Understanding New Product Development and Value Creation for the Internet of Things

Boyeun Lee

A thesis is submitted in partial fulfilment for the degree of Doctor of Philosophy at Lancaster University

December 2021

Lancaster University

Supervisors:

Prof Rachel Cooper OBE

Prof Paul Coulton

Dr David Hands

Declaration of Authorship

I, Boyeun Lee, do certify that this thesis has been written by me and that all the information resources that I have consulted are indicated in this thesis. I also certify that this work has not previously been submitted for the award of any other degree.

Signed:

December 2021

Acknowledgements

I want to express my eternal gratitude to all those who supported and helped me throughout this journey. First and foremost, I would like to sincerely appreciate my formidable supervisory team: Prof Rachel Cooper OBE for her enthusiastic and inspiring guidance and loads of opportunities she has provided to me; Dr David Hands for his unstinting and unfailing support that truly characterised this research; and Prof Paul Coulton for his detailed feedback with valuable insights. Their patient mentoring enabled me to have the confidence to see this journey through, which was challenging yet thoroughly enjoyable. In particular, Rachel, I want to thank you because you have offered me this fully funded PhD opportunity, connected me to the broader group of PETRAS scholars, and shown me the way how to become a respectable design scholar.

Of course, I would like to thank my wonderful family and friends who laid the foundation for this journey. Especially, Mum and Dad, for your unwavering support, always being there to listen and believing in me. I want to thank my sisters and brother, Sooyeon, Moonyeon, Jaewon, and Kocheon for their reassurance and encouragement. I extend my sincere appreciation for the support to my friends in Korea, Dajung, Inyoub, Suyeon, Seunghwan, Jiwon, Rammi, Kyunghwa, Hyojin, Seoyoung, and Jiyoung.

I would like to thank Ludwig, my loving partner, for all his support and for being a source of stability in my mental and physical well-being. As we both have gone through the PhD journey, I very much enjoyed our intellectual conversations and got inspired by them. I want to thank all my friends I made along the way in London and Lancaster, who shared in the ups and downs and made this time extra special by being my family away from home. I want to thank the other final year postgraduates who have offered support and advice along the way through the writing group.

I am incredibly grateful to all my participants who took part in my research; without them, my PhD pursuit would not have come to a successful completion. I want to extend my thanks to RADMA, Research and Development Management Association, for granting me the Doctoral Studies Award. The RADMA support lessened the financial burden of travelling expenses to collect field data, conference attendance and additional associated costs. Thank you!

Publications, Conference Presentations/Proceedings written during the PhD

Journal Articles

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2022) "Continuous cycles of data-enabled design: Re-imagining the IoT development process", *AIEDAM: Artificial Intelligence for Engineering, Design, Analysis and Manufacturing*. 36. Online release.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2022) "Emergent NPD process and development risks for IoT: an exploratory case study in agri-tech" *International Journal of Business System Review*, 16(2) Online release.

Conference Presentations/Proceedings

Lee, Boyeun., Gradinar, Adrian., Cooper, Rachel., & Coulton, Paul (2022) "Designing trustworthy IoT systems: critical challenges and approaches for generating value and building trustworthy IoT systems" *IIHIET 2022: International Conference on Human Interaction & Emerging Technologies,* Nice, 22nd-24th August.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2021) "Exploring design implications for IoT products and services through comprehensive case studies" *IPDMC 2021: Innovation Product Development Management Conference* . Virtual conference.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2020) "Designing for the Internet of Things: a critical interrogation of IoT processes and principles" *DRS 2020: Design Research Society Conference.* Virtual conference.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2019) [Finalist of Best Paper Award] "Design Drivers: A critical enabler to mediate value over the NPD process within Internet of Things" *4D: Designing Development, Developing Design Conference*. Osaka, 21st-23rd October.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2019) "Digital innovation and design Transformations: re-framing design and development within the context of Internet of Things" *R & D Management Conference.* Ecole Polytechnique, HEC. 17th-21st June.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul (2019) "Value creation for IoT: Challenges and opportunities within the design and development process" *Living in the IoT Conference.* London. 1st-2nd May.

Lee, Boyeun., Cooper, Rachel., & Hands, David (2018) "Are traditional NPD processes relevant to IoT product and service development activities" *DRS 2018: Design Research Society Conference*. The University of Limerick. 25th-28th June.

Lee, Boyeun., Cooper, Rachel., Hands, David., & Coulton, Paul. (2018) "[Re]-imagining vision and values: design as a driver for value creation in the Internet of Things" *Living in the IoT Conference.* London. 28th-29th March.

Book Chapters

Lee, Boyeun., Christou, Elisavet., and Hands, David. (Forthcoming) "Design for a Post-Pandemic World: Embedding Business Resilience Through Design" In Cooper, Rachel., & Mullagh, Louise. (editors) Design and CoVID from Reaction to Resilience. Bloomsbury Publishing Plc.

Lee, Boyeun. (Forthcoming) "Can designers and AI flourish together in harmony?" In Cooper, R., Dunn, N., & Cruickshank, L. (editors) Beyond Imagination Design Summit. Lancaster University.

Speed, Chris., **Lee, Boyeun**., & Hands, David (2019) "The Little Book of Creating Value through Design in IoT" Dr. Coulton, Claire. (editor) Lancaster University

Abstract

This thesis investigates IoT development processes and value creation from the perspective of the business. At the onset of the research there is a lack of existing research on how IoT products and services are designed and developed. IoT is distinctive to traditional product as it is the combination of physical components, smart components, and connectivity that allows for continuous value improvement. Consequently, New Product Development (NPD) process of IoT should reflect vital characteristics of networked artefacts and integrate the data science process. To achieve the research aim, the study is based on the literature review and an inductive approach, using a qualitative research methodology. Through a comprehensive literature review covering interdisciplinary subjects from economics, business, engineering, information systems, innovation, and design studies, a theoretical foundation of value creation activities, a NPD process and practice and design roles are developed.

An exploratory multiple case study is adopted to gain a primary understanding of IoT design and development. Six cases are selected for the study from various sectors, including healthcare, smart home, drain maintenance, dairy, vertical farming, and tropical farming. Within the case study methodology, semi-structured interview, document reviews and graphic elicitation are adopted to capture each participant’s distinctive experience and design challenges within the context of the given project. Thematic analysis is used for a purely qualitative, rich, detailed yet complex, account of data analysis in IoT development. The transcribed interview script contents and obtained documents for all the cases are carefully analysed through within- and cross-case analysis strategies, using thematic analysis. To enhance the study trustworthiness, triangulation of multiple data sources, member checks, peer reviews and experts’ reviews are drawn upon.

Through the discussion, the conceptual model of the IoT NPD process, the Mobius strip model, is developed, reflecting the attributes of complex development practice, challenges and value creation. The Mobius Strip Model implies three infinite loops of value creation and NPD activities each of which are a hardware centred, software centred, and data and algorithms centred IoT NPD. The hardware centred NPD cycle is hardware centred development which has stricter review gates compared to other two software centred and data/algorithms centred development cycles. The software centred NPD cycle is more flexible, efficient, and effective without major modification to the IoT system. The data and algorithms centred IoT NPD is slow and time-consuming, reflecting the challenges of the data science process. The IoT NPD process involves three different types of subject matter, hardware, software, and data/algorithms development.

This research confirmed that value of IoT system can be created through a hardware centred, software centred, and data & algorithms centred which was reflected to a conceptual model. Service-Dominant Logic is applied as the fundamental theory that can explain IoT value creation, including delivering service and scaling up, value co-creation, and user-driven development. However, emerging theories, such as the value space framework, and data as critical resource for value creation, complement to comprehend IoT value creation. Design is not utilised to its full extent but limited as styling and a process within IoT development. Design as styling is mainly focused on designing, prototyping, and testing the product or user interface of web and app, and design as a process is utilised to identify user needs and develop solution ideation.

This study provides businesses with an integrative understanding of the value creation, development process, and various challenges in IoT development. The proposed conceptual model of IoT NPD, 'The Mobius Strip Model', contributes to a body of research by combining interdisciplinary knowledge within the process. The model provides a foundation for scholars to construct other knowledge upon, including business models, development risks, innovation, design, and product management studies.

Table of Contents

List of Figures

List of Tables

CHAPTER 01

Introduction

1. Introduction

1.1 Research Background

Emerging technologies play a significant role in creating new market value (Christensen & Raynor, 2003; Hamel, 2000; Lucas & Goh, 2009). The Internet of Things (IoT), along with other disruptive technologies such as machine learning, big data, and blockchain, is considered one of the most critical emerging technologies and is gaining enormous attention from a wide range of industries (Lee & Lee, 2015). The Internet, an open and distributed network by which people can communicate and share information, allows almost any physical object to be connected and transformed into an IoT device. As such, it is predicted that 38.6 billion devices around the world will be connected to the Internet by 2025 and 50 billion by 2030 (Karie et al., 2020; Nasiri et al., 2017). This volume of connected devices propels forward a rich digital environment and creates value in various industries (D. Kyriazis, 2013; D. Evans, 2011). Regardless of the sectors, businesses consider the IoT to be a fertile field and some studies suggest that one in every six businesses will be engaged in the rollout of an IoT-based product (Burkitt, 2014).

It is widely recognised that a mixture of physical and digital components, such as sensors, actuators, and cloud computing, bring vital opportunities for innovation and value creation in businesses (Lasi et al., 2014; Nasiri et al., 2017; Radziwon et al., 2014; Xu, 2012; Yoo, 2013). For example, Breivold and Rizvanovic (2018) argue that the IoT can create recurring revenues, by releasing frequent updates of services that are continuously improved and adapted to customer needs. Furthermore, Wu et al. (2015) claim that IoT will enable new possibilities for information-intensive value creation, thereby revolutionising the production process. IoT as a new source of 'big' data helps businesses enter new relationships with their customers (Rymaszewska et al., 2017) and continuously reshape business models and strategies (M. Porter & Heppelmann, 2014), increasing opportunities for creating profit. In the broader context, Aivalioti et al. (2018) argue that horizontal connections of individual IoT ecosystems can accelerate innovation across sectors and regions, bringing different actors together. Porter and Heppelmann (2014) claim that the interaction and co-creation of value among multiple actors are where the potential of IoT lies due to the interoperability of devices and platforms. In this regard, it is forecasted that the total global market for IoT technologies could generate anywhere from $2.7 trillion to $ 14.4 trillion in value by 2025 (McKinsey, 2013).

To sum up, IoT has been predicted to change every aspect of our daily lives and provides novel value creation possibilities for businesses and industries (OECD, 2012). However, despite increasing popularity and opportunities for value creation from IoT development, the adoption of the IoT for most businesses is limited to the proof-of-concept stage (Patel et al., 2017), and nearly three-quarters of IoT system implementations are failing (Cisco, 2017). Several factors are identified which hinder the real added value that the IoT may bring: the non-maturity of the IoT industry, the complexity of IoT architecture, the lack of the interconnectivity and the interoperability between IoT systems (Kubler et al., 2015), as well as difficulty in leveraging data as an asset (Rieke et al., 2016). Internet of Things is intentionally designed unfinished because they are software embedded digital artefacts (Zittrain, 2008). Thus, the early initiators of IoT were challenged due to the lack of IoT development experience (Reichert, 2017). The challenges are shaped by not only the technological nature regarding hardware, sensors, cloud services, data and analytics, and system integration (Kahle et al., 2020) but also by the market drivers and dynamics between enterprises (Aivalioti et al., 2018; Weber et al., 2018).

Many studies and researchers argue that the complex and multi-faceted nature of IoT system radically alters and reshapes the business activities, such as marketing and manufacturing (M. Porter & Heppelmann, 2014), operating supply chain (Gartner, 2014), co-creating meaningful value (Hui, 2014)(Mejtoft, 2011), and business models (Aagaard et al., 2018; Leminen et al., 2012). Moreover, the economic involvement of big data requires reframing value creation distinctive to its counterpart in conventional innovation (Ekbia, 2009; Leonardi, 2011; Nambisan, 2018; M. Porter & Heppelmann, 2014). However, seeking literature on IoT design and development does not uncover many studies specifically investigating the New Product Development (NPD) model (Heinis et al., 2017). NPD is arguably one of the most critical business planning and implementation process activities undertaken within the organisation because structured NPDs enhance firms' competitiveness and survival (Awwad & Akroush, 2016; R. G. Cooper, 2014; Owens & Davies, 2000). Scholars from engineering, marketing and design claim that the conventional design and development practices and processes should be reframed to comprehend the entire value creation activities while reflecting the integration of the interconnected IoT components and multi-stakeholders (Ng & Wakenshaw, 2017; Speed & Maxwell, 2015; Urgese et al., 2020).

While IoT challenges are being recognised globally, the UK government initiated the Internet of Things Research Hub, the PETRAS project, funded by the Engineering and Physical Sciences Research Council (EPSRC) (project EP/S035362/1). This PhD research started as part of the PETRAS in July 2017, almost one year and a half after the research project began. Considering value creation, design and development for IoT as one of the significant challenges in the era of IoT, a research question was generated to explore under the umbrella of the 'Harnessing Economic Value' theme.

There were joint events and activities organised by the consortium, but this PhD journey has been relatively self-directed and involved little outside influence as it was guided by the author. Therefore, even though the thesis is conducted within and funded by the PETRAS project, the author hold the copyright of this PhD work.

1.2 The Concept of Internet of Things

1.2.1 The Definition of Internet of Things

The term 'Internet of Things (IoT)' was firstly coined by Kevin Ashton to illustrate how IoT can be devised by "adding radio-frequency identification and other sensors to everyday objects" (Ashton, 2009). The definition of IoT is exceedingly dependent on the target audience and explains the different kinds of IoT applications (Aagaard, 2018). Atzori et al. (2010) identified the IoT synthetically composed of two terms; a network oriented IoT and generic objects oriented IoT. Referring to existing literature, Lee et al. (2017) categorised IoT definitions into four groups: 1) IoT as intelligent objects, 2) IoT as an extension of the Internet, 3) IoT as global network infrastructure, and 4) IoT as the interaction of information. However, the last category of IoT definition is questioned in terms of its legitimacy for the following reasons: First, IoT definitions in three papers (Kang, 2015; J Kim, 2015; Shin & Ji, 2016) were originally written in Korean, and while being translated in English the meaning may be misrepresented by the authors; and second, the local journals and magazines published the papers is likely to be unreliable source. Consequently, several definitions are classified into three categories according to the scholars' emphasis (Table 1).

