson, 2012), and the dimensions of digital innovation (Yoo et al., 2012) which influence value creation and design and development activities for IoT. Therefore, the attention of this discussion focuses on more details of NPD process for IoT products and services and how they differentiate from existing design processes through the case study.

3. Design and development processes for IoT in digital economy

3.1 New process for IoT products and services development by SPHERE

Healthcare services in the UK need to be prepared for the transformation from clinical setting into the home (Burrows, Gooberman-Hill, & Coyle, 2015). SPHERE (Sensor Platform for Health in a Residential Environment) aims to contribute to this issue not only by developing a sensor platform for monitoring inhabitants' physical and mental wellbeing but also by measuring the value of the system and value and cost of acquiring pieces of data. The system does not target specific age groups or health conditions, but rather it intends to develop a generic but customisable system to support clinical diagnoses and self-management of wellbeing (Burrows et al., 2015).

Figure 4 NPD process for SPHERE IoT products and services

In the SPHERE project, the new process for IoT products and services development (Figure 4) is identified and illustrated by a researcher at Bristol University. The process involving eight

stages seems to be similar to a generic design and development process (discover, define and develop) however, due to the issues and characteristics of digital artefacts development, how IoT products and services are developed and what should be considered is distinctly different in a variety of subtle ways.

1. IDENTIFYING CUSTOMERS LATENT REQUIREMENTS

The IoT product and service development process begins with identifying customers latent requirements. In the SPHERE project, it was challenging to identify customers' requirements, as both of clinical researchers and customers were unfamiliar with IoT systems and did not know the opportunities and benefits it could give them. The risk at this stage is that customers generally are not trained to articulate and define their needs that is generally found in traditional NPD process. Requirements identified by customers could be badly defined, contradictory, or impossible to solve. Thus, the SPHERE team ran a series of workshops and meetings, making proper commitment to identify customers' requirements in greater detail (see Figure 5 below). More significantly, beyond understanding what the future customer wants, this first stage is vital in terms of building a strong relationship with customers to prepare scaling up or commercializing IoT system.

Figure 5 SPHERE Clinical-Brainstorming.

2. TECHNICAL DISCUSSION

This phase revolves around customers' requirement to explore adequate technology for the system. As it is argued that technical risks may be encountered in the majority of NPD process phases (Škec, Štorga, & Marjanović, 2013), with regard to data and complex IoT system, there are numerous technical risks require strategic discussions such as: what kind of system to develop; whether to use labelled data; and what level of smartness and intelligence the system would have. Having the customers' needs identified accurately, the way to deliver value could be various so that strategic discussion is inevitable in order to identify the system to develop. In addition, in relation to the smartness of IoT products, the appropriate set of capabilities should be strategically considered (Porter & Heppelmann, 2014) (Figure 6 below).

Figure 6 Capabilities of smart, connected products

Each capability (monitoring, control, optimisation and autonomy) is valuable and depending on the level of smartness of the product, different risks would follow. The issue of labelled data would elaborate this issue further in detail. If a company decides to have IoT system work autonomously and to use labelled data, they can save financial resources to deploy elsewhere; however, they might be challenged to differentiate their business to that of the competitors. Alternatively, having decided to build annotated data sets and testing the algorithm in-house costs more in terms of time and money; but they have opportunity to develop a novel service. Another significant risk at this phase is that not knowing the performance of the system until the system is actually developed and deployed. Thus, the sensor development and IoT system prototype stage must follow with agility in order to comprehend if the right decisions have been made.

3. TESTING FEASIBILITY AND ACCEPTABILITY, AND SENSOR DEVELOPMENT

After the Technical discussion phase, the IoT system was installed into the Sphere House (see Figure 7 below) which is a physical space for the purpose of prototyping the system. Feasibility and acceptability were tested through a combination of traditional ethnographic methods and participatory techniques. 15 to 20 households spent two weeks each living in the Sphere House and how they used and perceived the system was monitored during this time. The participants ranged a different group of people aged between 19 to 77, from having no formal qualifications to having a higher education degree (Burrows, Gooberman-Hill, & Coyle, 2016). At this point, the sensors had not been completely developed so that the Bristol University team used commercial sensors rather than their own. In this case, the feasibility and acceptability testing, and sensor development ran parallel to one another. The major risks identified at this stage was that the small sample size which result in: a) not enough data to make decisions and a consensus; and b) random data in acceptability depending on users' competence in digital technology. Evaluating IoT products and services thoroughly was almost impossible without completing the product and service ecosystems.