Table 1. Definitions of IoT

Category	Author/Institution	Definition
IoT as interconnected objects	(ECIS, 2008)	Interconnected objects having an active role in what might be called the Future Internet.
	(Gubbi et al., 2013)	Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications.
	(Patel & Patel, 2016)	The things, especially everyday objects, that are readable, recognisable, locatable, addressable through information sensing device and/or controllable via the Internet, irrespective of the communication means

	(Porter & Heppelmann, 2014)	The combination of physical components (hardware), smart components (sensors, software and data analytics) and connectivity (wired or wireless connection) that allows for continuous value improvement
IoT as an extension of the internet	(IEEE, 2014)	A network of items—each embedded with sensors—that are connected to the Internet
	Cisco (Bradley et al., 2013)	The intelligent connectivity of physical devices, driving massive gains in efficiency, business growth, and quality of life.
	(Gershenfeld et al., 2004)	An extension of the Internet to reach out to the physical world of things and places that only can feature low-end computers
IoT as global network infrastructure	CERP-IoT (de Saint-Exupery, 2009)	A dynamic global network infrastructure with seamlessly integrated active participants and things
	(ITU, 2001)	A global infrastructure for the information society, enabling advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies

First, interconnected things are identified as the most critical feature of IoT. 'Interconnected objects (ECIS, 2008)', 'Interconnection of sensing and actuating devices (Gubbi et al., 2013)', and 'everyday objects, that are readable, recognisable, locatable, addressable (Patel & Patel, 2016)' are emphasised. The smart components improve the physical product's capabilities, while the connectivity components have capability to retrieve, store and transfer large amounts of data.

Second, IoT is considered as an extended form of the internet, including 'A network of items (IEEE, 2014)', 'The intelligent connectivity of physical devices (Bradley et al., 2013)', and 'An extension of the Internet (Gershenfeld et al., 2004)'. The critical aspect of IoT in this vein is a web-based environment. Third, the extension of the internet is understood as a global network infrastructure for the information society (de Saint-Exupery, 2009; ITU, 2001) in which the ultimate integration of the physical and virtual worlds is envisioned through IoT (Mattern & Floerkemeier, 2010). The discussion on IoT definitions indicates that IoT is an umbrella term encapsulating various concepts. To comprehend IoT better, the next section explores the architecture of IoT.

1.2.2 The Architecture of Internet of Things

Different scholars have proposed different architectures for IoT, and there is no single architecture that is agreed universally. Broadly, there are three layers of architecture consisting of the perception (sensing) layer, network layer, and application layer (Mashal et al., 2015; Said & Masud, 2013; Wu et al., 2010). The perception layer includes sensors for sensing, collecting information about the environment, and identifying other smart things. The networks layer is liable for connectivity of other digitised objects, network devices, servers, and data transmission and processing. In the application layer, diverse applications can be defined and deployed; thus, specific services are delivered to the user.

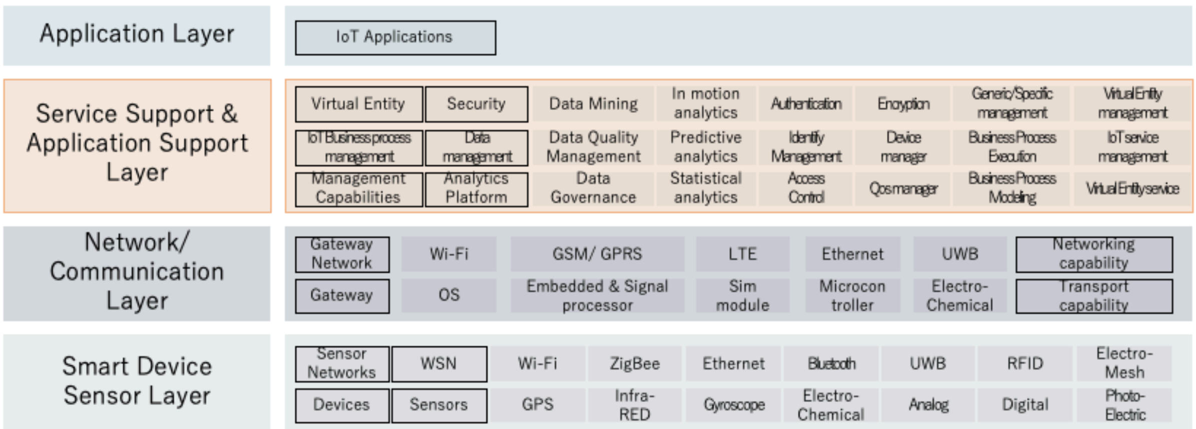


Figure 1 IoT Architecture modified from Patel and Patel

Compared to the three-layer architecture, Patel and Patel (2016)'s IoT architecture contains four layers in which the service support and application support layer is added (Figure 1). The first layer is the smart device and sensor layer, which comprises digitised objects with sensors and sensor gateways for connectivity. Then the network and communication layer are composed of a wired or wireless network infrastructure as a transport medium. The service support and application support layer include the IoT business management, data management, information processing through analytics, security controls, and management of devices. The application layer covers various services and user interfaces in different domains. As this new type of product instigates profound changes in the ways of NPD, understanding IoT architecture must precede (Yoo et al., 2010).

1.2.3 The Attributes of IoT affecting Design and Development

Along with the complex architecture and material properties of IoT, the unique properties and traits of digital technology and big data enable a new approach of value creation which are evidently distinctive from its counterpart in the mid to late 20th century. Yoo (2010) identify seven material properties of digitalised artefacts which include Programmability, Addressability, Sense-ability, Communicability, Memorability, Traceability, and Associability. The different properties are independent and interdependent under the umbrella of IoT design.

- Firstly, and most fundamentally, embedded software capabilities, non-digital artefacts are able to perform multiple functions and make them more malleable through programmability.
- Second, the digitalised artefacts become uniquely identifiable with the implementation of microprocessors, IPs and RFID chips which is identified as addressability.
- The embedded sensors into the non-digital products make them sense-able and collect data.
- Fourth, embedded digital communication capabilities allows the digitalised artefacts to have communicability with which they can interact with other digital artefacts, environments and actors.
- Due to the memory capacity in digitalised artefacts, they are able to store data on place, users and interactions which is identified as memorability.
- Sixth, with sense-ability and memorability, the digitalised artefacts have traceability, the ability to chronologically interrelate events and entities.
- Finally, associability is the ability that a digitalized artifact can be related and identified with other entities, such as other artifacts, place, and people, based on certain commonly shared attributes.

Including the seven material properties of digitalised artefacts (Yoo, 2010), scholars in information systems identified several factors that may affect IoT value creation which are the dimensions of big data, the characteristics of digital technologies, the six dimensions of digital innovation, and the fundamental characteristics of the IoT (Yoo *et al.*, 2010; McAfee & Brynjolfsson, 2012; Johnson et al., 2017; Patel & Patel, 2016) (Table 2).

Table 2 The Factors affect Value Creation of IoT

Name	**Dimension**	**Source**
Seven Material Properties of Digitalised Artefacts	Programmability; Addressability; Sense-ability; Communicability; Memorability; Traceability; and Associability	(Yoo, 2010)
The fundamental characteristics of the IoT	Heterogeneity; Dynamic changes; Enormous scale; Safety; Connectivity; Interconnectivity; Things-related services	(Patel & Patel, 2016)

The dimensions of big data (3Vs)	Volume; Variety; and Velocity	(McAfee & Brynjolfsson, 2012; Johnson et al., 2017)

Patel and Patel (2016) identify the fundamental characteristics of the IoT including heterogeneity (The devices in the IoT are heterogeneous as based on different hardware platforms and networks.); dynamic changes (The number of devices can change dynamically); enormous scale (The number of devices to be managed and communicate with each other will be an order of magnitude larger than the devices connected to the current Internet); safety (safety must be considered in IoT design); connectivity (Connectivity enables network accessibility and compatibility); interconnectivity (Anything can be interconnected); things-related services (The IoT is capable of providing thing-related services). The dimensions of Big data, Variety, Velocity, and Volume can create a diverse variety of services that dissolves product and industry boundaries (McAfee & Brynjolfsson, 2012; Johnson et al., 2017). The baseline of the factors is distinctive yet interrelated to each other which would make IoT development distinctive from traditional hardware, software, and service development. These critical attributes will be revisited for explaining value creation for IoT system in Chapter 2 and discussing the conceptual IoT design process in Chapter 6.

1.3 Thesis Aim, Research Questions and Objectives

With the recognition of complex IoT architecture and difficulties of IoT value creation, IoT development must count various considerations holistically, including the complex ecologies of value chain, integration of architecture layers, and data practice process; this thesis aims to investigate the IoT system development process and design roles which aims to create value propositions for organisations. Researchers from marketing, engineering and design (Heinis et al., 2017; Ng & Wakenshaw, 2017; Speed & Maxwell, 2015; Urgese et al., 2020) argue that it is time to reframe conventional NPD processes to satisfy current needs and potential commercial opportunities in the era of IoT. Indeed, as explained above, there is limited existing research on emerging development approaches or creation of systems that reflects vital characteristics of networked artefacts or integrates the data science within the development model.

Therefore, this research will explore emerging practices and attributes of IoT value creation, new product development and design contributions, comparing them to their traditional counterparts (Figure 00). The key research question is: What are the conceptual IoT NPD process and the design roles which aim to create value propositions for organisations?

And following sub-questions are:

- RQ1: What are the existing and emerging theories on value creation, NPD process, and design roles in the organisational setting?
- RQ2: How is an IoT system developed with the aim of creating value propositions for organisations?
- RQ3: How does design contribute to IoT development and value creation?
- RQ4: What is the conceptual model of IoT NPD practice and process reflecting value creation strategies and challenges?

This research aims to develop a conceptual model of NPD process for IoT products and services and investigate the role of design for value creation within IoT NPD process. The objectives are:

- RO 1: To understand existing and emerging theories on value creation activities, NPD models, and the role of design in the business context
- RO 2: To identify how IoT systems are designed and developed, aiming to create desirable value propositions
- RO 3: To develop a conceptual model and identify design interventions for value creation within IoT NPD process

1.4 Thesis Structure

This thesis consists of seven chapters, and this section briefly introduces the content of each chapter.

<u>CHAPTER 1.</u> provides an overview of the research background including economic value of IoT, significance of NPD, and the lack of knowledge in IoT NPD processes and practices. Also, the chapter reviews the definitions, architectures, and attributes of IoT as a starting point for this thesis. The PETRAS IoT research Hub is also described to provide the context of this PhD research. The later section sets the purpose of the research, research questions, aim, objectives and outline of the overall study.

<u>CHAPTER 2.</u> reviews literature in order to situate the research within the structured theory and knowledge on value creation activities, existing NPD models and attributes, and the role of design for value creation within organisational setting. The discussion arrives at the understanding of: how IoT value creation could be related to and distinctive from conventional value creation theories; various models and attributes of NPD in different disciplines; and how the roles of design have been

evolved within business activities. With particular focus upon different approaches and processes of different subject matters development, it identifies the generalisable phases of NPD process, attributes of different approaches, and three roles of design to contribute to creating value.

CHAPTER 3. provides the methodology for the research. The rationale behind a constructivist, qualitative research approach, and the strategy of inductive reasoning is explained. Then, the application of case study methodology, including selection of the research tools, choice of the bounded system, case selection, and the role of the researcher, are provided. Reflection on the limitations and recommendations drawn from the pilot study is explained to improve the main study design. Regarding analysis strategy, the process of thematic analysis, within-, and cross- case analysis is described. The later section of the chapter provides the types of theorising research findings from case study methodologies, and different strategies of enhancing internal and external validity, and the selected strategies to increase validity.

CHAPTER 4. summarises the six IoT development projects in the layout of within-case description. The factual description of each case is based on the interview, graphic elicitation, and document reviews. The result of within-case analysis of six cases is described in four sub-sections: project overview; IoT products and services development process; business activities for value creation; development challenges and design contributions towards value creation.

CHAPTER 5. presents the analysis and findings from the empirical data of each case study to develop narratives and compare across the cases. On the basis of the research objectives and interview protocols, four critical dimensions for cross-case analysis are constructed: IoT NPD processes and practice, Attributes of IoT NPD process; Value Creation Activities; Barriers, Challenges and Tensions. In the process of drawing out the initial research findings, the six cases are compared and contrasted with one other against the four dimensions.

CHAPTER 6. discusses and validates the findings. The results of the chapter 5 are reflected on by comparing these with the body of existing theories, and the insights are elaborated on. Through the discussion, the conceptual model of the IoT NPD process, the Mobius strip model, is developed, reflecting the attributes of complex development practice, challenges and value creation. Existing literature on business and marketing as well as emerging theories from information systems are supplemented to comprehend value creation of IoT systems. The role of design within the IoT NPD process is discussed and synthesised with design literature. As the way to validate the findings of this research, an expert audit review was conducted to validate the author’s argument. The results of the expert audit review are described in this chapter.

CHAPTER 7. concludes the PhD thesis. It presents a final summary of the research while summarising how the research questions are answered. It also describes its contribution and implications of this research for design and innovation disciplines. Lastly, this chapter addresses the research limitations and the directions of future research with the key questions.

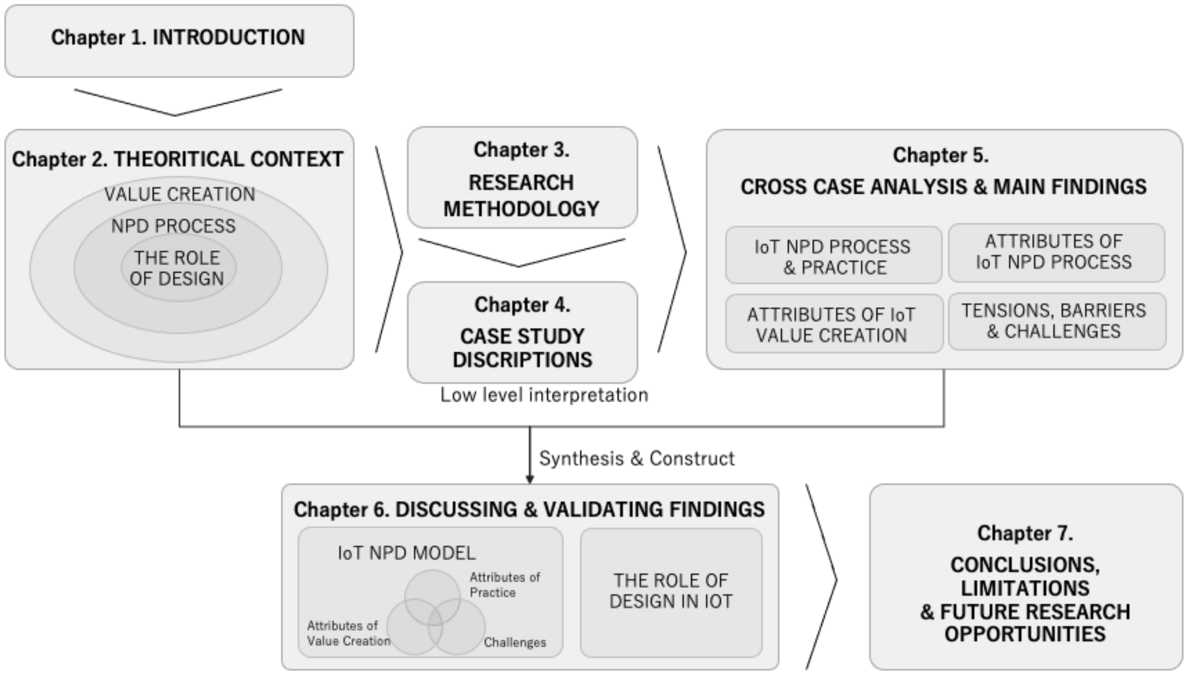


Figure 2 Structure of the Thesis

From the following chapters, this thesis attempts to broaden the conventional perspectives on value creation, New Product Development and Design contributions, which have been rarely discussed across disciplines. Through this journey, it will provide new opportunities for novice and experienced researchers to both feed and draw insight from the broader design and innovation discourse.

CHAPTER 02

Literature Review

2. Literature Review

2.1 Introduction

In Chapter 1, the research aim and questions were formulated and presented. This chapter focuses on the first research question, 'What are the existing theories on the NPD processes, value creation and design contributions towards NPD?' Thus, existing theories on three core themes are discussed: 1) value creation, 2) NPD models, and 3) the role of design within the NPD processes. Through a comprehensive review of the literature, this chapter provides a structured overview of the current state of the field. It enables the author to understand the theoretical background of the study. A comprehensive literature review across information systems, innovation, design, engineering, software engineering, service marketing, and management themes are reviewed and critically analysed. A wider scrutiny across the disciplines was conducted to obtain a deeper understanding of the conventional and emerging role of NPD, value creation and design activities in firms.

The chapter begins with a brief overview of value creation activities in section 2.2, an entry point to exploring conventional value creation and discussing how the novel approach towards value creation emerged, specifically around IoT development. It then broadens the understanding of emerging NPD processes in the context of digitally connected world. Then section 2.3 examines existing models of NPD for a product, software, service, and integrated product to identify the generic phases of the process, and the challenges and characteristics of these approaches. Section 2.4 explores theories on the role of design within new product development. Conclusions from the literature are drawn, and gaps in current knowledge are identified in section 2.5.

2.2 Value Creation

In Schumpeter's theory of economic development (Schumpeter, 1934), innovation is viewed as the source of value creation through technological change. Consequently, numerous business operators pay attention to value creation as the central purpose of economic activity (Ng & Smith, 2012). The businesses approaches towards value creation have been gradually changed in a more complicated way according to technological developments and changed values in society (Mejtoft, 2011). Conventionally, value creation is derived from a firm centric and linear value chain concept (M. E. Porter & Millar, 1985) which is also referred to as 'manufacturing logic (R. Normann, 2001)', 'firm-centric logic (Prahalad & Ramaswamy, 2004)'. As the economy grew towards services, scholars argued that this traditional view of linear value creation and exchange of tangible goods is limited to explain recent value creation activities for intangible service offerings. An alternative to the traditional Goods-Dominant paradigm, Service-Dominant logic is proposed to understand better the efficient production of intangible goods with a more systematic network-oriented perspective (Vargo & Lusch, 2004a).

More recently, research on value creation has become a growing interest of not only business, economy and marketing scholars but also the information systems and related disciplines. It is because the hybrid offerings of physical and digital products accelerate digitisation, big data and automation which affect organisations' value creation strategies. Researchers started to consider the attributes of technology in the context of value creation activities. Thus, this section aims to propose a comprehensive understanding of the current conceptualisations of value creation activities. It first explores existing theories on the attributes of value creation by comparing a Goods-Dominant logic and Service-Dominant logic and then the emerging research on value creation for IoT, which reflects the attributes of technology. The existing and emerging research on value creation activities is synthesised with empirical findings in the discussion chapter.

2.2.1 Defining Value for This Thesis

Since Aristotle, the notion of value has been discussed and debated in different contexts. It then becomes central to Smith's (1776) work in *The Wealth of Nations*. Based on the work proposed by Adam Smith, the economic philosophers and scientists refined value under the rubric of 'utility' (Walras, 1874) which continues to underpin contemporary business literature (Ng & Smith, 2012). Although there is no universal definition of value, several attempts have appeared to develop holistic notions of value. From pricing literature, Leszinski and Marn (1997) define value as the trade-off between customers' perceptions of benefits received and sacrifices incurred. From strategy literature, Porter defines value (1985) as the amount buyers are willing to pay for what a firm provides for them so that the competitive advantage comes from offering lower prices than competitors for equivalent benefits or providing unique benefits that compensate a higher price. Similarly, Normann and Ramirez (1994) define value as a customer's willingness to pay for access to resources that either lowered their costs or enabled them to do things they would otherwise not be able to do.

Value from a customer perspective is variously identified, including "The consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given (Zeithaml, 1988)"; "Understanding users today, seeking future opportunities for buyers, and intelligently creating innovations for payers (Paananen & Seppänen, 2013: 709)"; "The concept that captures the result of service (and goods) (Babin & James, 2010: 471), allowing the firm to measure its competitive advantage in the eyes of the customer (Desarbo, Jedidi, & Sinha, 2001; Gummerus, 2013)"; "A customer's perceived preference for and evaluation of those product attributes, attribute performances, and consequences arising from use that facilitate (or block) achieving the customer's goals and purposes in use situations (Woodruff, 1997: 142)."

The listed definitions are not exclusive, but they provide a certain level of consensus on how value should be understood in this thesis. However, the scope of this PhD research does not include how customers perceive the proposed benefits by the organisations but covers how the customer value of a product or service is developed. Therefore, 'value' in this thesis means 'benefits offered by a particular bundle of products and services delivered to the customers'. In other words, it can be called the value proposition, which is the value created for customers through the offering (Hartmann, Zaki, Feldmann, & Neely, 2016). With the conception of value for this thesis, the following section will explore how the theories around creating value of a product or service have been advanced.

2.2.2 Modern Conceptualisation of Value Creation

Through the historical foundations of value in economics, business and management, the conception of 'value' has evolved into two distinctive ways: 1) value as utility embedded in physical things (Dupuit, 1844; Marshall & Marshall, 1879); and 2) value as phenomenological experience of the customer (Holbrook, 1994, 1999, 2006). The first conception of value can be classified as the dominant classic theories of values (Marx, 1906; Ricardo, 1821; A. Smith, 1904). The latter one can be understood as the subjective theories of value (Jevons, 1871; Menger, 1871; Walras, 1874). The two conceptions of value are realised under the different economic activities: value in exchange and value in use (Ng & Smith, 2012).

Table 3 The related theories on the core constructs of G-D and S-D Logic concepts

Core constructs	G-D Logic Concept	S-D Logic Concept
Value as	Utility embedded in physical things (Dupuit, 1844; Marshall & Marshall, 1879)	Phenomenological experience of the customer (Holbrook, 1994, 1999, 2006)

Role of goods	Goods are end-products (Vargo & Lusch, 2004a)	Goods transmit embedded knowledge into the process of value creation (Vargo & Lusch, 2004a)
Economic Foundation	Value in exchange (T. N. Beckman, 1957), goods as primary unit of exchange	Value in use (Alderson, 1957; A. Smith, 1776), services as primary unit of exchange
Perspective on resources	Operand resource (Zimmermann, 1951)	Operant resource (Zimmermann, 1951) (Penrose, 1959)
Value Creation Model	Value chain (M. E. Porter & Millar, 1985) through Push Strategy (Trott, 2011) which is Static and finite (Vargo & Lusch, 2004a)	Value constellation (Richard Normann & Ramírez, 1994) through Pull, Push-Pull, or Network Strategy (Trott, 2011) which is dynamic and ongoing (Vargo & Akaka, 2009; Vargo & Lusch, 2004a)
Role of Customer	A destroyer of value (Vargo & Akaka, 2009)	A co-creator of value (Vargo & Lusch, 2004a)

Based on this view, Vargo and Lusch (Vargo & Lusch, 2004a, 2008) develop a modern conceptualisation of value creation through the Service-Dominant Logic (S-D Logic), which is opposed to Goods-Dominant Logic (G-D Logic). The two logics as a framework for comparison of different value creation approaches, economic foundation, perspective on resources, value creation strategy and the role of customers are explored in the following sections (Table 3).

Value in Exchange vs Value in Use

Within Goods-dominant logic, the approach of 'value in exchange' is dominant through which a firm embeds value in the operand resource (goods) over the production and value-added activities, such as distribution and sales (Dupuit, 1844; Marshall & Marshall, 1879). Services are understood as particular types of goods like perishable products or added value to tangible products, such as after-sales services (Vargo, Lusch, Akaka, & Maglio, 2010). As the economic paradigm shifted from manufacturing to services, services were perceived as an add-on to the operand resource and did not fit well with the G-D basis of exchange (Lai et al., 2017). Consequently, the traditional view of value creation has been challenged and shifted from 'value in exchange' to 'value in use' (Vargo & Lusch, 2008; Vargo et al., 2008).

Service-dominant logic argues that value is created not through the good or the product but the services rendered by the product, referred to as 'value in use'. Value stems from the beneficial application of operant resources which are often invisible and intangible (Vargo et al., 2008). Value is created through customers' phenomenological experience rather than being embedded in the utility of an offering (Holbrook, 1987). In essence, there is no value until an offering is consumed, and value is determined by users' subjective experience (Grönroos, 2008; Lusch & Vargo, 2006). Firms make value propositions in the domain of consumption by generating richer experiences for customers, and in return, they are benefitted by gaining access to customers' latent perceptions and preferences and capitalising on them (Agrawal & Rahman, 2015).

From Value chain to Value constellation

While G-D Logic is widely accepted, firms have predominantly used a 'push strategy (Trott, 2012)' through which organisations just push the products to the market (Speed & Maxwell, 2015). Value creation is often regarded as a series of firm level activities (Vargo et al., 2008), starting from technologists developing new product ideas, engineers and designers turning them into prototypes, and then lastly marketers promoting the product to potential customers (Trott, 2012). Michael Porter's (1985) value chain model represents a linear push strategy, illustrating a series of activities for value creation (Figure 3). Whilst value is created and determined by a manufacturer within G-D Logic concept, the fundamental concept of S-D Logic is that value is co-created within a value constellation (Figure 3).

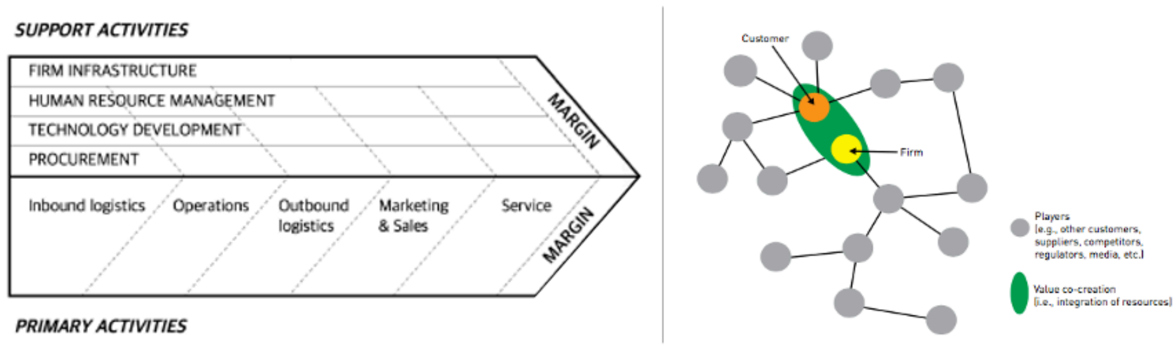


Figure 3 The Value Chain Model adapted from Porter & Millar's Value Chain (Left), Value Constellation (Right)

With the emphasis on value co-creation, the network models of value creation are developed, including value constellation' (Richard Normann & Ramírez, 1994)', 'network models of innovations' (Takeuchi & Nonaka, 1986), and 'the value network' (Allee, 2000). In value constellation, actors are considered as resource integrators (Barrett, Davidson, Prabhu, & Vargo, 2015) and "innovation occurs as actors seek better densities and improved ways for value co-creation (Vargo & Lusch, 2004a, p. 161)." Value is thus operant, contextual, and experiential rather than a unit of tangible outputs (Barrett et al., 2015). In the same manner, each value constellation appears dynamic in nature, and various needs of the same consumer may drive the creation of different value constellations (Gordijn, Weigand, Reichert, & Wieringa, 2008). According to Trott (2012), the 'Market Pull' or 'Push-Pull' process is more appropriate to generate business value in S-D logic.

The Role of Customers | A Destroyer or A Co-Creator of Value

Scholars from diverse disciplines have recognised the significant role of customers in value creation over half a century (Cavaye, 1995; Markus & Mao, 2004; Gassmann et al., 2006). In short, customers' roles in value creation are differently understood depending on the economic foundation: a destroyer and a co-creator of value. Over the traditional value creation process, the role of "manufacturers" and "consumers" are distinct, and there is no co-creation contribution from customers (Andreassen et al., 2016). Firms have limited access to information of customers' needs in a reactive manner at a single point beyond its selling point, the point of value exchange (Hui, 2014; Speed & Maxwell, 2015). After the point of sale, the customer is destroying the product's value (Vargo & Akaka, 2009) as the product becomes obsolete whilst being used. Consequently, companies are able to sell the next new product, which is how they continue to make profits and achieve long term growth (Andrews, 1975; Hui, 2014).

In S-D Logic, customers (users) contribute towards value creation as experience creators, referred to as co-creator of value (Grönroos, 2008; Salomonson et al., 2012). It is because users determine and co-produce value through consumption interactions that occur in the use and experience of an offering at a certain time and context (Ng & Smith, 2012; Warde, 2005). Grönroos and Voima (2013) further emphasises that innovation can only occur when both the provider and the customer interact in the value creation process. Consequently, over the value creation process, it becomes the firms' responsibility to collaborate with and learn from customers in order to adapt to their individual and dynamic needs (Grönroos, 2008; Vargo & Lusch, 2004a). The practices and methods of how to involve users in value creation loops have been proposed in the literature, such as co-design (Sanders & Stappers, 2008), participatory design (Schuler & Namioka, 1993), and Usability testing methods (Dumas, 1999).

Unpacking different concepts around value creation offers rich insights on value creation in a digital economy but some scholars argue that the innate characteristics of connected artefacts may challenge the current understanding of value creation (Arthur, 2009; Kallinikos et al., 2013; Yoo, 2010). Thus, the next section will explore different and emerging aspects of value creation for digitally connected artefacts.