Figure 7 Left, a woman with SPHERE wearable technology on her arm. Right, the SPHERE House in Bristol.

4. FINALISING THE DESIGN AND, INTEGRATING AND DEBUGGING THE SYSTEM

After testing feasibility and acceptability, and sensor development, a company is able to finalise their design, integrate, and debug the system. Developing physical and digital product challenges the designer with a continual pressure of never being able to finish design and integrate system. In NPD projects, keeping the design fluid is regarded as a primary risk, increasing the time and/or cost required for project completion (Gil & Tether, 2011). However, in the context of IoT development, this risk is more vulnerable due to the pace of innovation and programmability, one of the material properties of digitalised artefacts (Yoo et al., 2010).

For example, the old chip may no longer be available in the marketplace, or new vulnerability issues may make you have to change the processor or software. Another issue in integrating IoT system is that it is notoriously complex to build strategic alliances with device manufacturers, software developers, or service providers. To create value through IoT products and services, it is important for a company to have the whole value constellation. Having bigger value constellation means there are likely to be more opportunities in value creation. However, with more partners getting involved, there is likely to be significant risks in data leakage and managing distributed diverse stakeholders.

5. PROCUREMENT

During the procurement phase of the IoT system development, it was identified that special attention should be paid to issues around quality control. For example, issues in being unable to procure hardware components that can lead to new suppliers found, the design being changed or the whole system having to be started again. In an unconnected world, a single device may have a minor problem, but for the IoT system as a whole, the chain reactions of other connected devices can become catastrophic (Lee & Lee, 2015). Prior to moving to

the installation stage, there would normally be a recruitment, marketing and retail phase. However, it has been omitted within this discussion, as the process is based on the SPHERE project, which did not aim to commercialise the IoT products and services.

6. INSTALLATION

In SPHERE project, the team did not have many issues regarding installation as their system was not being commercialised. However, in the installation phase, SMEs and start-ups should consider who installs the IoT devices. If qualified technicians are used, this will raise costs, result in a company's business model, and as such, this could prove to be a risk to its overall success (Figure 8).

Figure 8 Pilot home installation

7. MONITORING AND MAINTAINING THE IOT SYSTEM.

During monitoring and maintaining the IoT system, the user data and diagnostic data is collected on the products and services in order to evaluate and improve the IoT offering(s). If a company build their own annotated data sets, they can start to test their AI algorithm within the IoT system.

8. RE-DESIGNING PRODUCTS AND SERVICES BASED UPON QUALITATIVE AND QUANTITATIVE EVALUATION

This is the final phase that involves quantitative and qualitative evaluation of the system and users, and the value proposition of IoT offerings would be defined and redefined. As IoT is multi-disciplinary area, the data collected is generally outside of technology domain, such as air quality, health, or energy consumption. Consequently, it is more than likely that external experts' opinions will need to be obtained in order to generate insights from the data and again building strong relationships with experts is significant in this regard. The properties of digital technologies make solutions for a wide variety of needs possible (Yoo, 2013; Yoo et al., 2010); hence, through this phase it is essential to continue identifying the way of transforming needs to value. In this way, the IoT development process continues to re-designing IoT products and services in an iterative way.

4. Discussion

The NPD process found in SPHERE project seems to be similar to a generic process as a) it is likely to work with various customers; b) the stages run simultaneously; and c) the stages within IoT NPD process are not much different to its counterpart within traditional NPD processes. However, the approach towards NPD for IoT system is not linear but a continuous and never-ending process. The cycle of discover, define and develop phases are supported by an enormous amount of real-time information. It is succinctly explained through a model developed by Jacobs and Cooper (2018) (Figure 9). This new approach is due to digital components in IoT which are able to modify subsidiary functionality or introduce entirely new functionality over the product lifecycle (Benkler, 2006; Svahn & Henfridsson, 2012; Yoo et al., 2010; Zittrain, 2006). With these distinct characteristics, the scope, feature and value proposition of IoT products and services can continuously evolve even after being launched and whilst being used.

Figure 9 A new process for designing IoT products and services.