2.2.3 Digital Disruption in Value Creation

Several scholars argue that a service dominant logic (S-D logic) perspective is a fundamental logic for understanding IoT value creation (Lai et al., 2017; Turber *et al.*, 2014; Ng & Wakenshaw, 2017). However, others argue that with the digital technologies, fundamentally changing the prevailing rules of competition and business activities (Brynjolfsson & McAfee, 2014; Iansiti & Lakhani, 2017; McAfee & Brynjolfsson, 2017; Mejtoft, 2011), thus, complex value creation for IoT should be way beyond two-dimensional value chain and value networks (Bhattacharya et al., 2017; Mejtoft, 2011). Particularly, for example, Mejtoft (2011) proposes a conceptual model on value creation considering the concept of the IoT; Rymaszewska et al. (2017) argue as to how IoT expands the scope of companies value creation beyond traditional manufacturing; Henfridsson et al. (2018) propose a framework that could explain value creation through non-human factors; Kugler (2020) introduces data-dominant logic as an alternative to S-D logic; and Mazhelis et al. (2012) and Aivalioti et al. (2018) suggest that IoT ecosystem is specific type of it with a mixture of co-creation and coopetition.

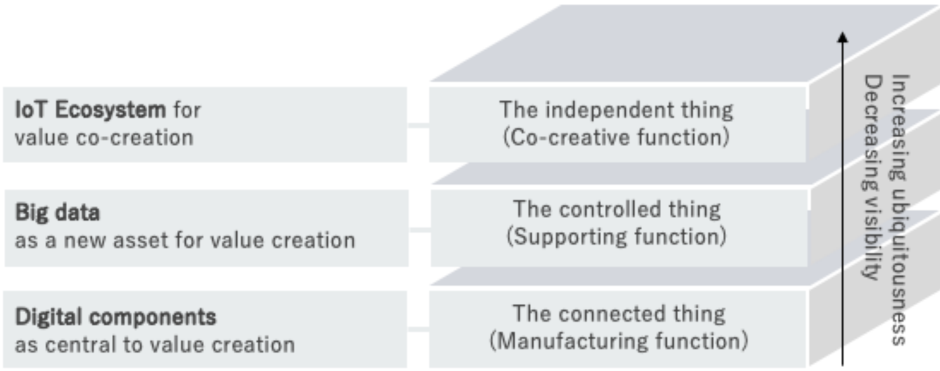


Figure 4 The IoT value creation framework as a theoretical lens. Adopted from Mejtoft

The majority of IoT value creation activities can still be defined by S-D Logic, as the existing concept of value creation does not change overnight. However, exploring emerging theories and increasing interest in the subject area is required to find a knowledge gap and contribution to academic discourse. Thus, this section explores theories recently published to understand value creation for connected devices from different perspectives. The three sub-sections are constructed through the model on value creation considering the concept of the IoT as a theoretical lens (Mejtoft, 2011) (Figure 4).

Digital Components as Central to Value Creation

With the importance of the digital components in value creation, not only human actors but also digital resources are considered as value creation actors. Arguing that recombination is at the heart of innovation, Henfridsson et al. (2018) propose the value spaces framework to theorise how digital technology architecture relates to the settings, activities, and outcomes of value creation and capture (Figure 5).

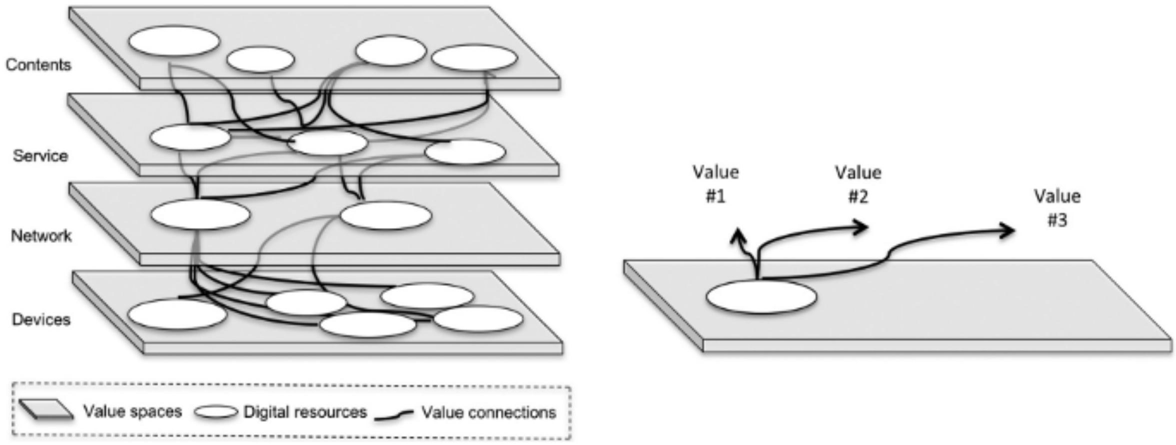


Figure 5 The value spaces framework (Left: Space, resources and connections, Right: the multiple value paths of a digital resource)

Value space is 'an evolving network of digital resources interlinked through connections established and dissolved by actors seeking to generate and appropriate value' within which multiple possible values can be created, associated with digital components (Henfridsson et al., 2018). This framework focuses on the interface between 'design recombination' and 'use recombination' as a multi-dimensional space of possible value (Henfridsson et al., 2018). While firms generate value paths as possible value propositions to users, the individuals create value by connecting digital resources in use (Henfridsson et al., 2018). Although Nambisan argues (2018) that this approach may limit a comprehensive understanding of value creation in digital innovation and require a broader framing such as the digital ecosystem, this architectural perspective is considered helpful in understanding the role of digital components and their connections in value creation.

Reprogrammability , one of the characteristics of digital technologies (Yoo et al., 2010) which can be a critical aspect of IoT value creation, closely related to digital materiality of artefacts. The materiality can be understood as an affordance which is firstly coined by James Gibson (1986), perceptual psychologist, then most notably applied to discussions in Human Computer Interaction by Donald Norman. Norman (1988) identified an affordance as 'a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used'. Affordances are unique to the particular ways in which an agent perceives materiality. However, in the digital realm, affordances become malleable and flexible with *digital materiality* which is 'what the software incorporated into an artefact can do by manipulating digital representations (Yoo et al., 2012)'. The affordances of pervasive digital technology lead to *Convergence* of multiple affordance with a single smart device (Yoo et al., 2012). The convergence of media and products increases the competition among heterogeneous markets and industries. In the next section, Data science processes as another significant factor to be considered for IoT NPD will be discussed.

Data-Dominant Logic as The Next Wave of Innovation

Big data is often complicated, messy, live, and large, which can be explained by the dimensions of big data: Variety, Velocity, and Volume of Big data (Table 4) (McAfee & Brynjolfsson, 2012; Johnson et al., 2017; Kwon & Sim, 2013). Other scholars identify the dimensions of big data as 4Vs adding value as fourth attribute (Forrester, 2012; IDC, 2012; Oracle, 2012) or 5Vs adding veracity as fifth attribute (Wamba, Akter, Edwards, Chopin, & Gnanzou, 2015; White, 2012). Big data as a discrete representation of data in bits of 0 and 1, which empowers all types of digital data collected from different sources to be efficiently combined with other digital data, unlike analogue data with a tight coupling between data and special devices (e.g., pictures and camera) (Yoo et al., 2010). This homogenisation of data creates a diverse variety of services that dissolves product and industry boundaries.

Table 4 Dimensions of Big Data

Dimensions	Descriptions
Variety of Big Data	Big Data is many different types, such as texts, weblogs, GPS location information, sensor data, graphs, videos, audio data and more online data
Velocity of Big Data	In terms of velocity, huge amounts of data are generated real-time and every second.
Volume of Big Data	The volume of data collected every day is radically increasing compared to a decade ago. The explosion of data is a natural tendency and, if harvested properly, can provide companies with better product innovation.

For value creation, data has to be analysed through a data science process that scholars identify differently (Fayyad et al., 1996; Kandel *et al.*, 2012; O'Neil & Schutt, 2013; Baumer, 2015; Alspaugh *et al.*, 2018). Even though each process presents slightly different phases, they share resembling phases, which can be summarised as five key activities: 1) selection and collection of a data set; 2) pre-processing and cleaning the data; 3) data mining so called identifying data patterns; 4) building ML Algorithms; and 5) identifying and building data product. Hartmann et al. (2016) describe that collecting, storing and analysing data through a non-linear and iterative data science process (Kandel et al., 2012; Sands, 2018) is not an end in itself for organisations but a start of creating actual business value. Scholars identify the types of offerings and values through a series of activities within a data science process framework.

Hartmann et al. (2016) and Chin et al. (2017) introduce three offerings, including raw data being primarily ‘a set of facts’ without an attached meaning, information or knowledge after data being interpreted, and value-added products or services. Porter and Heppelmann (2014) identify five values created from big data which includes quicker product introductions, new business models, supporting customer success, product as part of broader system and data analytics. The incremental improvement and optimisation of current business practices, processes and services is emphasised as organisational value by a number of scholars (CEBR, 2012; Hagen et al., 2013; McKinsey, 2011; Petter & Peppard, 2012; Schroeck, Shockley, Smart, Romero-Morales, & Tufano, 2012). Raw data is likely to be of little value as it may lack understanding of underlying context and provenance whereas information or knowledge can have more value if it appropriately analysed and interpreted (Emmanouilidis et al., 2019).

The data-based value is offered through recombination, re-contextualisation or re-interpretation of the different datasets (Alaimo et al., 2020). This analytics (synthesising) activities are subdivided into three categories: descriptive (describing the past), predictive (predicting future outcomes), and prescriptive analytics (forecasting future outcomes and recommending decisions) (Delen & Demirkan, 2013; Hartmann et al., 2016). Depending on the level of analytics activities, a company may adjust and automate machine performance to deliver its customer value and define its competitive positioning (M. Porter & Heppelmann, 2014). Each activity is valuable in its own right depending on what level of smartness the company embeds into the IoT system, but the path of how an organisation embeds smartness in IoT system and extracts value for stakeholders is far from straightforward (Alaimo et al., 2020; Chin et al., 2017). In this vein, Kugler (2020) coined the term Data-Dominant Logic, arguing the firms need to ground their business in data and data science insights by: learning how to manage opportunities and barriers of data science driven approaches, hiring data science experts, and changing organisational structure.

With regard to value creation through data, the concept of selling or providing data to customers to produce profit is introduced as data-as-a-service (D. Machan, 2009). This concept is emerged as a limited amount and kind of data that can be collected within a single firm (JANG, PARK, LEE, &

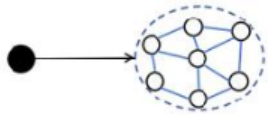
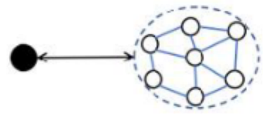
HAHN, 2018). Consequently, the data market is required to embrace open data-trading to effectively utilise data sources in customers value creation (JANG et al., 2018). In data market, there are three different types of data players: 1) data broker; 2) data service provider (or data consumer); and 3) service consumer (Cavanillas et al., 2016). A data broker collects raw data from different data sources and trades them to third-party data service providers (Federal Trade Commission, 2014; Rieke et al., 2016); the data service providers deploy big data from the data brokers to generate profits through improving the quality of their services and satisfying customer's needs; and service consumers who pay for the service (Oh, Park, Lee, Choi, & Noh, 2020).

IoT Ecosystem for Value Co-Creation

The potential value of IoT comes from the interplay and the value co-creation activities among multiple actors (Ghanbari et al., 2016)**.** This is supported by several scholars who argue that S-D logic perspective should be adopted as a foundational logic for understanding IoT value creation (Lai et al., 2017; Turber *et al.*, 2014; Ng & Wakenshaw, 2017). Based on its value co-creation and value constellation premise, a number of scholars propose that an IoT ecosystem should be considered a particular type of business ecosystem formed by a group of organisations and individuals where all the actors are competing and cooperating through the usage of shared resources (Mazhelis et al., 2012). Aivalioti et al. (2018) identifies two levels of actors interactions within a value constellation network: Co-creation and Coopetition. Co-creation is where value is generated through the interaction between stakeholders in which both share resources and services to be mutually beneficial through a synergetic relationship. Coopetition is where value is generated through the interaction between stakeholders in which both share resources and services to be mutually beneficial but will compete in the end for their own market share.

Although co-opetition has been described in business literature since the 1990s (Mejtoft, 2011), it is highlighted as more challenging in an IoT ecosystem (Aivalioti et al., 2018). Due to the complex nature of IoT architecture, the resources often do not coexist inside a single company, resulting in system integration and these collaborations more critical. Based on previous research on stakeholders' role in value co-creation (Lusch & Nambisan, 2015; Smedlund & Toivonen, 2005) and multiple case study, scholars identify three types of roles and their activities in an IoT value constellation (Ikävalko, Turkama, & Smedlund, 2018; Lusch & Nambisan, 2015; Smedlund & Toivonen, 2005) (Table 5). The ideator represents the end users or customers, the beneficiaries of the service who works within user-driven development paradigm; Designers represent commercial actors; and intermediaries include public agencies and organisations.

Table 5 Roles and activities in IoT ecosystems adapted from (Lusch & Nambisan, 2015; Smedlund & Toivonen, 2005; Ikävalkoet al., 2018)

Role	Definition	Main activities	Illustration
Ideator	Bring knowledge about own needs, to the ecosystem. One- way knowledge flows. Providing input for service innovation	Articulate need Volunteer data Consume commercial service	
Designer	Mix and match existing knowledge components in the ecosystem. Reciprocal knowledge flows. Developing service innovation	Analyse data Develop and deliver commercial service	
Intermediary	Intermediate flow of knowledge and relationships in the ecosystem. Multi-way knowledge flow, orchestrating service innovation	Coordinate activities Enable access Control platform	

Multiple actors become more connected, which not only increases the complexity of value co-creation in both a vertical (co-creation to build an IoT architecture) and a horizontal manner (co-creation across sectors and industries) (Centerholt, Kjidderö, Saarikko, & Grahn, 2020). It also results in co-creation activities that are increasingly distributed, moving toward the periphery of organisations. The emergence of distributed innovation (Yoo et al., 2012) challenges companies to ensure the system and data control through the process of system integration, data sharing and data aggregating, which is critical for IoT value creation (Deichmann, Heineke, Reinbacher, & Wee, 2016; Kahle et al., 2020). This is further emphasised by Rymaszewska et al. (2017) that value creation can be much more effective if real-time information is flowing seamlessly and when it is shared between collaborating entities, such as human and non-human actors.

2.2.4 Overview

This section explored a multitude of theories on value and value creation. Value has long been regarded as a complicated term to comprehend across disciplines (Karababa & Kjeldgaard, 2014). Thus, the section began with identifying working definition of value for this thesis as 'benefits offered by a particular bundle of products and services delivered to the customers'. Then, to critically interrogate how value is created, it explored the related theories around the core constructs of G-D and S-D Logic concepts. G-D Logic is a worldview characterised by 'value-in exchange', 'a firm-centric approach', 'a linear-view of value creation', 'a customer as a destroyer of value'. On the contrary, S-D Logic is an alternative worldview of G-D Logic. It embraces 'value-in use', 'a network-oriented value creation perspective', and 'a customer as a value co-creator'.

Several scholars argue that S-D Logic is suitable to explain value creation for IoT (Lai t al., 2017; Breivold & Rizvanovic, 2018). In contrast, others disagree with the claims, saying that S-D Logic is not mature enough to be used as a concrete framework (Centerholt et al., 2020; Mejtoft, 2011). Consequently, this section critically reviewed emerging literature on value creation reflecting the attributes of this novel technology. Using the IoT value creation framework as a theoretical lens, the IoT ecosystem for value co-creation, Big data as a new asset, and digital components are discussed as central to IoT value creation. Understanding the wider context of how the '*value of IoT*' -benefits created by a particular bundle of IoT products and services delivered to the customers- is created over the NPD process will be further explored and synthesised with the findings in the discussion chapter. The following section examines a select number of NPD processes and attributes.

2.3 New Product Development (NPD)

As contemporary competitive pressure and pace of technological change increases, organisations face the challenges of increasing cost-efficiency, pre-empting competitors, and creating breakthroughs (Kessler & Bierly, 2002; M. H. Meyer & Utterback, 1995). In this context, New Product Development (NPD) is argued as the supreme determinant for competitive advantage for many corporations (Alam, 2006; S. L. Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991; Crawford, 1997; Kleinschmidt & Cooper, 1991) and the engine of renewal and survival (Andrews, 1975; K. H. Bowen, Clark, Holloway, & Wheelwright, 1994; Fairlie-Clarke & Muller, 2003). Consequently, the subject of NPD has gained a considerable amount of attention from professionals and researchers of product development and innovation (Durisin et al., 2010), business research and service innovation (Blazevic & Lievens, 2004; Froehle *et al.*, 2000; Johne & Storey, 1998; Menor et al., 2002), and software engineering (MacConell, 1996; Royce, 1970) over the decade. As the definitions of a product become broader and inclusive, wide variety types of a new product, service, and software development processes are identified within the literature.

The processes and methods of not only product development but also service and software development have evolved significantly over the late 20th century. However, they are regarded obsolete for digitised artefacts supported by software services which require entirely new approaches, considering the development of hardware, software, service, and data process in a holistic manner. Whilst there is research on the development process for integrated product and service offerings, such as product-service systems (PSS) (Aurich et al., 2006; Alonso-Rasgado & Thompson, 2006; Maussang et al., 2009; Tan *et al.*, 2010; Morelli, 2002; Vasantha *et al.*, 2012), systems of hardware and software (Department of Defense, 1988), or IoT development process (Jacobs & Cooper, 2018), there is a paucity of empirical studies that analyses the process of IoT development which not only combines NPD with Data Science Process but also considers several factors that affect reimagining entirely new approaches towards IoT. With so much potential value in the investment of IoT technology, organisations need to develop guidelines of NPD process to create income and minimize the risk in IoT development. As such, a discussion of the NPD begins with reviewing: a definition of what is meant by a 'product' and different definitions of NPD, NSD and SDLC; and existing NPD, NSD, and SDLC models and emerging models of integrated product development. Then the NPD chapter will conclude by identifying the generic phases of the NPD processes, characteristics, tensions and the challenges of different NPD approaches.

Before reviewing the definition of NPD, it is worthwhile to understand how the term 'product' is defined. In the Cambridge Dictionary "a product is something that is made to be sold, usually something that is produced by an industrial process or less commonly, something that is grown or obtained through farming". In marketing theory, a product is regarded as a bundle of utilities consisting of various features and accompanying intangible attributes (International Organisation for Standardization, 2015; Kahn, 2005; Kotler, 2000). In software engineering, it is still a controversial topic to scholars whether software and data are defined as either a product or a service or both are a product and a service. Meyer (2001) identified software as a product and a service. Sidi et al. (2012) and Huang et al. (2015) viewed data as a product (DaaP) whereas Psomakelis et al. (2020) viewed data as a service (DaaS). Whether they are a product or service, as a service is more commonly accepted as a product, in this thesis a product is defined as a broader concept encompassing physical and digital products/services/data regardless of its attributes.

2.3.1 Definition of NPD

New product development is defined variously, as the transformation of a market opportunity and a set of assumptions about product technology into a product available for sale (Krishnan & Ulrich, 2001). Similarly, product development is defined as a set of activities beginning with the perception of a market opportunity and ending in the production, sales, and delivery of a product by Ulrich and Eppinger (2011). The definition of NPD by Bruce and Cooper (2000) reads more inclusive, describing it 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. Johnson et al. (2000) define New Service Development (NSD) as the 'overall process of developing new service offerings'. This perspective is shared and extended by Edvardsson et al. (2000) to the scope of NSD to embrace strategy, culture, and service policy deployment and implementation.

NPD in software engineering is referred to as Systems Development Life Cycle or Software Development Life Cycle (SDLC). SDLC is defined as a process of creating and adapting software products, as well as a basis for creating methodologies and models in software engineering (Matkovic & Tumbas, 2010). The Department of Defense in the US (1988) define that the software development process is a process for managing the development of the deliverable software including major activities, which may overlap and may be applied iteratively or recursively. Ruparelia (2010) identifies it as a conceptual framework or process that considers the structure of the stages involved in the development of an application from its initial feasibility study through to its deployment in the field and overall maintenance. Ruparelia's definition of a software development process is distinguished to others by emphasizing its activities in maintenance.

Based on reviewing the definitions of NPD, NSD, and SDLC, a slightly nuanced view on each term is identified. NPD and NSD are likely to cover the complete set of business activities from ideation to launch whereas SDLC focus on development activities from the technical perspective. For this research, the working definition of NPD can be taken as a complex set of business activities for the transformation of market opportunities into a set of offerings for customers. There has been an active debate in the literature about the distinctive characteristics of products, services, and digitized products, and different models and approaches of development processes are reviewed in the next section.

2.3.2 Conventional NPD Processes Across Sectors

Over several decades, more than 600 diverse NPD models including all the variations of models have been developed by researchers with the aim of improving existing NPD practices (Nijssen & Lieshout, 1995). Through the review of models of innovation, Saren (1984) identified a taxonomy of innovation models into five different types: (a) Departmental-stage models; (b) Activity-stage models; (c) Decision-stage models; (d) Conversion process models; and (e) Response models. It is the most common to clarify particular activities that are performed during the innovation process which may be divided up into a series of discrete activities. Due to the limitations of this chapter, the review and discussion are mainly focused on activity-based NPD models. Specifically, those of the existing NPD models that are recognised as widely adopted and applied in industry, or influential works. This section comprehensively reviews conventional NPD processes in order to identify the differences and commonalities between approaches as well as between the development of physical products, software, or services.

New Product Development (NPD) Models

Within manufacturing economies in which Goods-Dominant Logic was dominant and companies were developing innovative products with push strategy, NPD processes are close to conventional linear approaches. Booz, Allen and Hamilton's BAH model (Booz et al., 1982), Walsh's over the wall process (Walsh, Roy, Bruce, & Potter, 1992) and Robert Cooper's stage gate model (R. G. Cooper, 1990) epitomise the early form of new product development model (Trott, 2012) (Figure 6). Within this sequential linear process, work is done in order through transferring the problems and solutions from one department to another and no one is responsible for the overall development process. A Stage-Gate System is one of the representatives of decision stages models which illustrates the NPD process as a series of decisions that need to be made in order to progress the project (R. Cooper & Kleinschmidt, 1993).

These types of models are popularized by Cooper (1994) who has developed a number of variations of a stage-gate process. One of the differences of a stage-gate model to the waterfall and 'over the wall' process is that at each stage all the team members meet to review and approve progression to the next stage. Despite the issues that occurred from the insular departmental view of the process such as increasing time and cost of product development, this conventional approach has been adopted by many large manufacturers. However, these sequential approaches are regarded too prescriptive and mechanistic, slowing down the process, so failing to take into account overlaps of activities that will occur naturally in the workplace (Margaret. Bruce & Cooper, 2001).

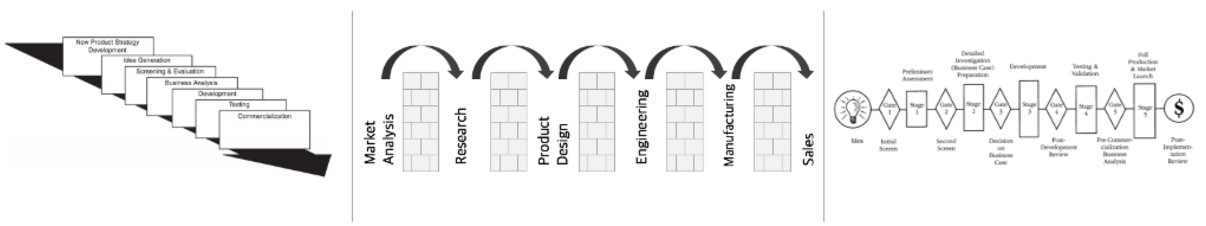


Figure 6 Over the wall Processes (The BAH model (Left), Walsh's Over the wall process (Centre), A Stage-Gate System (Right))

In an effort to increase the speed and quality of product development, the concurrent engineering approach attracts interest amongst many organisations. With the idea to consider the project as a whole rather than the singular stages (Trott, 2012), improved approaches, 'simultaneous approach' or 'rugby approach', have emerged, specifically, parallel processing models (Takeuchi & Nonaka, 1986), Activity-stage models (Crawford, 1997), and Concurrent Engineering (Pennell, Winner, Bertrand, & Slusarszuk, 1989) (Figure 7). Essentially, these approaches have key assets of: a) emphasizing the cross-functional approach (Trott, 2012) in which multidisciplinary teams working together from the beginning of the process; b) focusing attention to customer needs and quality improvement; c) promoting employee involvement in generating new ideas for improvement; d) establishing closer relationships with suppliers to include supplier involvement during the conceptual design phase (Allen, 1990; Pennell et al., 1989). It aims to increase the speed of the development process and 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 needs and preferences, allowing products to be more tailored, adaptable and desirable to the market (B. Evans, 1985).

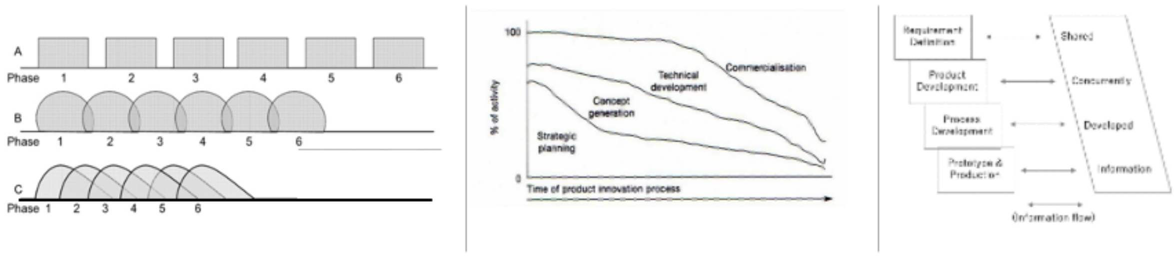


Figure 7 Rugby Approaches (Parallel Processing Model(Left), Activity Stage Model (Centre), and Concurrent Engineering (Left))

From the innovation literature, notable innovation models can be identified, such as Chesbrough's open innovation model (Chesbrough, 2004) and Berkhout's (2010) cyclic innovation model (Figure 8). Both of them are not presented as a model of design process nor activity-based model per se; however, they reflect the changing dynamics of new product development. The open innovation approach presents a funnel starting with scientific exploration and progressing via technological and product development to the market which emphasises the significance of having openness for ideas and suggestions driven from outside a company with regard to development activities. Due to its simplicity the open innovation model has been readily embraced by companies in the R&D community (Trott & Hartmann, 2009). More specifically, Caputo et al. (2016) argue that several factors result in the open innovation model being widely recognized which include the reduction of the product life cycle, the aggregation of global competition, and the rising cost of research and development. Although this model proposes a novel approach towards new product development, underlining the significance of external resources and interactions, its limitations have been critically identified.

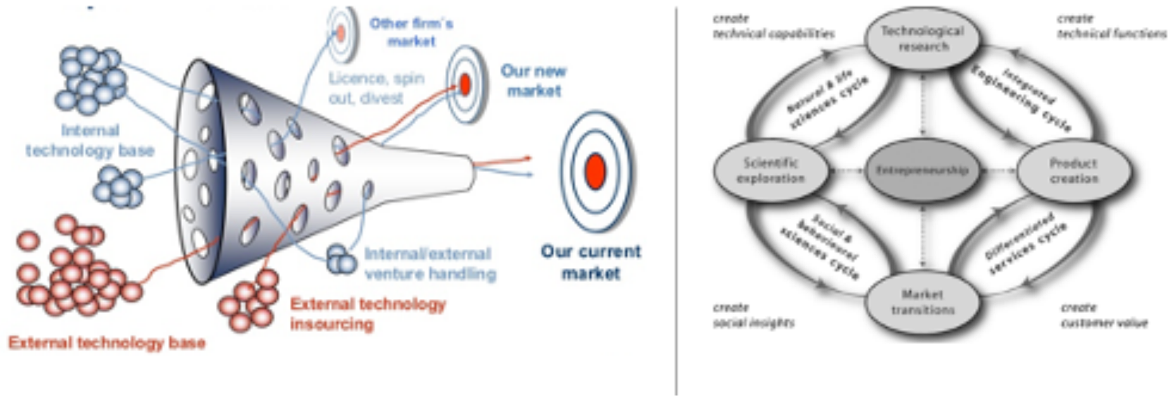


Figure 8 Chesbrough's Open Innovation Model (Left) and The cyclic innovation model (Right)

First of all, it is limited to a linear approach from R&D to marketing (Berkhoutet al., 2010) and it does not delineate a number of feedback loops and interactions which are likely to occur between the stages of the development process (Kline & Rosenberg, 1986). In order to supplement the limitations of the open innovation process, Berkhout et al. (2010) devised the Cyclic Innovation Model (CIM) which presents the processes in innovation by a circle of change (Figure 8). As shown in the visualization of CIM, Changes in science and industry, and changes in technology and markets are cyclically interconnected and knowledge and ideas are freely exchanged. Each node functions as a roundabout and entrepreneurs' function as circle captains. Unlike the linear innovation model which focusses on a technological and scientific breakthrough thus results in the market saturated with supply-driven products, the interactive model links the technology push and market pull models of innovation (Rothwell & Zegveld, 1985; Sundbo, 2002) which leads to clearer value creation.