As the primary aim of the SPHERE system development was not to commercialise it, the discussion of the SPHERE process is limited. However, a couple of commonalities and differences in the fundamentals of business success between IoT business and traditional business are identified as below (See Table 1). The fundamentals of business success from traditional economy still applies to IoT businesses, however different factors are required for IoT business success. In the phase of Discovery, it is vital to make customers understand what benefits they would derive from the IoT system. This is because awareness of IoT remains low, with less than 1 in 4 people fully understanding the term (Bayern, 2019). Moreover, during this phase, to establish a firm relationship with stakeholders and future customers is identified as one of the key success factors in order to commercialise the system in the future.

Table 1 Commonalities and differences of the fundamentals of IoT business success to its counterpart of traditional business activities.

	Commonalities	Differences
Discover	Understand customers' requirements	Make customers to understand what they would benefit from the IoT system Establish a mutually rewarding and strong relationship with experts and future customers
Define	Accurately identify customers' requirements Fuse users' needs into the right solution within the right business purpose	Strategically consider the level of smartness of the system for the right solution
Develop	Quickly start to build products Be agile	Carefully expand the value constellation Access to many users to test and refine algorithms
Deliver	Manage customer relationship and supply chain	Critically question how to curate data Continuously strive to add meaningful value by speaking to various stakeholders within different domain knowledge Transform business orientation from product to service

At the Define and develop phase, it is identified that the development risks in IoT are more difficult to manage compared to its counterpart in traditional product development due to the distributed innovation activities of IoT, the complexity of building smart products and the diverse ways of creating value. The level of smartness and the access to many users should be strategically considered for testing and refining the algorithms. Moreover, there are many dependencies on the development context and circumstances especially when the system relies on AI or complex ecosystems; and IoT systems are developed with diverse players within a value constellation which means the risks do not fall under the one company but falls out of the company.

Data is not only changing the design process but also the role of the designer(s) within this process. They no longer have to anticipate and develop generic products at the early stage of design process, with limited access to the data on customer needs. Designers, within this context, should continuously and critically question how to curate data to add meaningful value to IoT systems by speaking to various stakeholders within different knowledge domains even while delivering products and services. Value in the IoT era is created through data within the value constellation. Consequently, IoT firms need to have a robust approach toward IoT design process that are more strategically able to contribute to the value of products and services. Therefore, the attention of this discussion now focuses upon a new approach towards design and development for IoT.

4. Conclusions

As IoT innovation advances and permeates our daily lives, it will disrupt entire industries and have a profound impact on business. Despite a number of companies considering incorporating IoT components to their products and service portfolio (Gerpott & May, 2016), there is still a paucity of academic studies on the development process of IoT products and services. Through examination of established literatures, a series of exploratory interviews and a primary case study, this paper provides attention to the core research questions at large: 1) What are the characteristics of design and development processes in the traditional economy and how they could be related to its counterpart in the digital economy? 2) How IoT products and services are actually developed and what risks are inherent over the development process? 3) How could the design and development process for IoT could be reframed?

In this paper, the characteristics of existing NPD processes and the factors affecting value creation for IoT were critically reviewed. Then through exploratory interviews and the case study, how IoT products and services are developed and value is created, and distinctive risks and issues in IoT development are identified. Finally, it suggests a new approach towards design and development process for IoT. Although this research study has explored issues related design and development process for IoT, there are limitations which is that it solely relies on a limited literature review and a single case study. Thus, it leads to having the research outcomes difficult to generalise to a wider set of context and applications.

Notwithstanding these limitations, however, the authors argue that our research also has some important contributions. For academics, this research project contributes to augmenting the body of literature regarding design and development process for IoT and can serve as starting point of future in-depth research on IoT NPD processes. For practitioners, this research helps industry to understand how value should be created through NPD process. When a company decides to apply IoT technology into a specific proposition, this study serves as a tool to guide as to how IoT products and services could be developed.

Related to the limitations of this study, practical questions are identified for further research: How IoT organisations manage risk(s) in terms of scaling up their value constellation during the NPD process for IoT? What is the role of designers in respect of generating values for IoT products and services within value constellation? Further research will enable organisations to have a deeper understanding of the economic value through IoT and enlighten design academia's expanded role of developing designers for emergent digital economies.

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