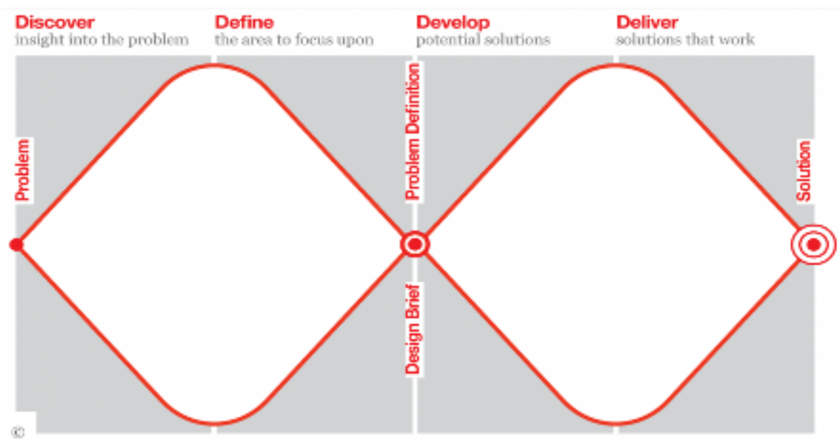


Figure 9 Double Diamond Design Process Model. (Design Council, 2007)

Similar to innovation models, the design process does not represent the full scale of a new product development process; however, the double diamond design process model (Figure 9), a representative of design processes, is included in reviewing with the rationale that understanding how to manage the design process is significant regardless of which process model used for new product development (Press & Cooper, 2003). This linear-shaped process for designing tangible objects shows four distinct phases, Discover, Define, Develop and Deliver, which mapped on the divergent and convergent stages of the process and the different modes of thinking that designers use. It matters significantly among organisations as this approach requires designers to be involved in creating value from initial ideas to final recycling (Design council, 2007).

Software Development Life Cycle (SDLC) Models

The oldest Software Development Life Cycle (SDLC) was established and presented by Herbert Benington (1956) (Figure 10 Left). It describes phases and the nature of a software development process which is commonly known as the Waterfall Model. Although the term 'waterfall' was first coined by Bell and Thayer (1976) in their paper, the numerous versions of the Waterfall models emphasise each development phase flowing downwards through pre-stated phases of a linear process (Larman & Basili, 2003). In Benington's process which consists of nine stages, each phase has to be conducted sequentially only once the previous phase is completed (Larman & Basili, 2003). In 1970, Royce (1970) introduced the most commonly known waterfall approach to systems analysis and design as the modern approach with the consideration of delivering projects 'at an operational state, on-time, and within costs' (Figure 10 Centre).

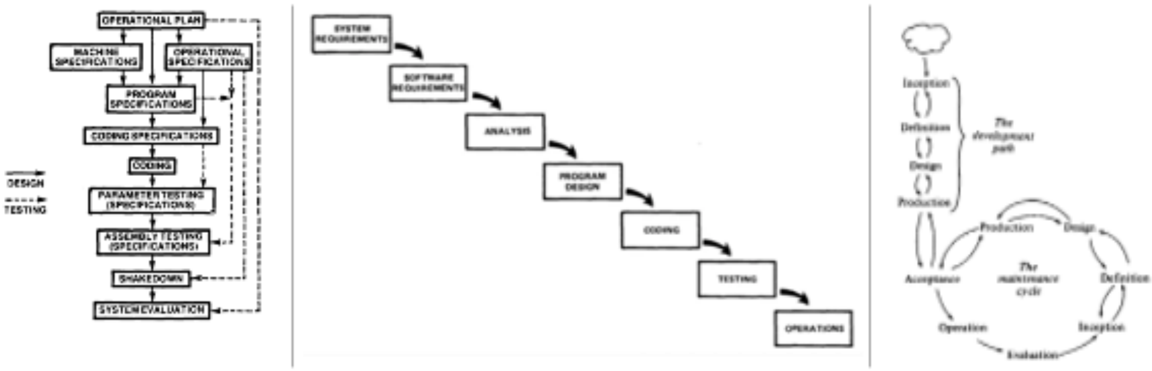


Figure 10 Waterfall Approaches (Herbert Benington's SDLC Model (Left), Royce's Waterfall Process (Centre), The b-model extends the waterfall model (Right))

Royce's waterfall process contains seven steps including analysis and coding which are the two essential steps for computer program developments. It begins with system requirements, software requirements, analysis, program design, coding, testing, to operations. In the Waterfall process, all requirements specifications are determined in advance with the assumption that they are known up-front and remained unchanging (Bassil, 2012; Royce, 1970). As Royce's waterfall process is strictly defined, it is largely adopted, being characterised by standardised activities with which the development flows systematically (Boehm, 1995; Matkovic & Tumbas, 2010). Birrell and Ould's b-model (1985) extends the waterfall process but divides the path into the development path and the maintenance cycle which reflects the attributes of the software lifecycle (Figure. 10 Right).

This model puts emphasises on the constant improvement of the software or system as part of the development stages. Despite its large adoption throughout industries, critical disadvantages initiated a number of alternative versions of traditional waterfall model which includes its' emphasis on fully developed requirement documents as completion criteria for the early phases, inflexibility between separate phases, impossiblity of iterations during the development, difficulites of adaptation to uncertainty, hardship to avoid erros in individual phases which lead to tremendous distortion impact on the development as a whole, lengthy development process and high development costs (Boehm, 1986; Matkovic & Tumbas, 2010).

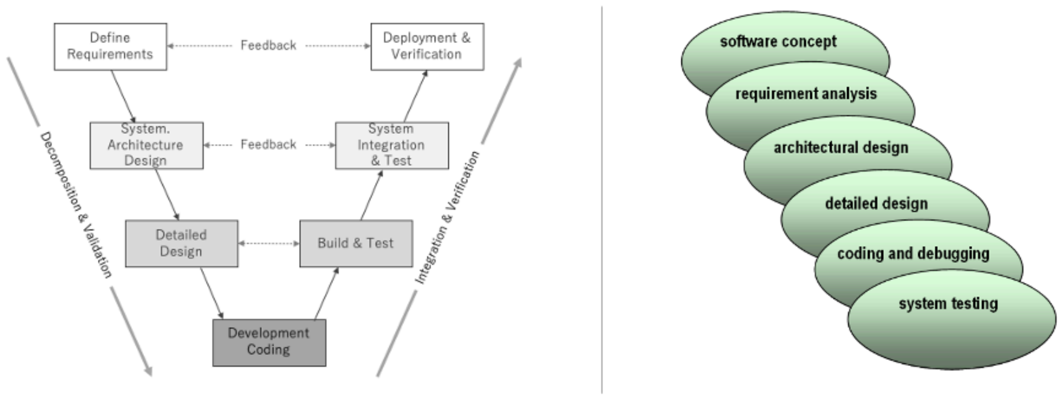


Figure 11 V-Shaped life cycle (Left) and Sashimi waterfall model with overlapping phases (Right)

The V-Shape life cycle (Forsberg & Mooz, 1991), first presented at the 1991 NCOSE symposium and developed by NASA, is one of the numerous modifications to the traditional waterfall process which focuses towards Verification and Validation (Figure 11 Left). It is an adaptation of the traditional waterfall process for modular system development, but the key difference of the V-model to classic sequential processes is its incremental approach through testing of the product and updating requirement documents in parallel with a corresponding phase of design. The left-wing of the process starting with define requirements, system design, architecture design, and detailed design then each step followed by testing activities such as deployment and verification, system test, integration test, and unit test happens before coding and development (on the right-wing of the process).

Each subsequent release of the module adds function to the previous release and the process continues until a complete system is achieved. Similar to parallel processing models, Activity-stage models, and Concurrent Engineering, a simultaneous approach which is a modified version of the waterfall model was proposed in software development, the so-called Sashimi model (Mcconnel, 1996) (Figure 11 Right). There are a couple of attributes of this model which are: a) to identify the errors while the development and implementation are still in progress; and b) to integrate each phase of the process as a whole and treat the requirement documentation as a unified document without the need of the document exchanged by the teams in charge of completing each individual phases (Balaji & Murugaiyan, 2012; Matkovic & Tumbas, 2010). Overall, the modification of the classical sequential process is to add iterative and incremental elements into the process which led to diverse approaches to SDLC that emerged, such as the spiral and agile process.

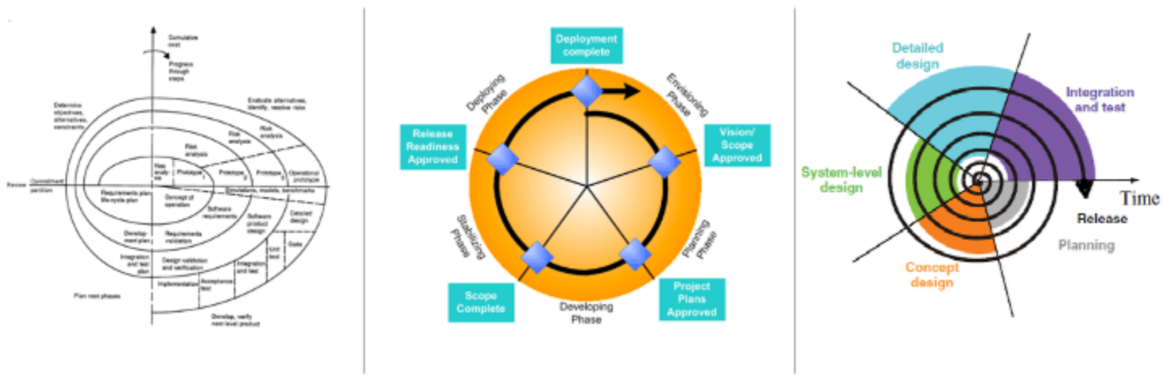


Figure 12 Iterative approaches (Boehm's spiral life-cycle (Left), MSF Process model (Centre), Unger and Eppinger's Spiral Model (Right))

The iterative approach is not completely new in recent SDLC. For example, Royce argued that the sequential process does not apply to the entire project, further suggesting complex communication and workflow through the modifications of the original waterfall model. However, the spiral model that has a great impact on promoting the iterative approach in software development is Boehm's spiral life-cycle model (Boehm, 1986)(Figure 12 Left) and later more spiral models have been developed such as Microsoft Solutions Framework (Microsoft Team, 2003) (Figure 12 Centre) and Unger and Eppinger's Spiral model (2009) (Figure 12 Right). They emerged from the concerns of a document-driven approach in sequential process with which the specification is elaborated at the early stage of the design phases, often resulting in poor understanding in user interfaces and decision support functions (Boehm, 1986).

Its emphasis is on risk analysis and an incremental approach, starting with the planning of business requirement specifications (BRS) and system requirement specifications (SRS), risk assessment, development, evaluation and planning for the next iteration (Ruparelia, 2010). The process reflects the bottom-line concept that each cycle entangles a progression that addresses the same sequence of phases (Boehm, 1986). Although the process enhances the possibilities of avoiding risks, strong approval, and control, and flexibility in development, due to the emphasis on risk analysis the process could turn out that it is costly through requiring highly specific expertise in risk analysis, and that project's success is highly dependent on the risk analysis phase.

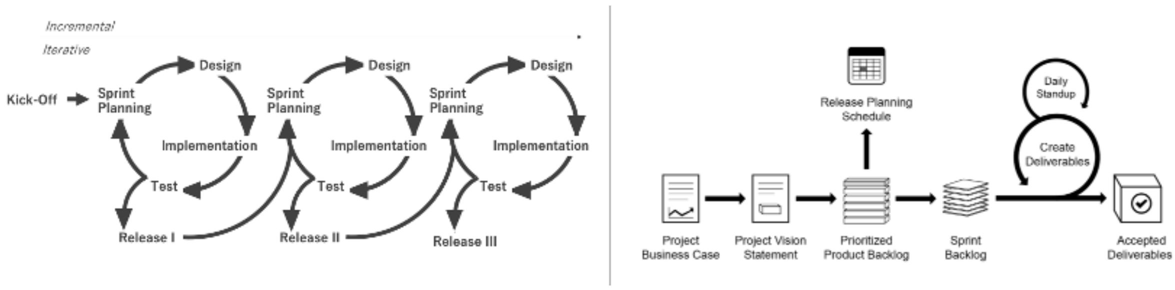


Figure 13 An Agile Software Development Process (Left) and Scrum (Right)

In the late 1990s, the flexible approach has been the primary aspect of NPD, based on the assumption that requirement specifications are likely to change during the design development phase. Thus, the processes that emphasise iterative, flexible, and incremental development are proposed, including the Agile development method (R. C. Martin, 2002) (Figure 13 Left), the Scrum software development process (Schwaber & Beedle, 2002) (Figure 13 Right), and Lean Development (Poppendieck & Poppendieck, 2003). These processes are comprised of a series of short development cycles, known as sprints starting with planning, design, implementation, test, and release. The key attributes of the Agile process are that the small incremental releases encourage ongoing changes to the product specification, and it aims to reduce documentation during development and a formal process-driven steps.

As advantages of these 'short iterative loops', it is argued that they improve close communication and coordination activities between business people and developers, speed to market, and faster responses to changing customer requirements (Beck et al., 2001; Begel & Nagappan, 2007). It begins to attract interest from hardware developers (R. G. Cooper, 2014; Ovesen & Sommer, 2013) who experienced the limitations and challenges of traditional design and development processes. The shift towards the agile development approach has become one of the most critical factors affecting the industry (Leffingwell & Widrig, 2010). Although disadvantages of the agile process, a lack of management, high potential of the project taken off track if the customer needs are not clear (R. G. Cooper, 2017), it is identified that software applications developed through the agile approach tend to have three times higher success rate compared to the waterfall approach (The Standish Group, 2014).

New Service Development (NSD) Models

In an era when manufacturing economies are replaced by service economies (Vargo & Lusch, 2004a), service development is considered a significant competitive concern to create value for customers in the industry (Andreassen et al., 2016; Corley et al., 2004; S. P. Johnson et al., 2000). The rationale is the changing focus from product-orientation to understanding why customers buy a particular service (i.e., a focus on value creation) (Andreassen et al., 2016). A recurring theme among scholars is that new service development should be different from new tangible product development (Johne & Storey, 1998) which stems from four characteristics of services, namely intangibility, inseparability, heterogeneity, and perishability (Zeithaml et al., 1985). Compared to the research on the models of NPD and SDLC, the paucity of NSD models is identified (Page & Schirr, 2008). There are a small number of papers examining the existing NSD models (M.-J. Kim et al., 2018; F.-R. Lin & Hsieh, 2011) but the majority of the models explored in the papers are the generic phases of NSD process. Thus, existing NSD models can be summarised including Scheuing and Johnson's proposed model for NSD (1989), Ramaswamy's service design and management model (1996), Johnson's New Service Development Process (2000), and Lin and Hsieh's Stage-Activity Framework of a NSD (F.-R. Lin & Hsieh, 2011).

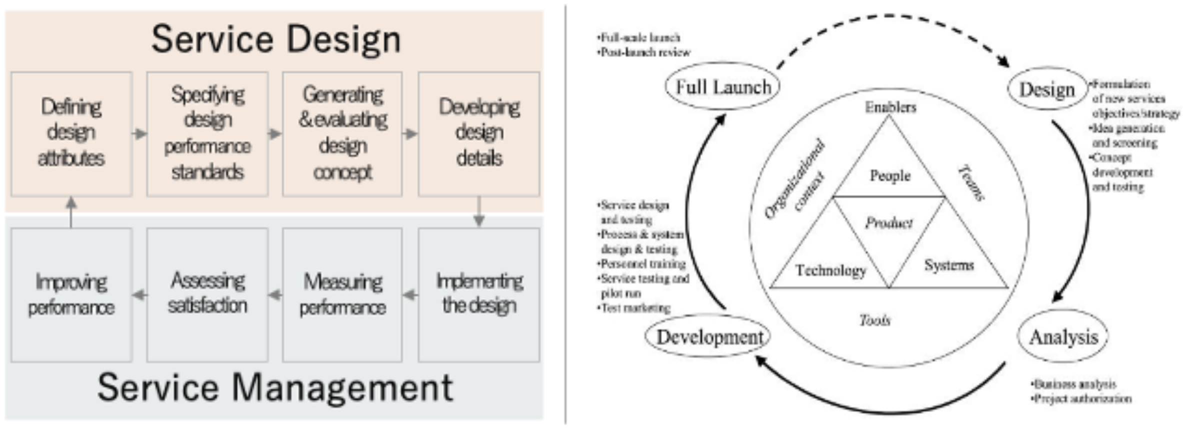


Figure 14 The service design and management model, adapted from Ramaswamy (Left), and Johnson et al.'s New Service Development Process (Right)

Reflecting upon the characteristics of services, Scheuing and Johnson (1989) propose a 15 stage linear NSD model through a survey of 66 US financial service companies. Ramaswamy's model (1996) consists of 8 stages of a development cycle, divided into the phase of service design and service management (Figure 14 Left). Once the service is launched, improvements of the service can be promoted at any stage in the NSD process by feeding back through earlier stages (Menor et al., 2002). Lin and Hsieh (2011) develop a spiral approach of stage-activity framework with five stages and sixteen activities for the NSD process. Johnson et al. (2000) integrates the previous research and propose their NSD Process cycle which now known as one of the representative service models. It encompasses 4 broad phases of design, analysis, development, and then full launch, and 13 activities that must be conducted to launch a new service, and the components of the firm that are involved within the process (Figure 14 Right). The cyclic nature of the development process implies the non-linear and highly iterative approaches which is common in most NSD. It is widely acknowledged that NSD process tends to be less formal than those found in NPD (Griffin, 1997).

2.3.3 Integrated Development Approaches and Others

Product/Service Lifecycle Management

Similar to NPD, SDLC and NSD, Product Lifecycle Management (PLM) is a product centric – lifecycle-oriented business model (Terzi et al., 2010). However, the stages of the process it covers are different. Particularly, PLM covers three main life cycle phases, Product Beginning of Life (design, production, and distribution), Middle of Life (usage and maintenance), and End of Life (upgrade and recycle) (J. Stark, 2011). In contrast, NPD is most likely relevant to BoL, which consists of stages like generating ideas and defining a detailed product specification and manufacturing. Service Lifecycle Management (SLM) has recently become significant due to servitisation, consisting of three main phases, service creation, service engineering, and service operations management (Wiesner, Guglielmina, Gusmeroli, & Dougmeingts, 2014). Understanding PLM and SLM is critical in NPD. It covers the entire lifecycle, and IoT blurs the boundary between physical and digital products, transforming a conventional lifecycle of a product and service.

Product Service System (PSS) Process Models

One of the widely recognised integrated development approaches, Product Service System (PSS) is proposed as a methodology to develop innovative business models from economic, environmental and socio-cultural perspectives (Komoto & Tomiyama, 2009). The notion of PSS differs depending on perspectives, such as a marketing, a service marketing, and a product management (Vasantha et al., 2012). But the common theme is that PSSs are composed of mutually interrelated physical and non-physical units (Aurich et al., 2006; Maussanget al., 2009; Marques *et al.*, 2013; Wiesner et al., 2015). Thus, a PSS methodology is the integration of product, and service development processes along their entire life cycle. There are a couple of PSS methodologies proposed with design process approaches, including Aurich et al. (2006)’s technical service design processes and Marques et al. (2013)’s product-service development methodology (Figure 15) both of which are thematic processes of integrated product and service design.

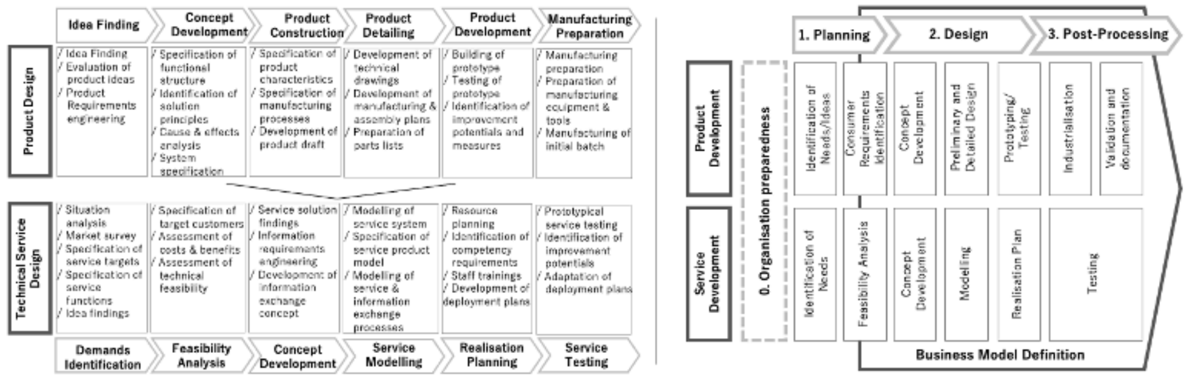


Figure 15 Aurich et al.’s Technical service design processes (Left) and Marques et al.’s Methodology proposal for product-service development (Right)

Aurich’s model is focused on the systematic investigation of the interrelations between products and technical services as well as corresponding design activities. Similarly, Marques’s methodology integrates both product and service development within four phases. Whereas Maussang et al.’s PSS design model illustrates the flows of development from customer’s needs to component development; from internal to external activities; and from system level analysis to component level analysis. Wiesner et al.’s PSS Lifecycle Model (2015) presents a combination of the high-level integration of PLM and SLM approaches. Although they are the hybrid of tangible and intangible products development, scholars identified a couple of limitations of current PSS processes, for example, the lack of details (Komoto & Tomiyama, 2009; Vasantha et al., 2012) representing partial rather than entire process from a life-cycle perspective (Welp, Meier, Sadek, & Sadek, 2008)(Mont, 2000). The scholars argued that identifying and differentiating products and services in modelling is a challenge (Vasantha et al., 2012).

Data-driven Design Process

Due to an ongoing lack of studies on integrated development processes, there are few stage-based process describing IoT development (figure 16 and 17). Jacobs and Cooper (2018) proposed a new approach to IoT development which is developed through combining existing design processes with underlying principles and related tools that must be taken into consideration when designing IoT products and services. This continuous IoT development process reflects one of the attributes of IoT development which is the functions and values of the IoT product and service can continuously evolve even after being launched, whilst being used (Jacobs & Cooper, 2018). Unlike this conceptual IoT NPD model, Hartsell et al. (2020) develop specific workflow automation for cyber physical system development processes which combines engineering and data processes. Moreover, Janne and Bogers (2019) propose the 8-shape model through empirical study in their research studies. It illustrates data-enabled design process and the role of data while the IoT system being used. Similarly, scholars from Information systems, Yu and Yang (2016) develop a big data analysis model within the NPD process, specifically for market analysis.

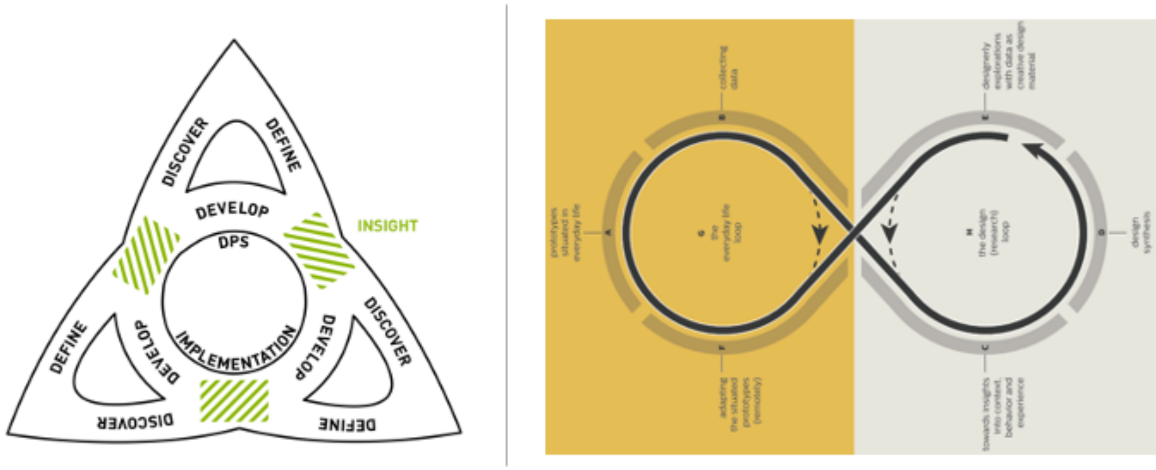


Figure 16 Jacob & Cooper's IoT Development Process (Left), and Janne & Bogers's The 8-shape design process (Right)

Tao et al. (2018) propose a digital twin-driven product design (DTPD) framework, which may guide manufacturing companies to develop digital twins and take advantage of the information provided by the digital twin to support the product design process. The authors devise five stages of the digital twin design process by adding virtual verification based on Pahl et al.'s systemic design process (2007). Then the relevant design and data lifecycle management activities in each stage are mapped on the framework. What is interesting in this model is that it adopts the form of the v-model to explain the interaction of each design activity. However, the model is expected to be used for the iterative redesign of an existing product instead of new product development, and it does not include algorithms development practice. Similar to Tao et al.'s framework, Feng et al. (2020) propose a data-driven product design framework. Through the model, the authors explain how different data can be utilised through different phases of a product's lifecycle, including design, production, distribution, usage, maintenance, upgrade and recycling.

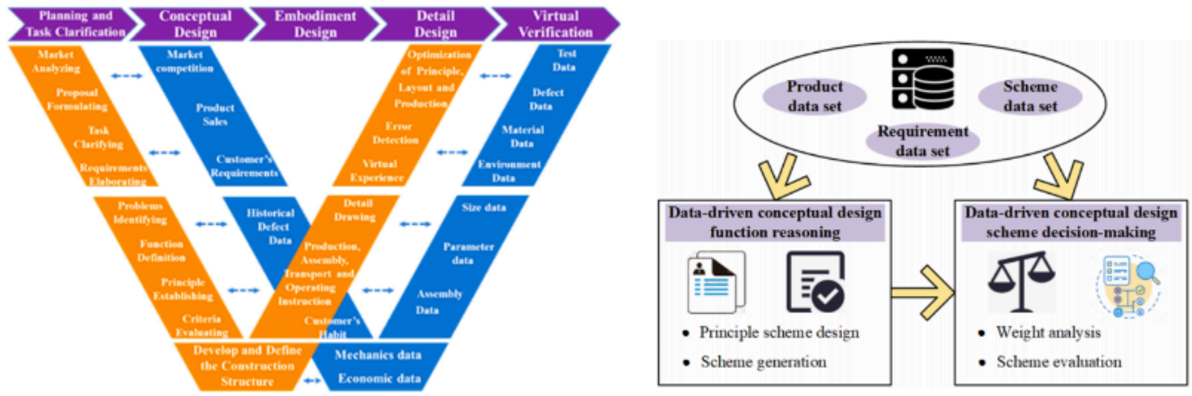


Figure 17 Tao et al.'s DTPD Framework (Left), & Feng et al.'s Data-driven product conceptual design (Right)

Although the existing data-driven design processes contributes to knowledge development, they are limited in several perspectives. Firstly, none of the processes illustrate entire activities and stages of the new product development. Secondly, they do not fully reflect the attributes of IoT development, nor encompass the different approaches of digital, physical and algorithms development. Last but not least, data-driven design explained through the existing models does not include algorithms development which is critical in IoT development. Overall, these processes still remain unclear regarding how to develop IoT products and services in order to continuously create value propositions; and how different development processes, NPD, SDLC, and data science process, run simultaneously and interact to each other alongside the IoT system development, and what are the challenges and risks of developing digitised products.

2.3.4 The Generic Phases of NPD Process

Each model consists of differently named stages but these are usually comprising of stages of new products or service strategy, idea generation and screening, concept development, business analysis, design, development and test, marketing and commercialization (Alam & Perry, 2002; Trott, 2012). The different NPD process models share similar stages from identification of opportunities to production (Ulrich & Eppinger, 2011) and the differences in stages between different models may be owing to the differences of the product attributes, innovativeness, and production process (Murthy et al., 2008). Through a thorough comparison amongst different development processes, the generic phases of NPD process for this research study and a couple of differences and commonalities are thus identified.

One of the strong commonalities firstly identified is that whether it is NPD, NSD, SDLC, or integrated models, it all starts with the Fuzzy-Front End (FFE) (P. G. Smith & Reinertsen, 1992) which is the initial stage of the process in which the organisations decide to build on an idea or not. Generally including idea generation, opportunity validation, and concept development (Dewulf, 2013), these activities are dynamic and feature a series of adaptive interactions between involved participants with varied skills. Even though the SDLC is likely to encompass technical aspects of activities, it still has FFE, involving defining software requirements, and software concepts. Referring to Stevens and Burly's observations (2003, p.17) 'the first few plays of the game determine the outcome', it is widely recognized that FFE is a critical phase, providing the foundations on which the overall development project is based. Consequently, an increasing interest on FFE research indicates that the fuzzy front-end shall be proactively managed and optimized to encourage the successful innovations (Khurana & Rosenthal, 1997; Jongbae. Kim & Wilemon, 2002; Reinertsen, 1999).

The distinctive characteristics of the physical and software products, the different emphasis on the NPD processes is identified in the literature. Pertaining to information systems literature, the different ways of product development between hardware and software, and tensions between the two in the digitisation of physical products were examined (Svahn, Henfridsson, & Yoo, 2009). A linear logic of innovation process powered by waterfall models originated from designing physical artefacts underlining the design hierarchy in which requirements of physical components are gradually broken down (Boehm, 1976; Royce, 1970). Thus, in hardware development, the NPD process is managed and controlled through the decomposition of requirements, whereas the main emphasis of software development is agility with a service orientation (Svahn et al., 2009). This is something to do with Goods-Dominant Logic and service-Dominant Logic. Without physical constraints, software service as a reusable unit of business-complete work (Papazoglou, Van Den Heuvel, Papazoglou, & Van Den Heuvel, 2007) can easily be reassembled to deliver novel features and user value. In this respect, the fundamental elements of software development process are agility with a sense-and-respond capability.

The differences between traditional product development, and service and software development is that NSD and SDLC processes tends to be less formal than those found in NPD (Griffin, 1997). Moreover, NPD processes tend to have a beginning and an end of the process as their final phases are commercialization, sales or deliver the products, whereas the final phases of SDLC and NSD processes are *evaluation*, *post-launch review*, and *planning next phase* which imply the following loop of the next development process. A recurring theme of NSD and SDLC is premised on that they are developed differently than new tangible products. These differences arise from characteristics of service, namely their intangibility, inseparability, heterogeneity, and perishability (Zeithaml et al., 1985) and the characteristics of software, the ability of constantly being revised and improved while being offered to customers. These characteristics of FFE and the final phase of development process will be carefully revisited when analysing IoT development processes.

Generic Phases of NPD	NPD						SDLC									NSD		PSS
	BAH model	Over the Wall	Stage-Gate Process	Activity Stage Model	Concurrent Engineering	Double Diamond Process	Program production	Waterfall	b-model	V-shaped life cycle	Sashimi waterfall	Boehm's Spiral lifecycle	MSF Process Model	Unger & Eppinger's Spiral	Agile	NSD process	service design & management model	PSS Design
1. Discovering Users & Business Needs	New product Strategy Development	Market Analysis Research		Strategic Planning		Discover			Inception			Risk Analysis				Formulation of service strategy	Defining design attributes	Customer needs External system analysis & Usage scenarios
2. Defining Concepts of & Strategies for Business & Technical Solutions	Idea Generation	Product Design	Idea	Concept Generation	Requirement Definition	Define	Operational Plan Machine/ Operational Specifications Program Specifications	System requirements Software Requirement	Definition	Define Require-ments	Software Concept	Concept of Operation Software Requirement Requirements Validation	Envisioning	Planning Concept Design	Sprint Planning	Idea generation Concept development & Testing	Generating design concept	PSS Function Mapping Approach PSS Layout & Running Scenarios
3. Testing Feasibility of Business & Technical Solutions	Screening & Evaluation Business Analysis		Preliminary Assessment Business Preparation					Analysis			Requirement Analysis	Development Plan	Planning			Screening Ideas Business Analysis	Evaluating design concept	External Component Analysis
4. Designing, Prototyping, & Testing Solutions	Development Testing	Engineering	Development Testing & Validation	Technical Development	Product Development Process Development	Develop	Coding Parameter Testing Assembly testing System Evaluation	Program Design Coding Testing	Design	System Architecture Design Detailed Design Development Coding Build & Test	Architectural Design Detailed Design Coding & Debugging System Testing	Software Product Design Design validation & Verification Detailed Design & Code Unit Test	Developing	System Level Design Detailed Design	Design Implementation & Test	Service Design & Testing Process & System Design & Testing	Developing design details	Component Development
5. Manufactur-ing, Marketing & Releasing Solutions	Commerciali-sation	Manufacturing Sales	Full Production & Launch	Commercialisation	Prototype & Production	Deliver		Operation	Production Acceptance Operation	System Integration & Test Deploy-ment & Verification		Integration & Test Acceptance Test Implementa-tion	Stabilising Deploying	Integration & Test Release	Release	Service Testing and Pilot Run Test Marketing & Full-scale launch	Implementing the design	
6. Evaluating & Planning the Next Phase									Evaluation			Plan Next Phase		Planning		Post-Launch Review	Measuring & Improving performance	

Figure 18 Generic Phases of the NPD, SDLC, NSD, and PSS process

Reflecting on the phases of different processes, the generic phases of NPD process can be identified that it contains six phases commencing with:

1) Discovering users and business needs (market research and analysis),
2) Defining concepts of and strategies for business and technical solutions (system and software requirements, business model, concepts of software, product, and service),
3) Testing Feasibility of business and technical solutions (system and business analysis, screening and evaluating the solution ideas),
4) Designing, Prototyping, and Testing solutions (developing prototyping, integrating, and testing plan, coding and debugging, casting),
5) Manufacturing, Marketing and Releasing solutions (Process development, Resetting organisation, and Modifying product design),
6) Evaluating and Planning the next phase (maintaining and after-sales service).

The generic phases of NPD process are intended to traverse the entire set of business activities from the transformation of market opportunities into a set of offering(s) for customers which is coherent with the working definition of the research study. The last phase of 'evaluating and planning the next phase' is supplemented by reflecting upon the recurring theme of NSD and SDLC. The term ‘products’ in this research study is not restricted to physical products but comprehensive of software, service and data products or the combination of all. This not only broadens the scope of NPD process for IoT but also considers significant design aspects of the combination of physical and non-physical products. The six generic phases will be used as a frame to examine and analyse the IoT NPD process.

2.3.5 Different Development Approaches

The waterfall model was highly influential around 1970 (Boehm, 1995), then when the sequential linear process was seriously being challenged in 1980s (Berkhout et al., 2010), other approaches have emerged, including parallel approaches, the spiral approaches, and agile methodologies (Figure 18). Existing NPD models are continuously evolving, supported by emergent trends of increasing significance of NPD activities which are closely related to the key attributes of value creation.

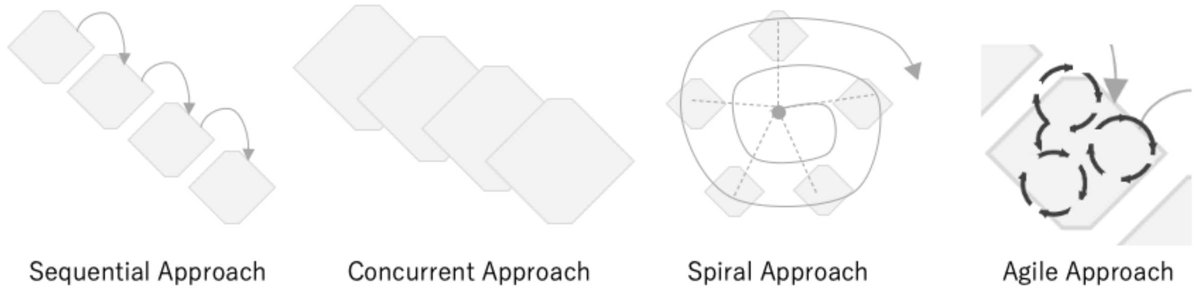


Figure 19 Different Types of Development Approaches

Sequential Approach

In literature, various types of product development models are found. The most commonly used and conventional models represent sequential processes often referred to as ‘BAH model (Booz et al., 1982), ‘a stage-gate system (R. G. Cooper, 1990)’, ‘over the wall process (Trott, 2012; Walsh et al., 1992),’ ‘Program production process (Benington, 1956)’, ‘The waterfall process (Royce, 1970)’, ‘The V-Shape life cycle (Forsberg & Mooz, 1991)’, and ‘The service design and management model (Ramaswamy, 1996)’. The attributes of the traditional sequential models are that the linear continuation of the process to the next stage is determined by a review and approval at the preceding gate in order to minimise investment risks; and the model strongly depends on fully developed requirement documents as completion criteria for early phases. Therefore, the sequential approaches are regarded as a lengthy development process, high development costs, difficulites of adaptation to uncertainty, inflexibility between separate phases, and the inability to react to changes.

Concurrent Approach

Concurrent approaches referred to 'Parallel processing models (Takeuchi & Nonaka, 1986)', 'Concurrent Engineering (Pennell et al., 1989)', 'Activity-stage models (Crawford, 1997)', 'Sashimi model (Mcconnel, 1996)', 'Unger and Eppinger's spiral model (2009)', and 'NSD model (S. P. Johnson et al., 2000)'. The approach is distinctive to sequential approaches as the feedback loops and overlaps of the phases emphasise the iterative nature of product development, the cross-functional approach, customer involvement, closer relationships with suppliers. As such, it increases the speed of the development process; enables flexibility to react to changes or errors while the development is still in progress; and leads to new philosophies of design in order to respond to the flow of new information on customer needs and preferences, allowing products to be more tailored, adaptable and desirable to the marketplace.

Spiral Approach

The representative spiral approaches include 'Boehm's spiral life-cycle model (Boehm, 1986)', 'Microsoft Solutions Framework (Microsoft Team, 2003)' and 'Unger and Eppinger's Spiral model (2009)'. The key attributes of the spiral approaches are that risks are assessed and monitored at each milestone; and complex communication and workflow is possible. With strong approval, control, and flexibility in development, the approach enhances the possibilities of avoiding risks. However, due to the emphasis on risk analysis, the process may become costly through requiring highly specific expertise in risk analysis.

Agile Approach

The agile processes, including Agile development method (R. C. Martin, 2002), the Scrum software development process (Schwaber & Beedle, 2002), and Lean Development (Poppendieck & Poppendieck, 2003), are overlaid over a traditional NPD process. The agile approach emphasises the small incremental releases for ongoing changes to the product specification; and the focus on reducing documentation and a formal process-driven steps. Although these approaches lack formal management, they improve closer communication and coordination activities, speed to market, and faster responses to changing customer requirements.

2.3.6 Varied Characteristics of NPD Processes

Reviews and Iterations

Balancing between structured review and flexible iterations is one of the significant characteristics in NPD. Unger and Eppinger (2009) argued that reviews and iterations vary in rigidity, frequency, scope, or several other parameters that affects risk management. Although all of the NPD, NSD, SDLC and integrated development processes have managerial control and allow flexibility, the manner of reviews and iterations varies dramatically. 'A stage-gate system (R. G. Cooper, 1990) and 'Boehm's spiral life-cycle model (Boehm, 1986) emphasise the review system with managerial control on risks, whereas an 'Agile development method (R. C. Martin, 2002)', and 'the Scrum software development process (Schwaber & Beedle, 2002)' emphasise iteration and flexibility to reduce ambiguity.

Flexible, Rapid and Lightweight Processes

Stability and predictability were highlighted as the promise of development within the traditional NPD process, thus rigorous requirement specifications on a fixed schedule and with fixed resources are required. However, regardless of service, tangible products or software development, the shift to more iterative, rapid, and lightweight processes with agility becomes a dominant trend over time, delivering 'outstanding benefits' on quality and productivity. Although some of the NPD models are illustrated as linear processes, they are commonly described as non-linear and iterative. Specifically, in software development, due to the fact that the continuous changes of system requirements occur over the process, the rapid and lightweight processes become a dominant and consistent theme over time.

Simultaneous Running with a Cross-Functional Approach

Firstly, the NPD process has evolved to run simultaneously with a cross-functional approach. From innovation theory, it is argued that the notion of a strictly linear process has been largely perceived as a parallel process in the 1990s. It is caused by several factors observed in industries such as innovation becomes faster, increasingly involves inter-company networking, and uses a variety of new technologies (Rothwell, 1993). This led to the multidisciplinary teams working together from the beginning of the process that was accompanied by market-led design.

Emphasis on External Network Interactions

As well as inter-company interactions, external network interactions are also emphasized to reduce uncertainty. As market conditions become more ambiguous, customer expectations change and marketing strategy evolve, recent approaches to product developments are more likely to co-work with customers, competitors, and suppliers specifically during the front-end stages. This enables enterprises to foster new strategic partners and establish comprehensive networks to create greater value. This can be further explained through the marketing and innovation theories on the value constellation model (Richard Normann & Ramírez, 1994), open innovation (Chesbrough, 2004) and co-creation with the customer (Royce, 1970). With the rationale of a distributed innovation environment in which ideas and knowledge derive from external sources, information systems studies argue that firms are required to organize for agility (Sambamurthy et al., 2003).

Hybrid of Different Development Processes

In an era of service-dominant logic(Vargo & Lusch, 2004a), the classical distinction of products and services on the basis of the so-called "special characteristics of services" is challenged (Lovelock & Gummesson, 2004; Vargo & Lusch, 2004b). Moreover, with the blurring boundaries of digital and physical products, the hybrid of hardware, software and service development approaches have emerged, and manufacturing and service activities are becoming progressively interwoven. In electronics, hardware development is becoming more like software development with shorter and faster iterations, the agile and the sprint approach becomes more suitable within the design and development processes.

2.3.7 Overview

This section explored the comprehensive literature to provide a deeper understanding of the existing theories surrounding NPD models and approaches in the landscape of engineering, software engineering, service development, innovation, product-service systems, and design. This section also examined emerging NPD processes with regard to IoT development which identified two shortcomings. Firstly, they do not reflect the distinctive factors that affect IoT development. Secondly, even though there is a limited number of integrated development processes including IoT development process, few existing models incorporate the data science process. Therefore, supports the primary research question:

- What is the conceptual model of the IoT NPD process, and how value for IoT is created?

Although the meaning of NPD is not commonly agreed among scholars, through the critical comparison between different models and approaches, the generic phases of the NPD process, the characteristics, tensions and challenges of different NPD approaches are identified. The discussions on the attributes and generic phases of the NPD process will be continued further in Chapter 6 while synthesising the findings from empirical data. In the next section, existing research on how design contributes towards value creation will be examined.

2.4 Design Contributions Towards Value Creation

Since Herbert Simon (1969) identified the diverse ways of how designers approach problem-solving, scholars have explored the role of design in organisations' competitiveness and innovation in the NPD process (Brown, 2008; Verganti, 2009; Luchs et al., 2016; Ostrom *et al.*, 2015; Press & Cooper, 2003) Design contributions towards value creation over the NPD process are varied from improving the functionality, aesthetics, and usability of products (Chiva & Alegre, 2007), developing corporate identity and brand (Beverland, 2005; Noble & Kumar, 2010), improving financial and nonfinancial performance of organisations (Gemser, Candi, & van den Ende, 2011; Ravasi & Stigliani, 2012), to creating and developing meanings (Verganti, 2008). Numerous studies demonstrate the significance of design in NPD and value creation in the business context (D'Ippolito, Miozzo, & Consoli, 2014; Moultrie & Livesey, 2014; Verganti, 2009).

While rapid and complex social, political and economic changes become the new imperative, the expectations of design as a transformational agent have been increased, and the role of design has been broadened its remit within both public and private sectors. However, despite diverse factors affecting the transformation of IoT value creation and development process, little is known about the current status of design activity within IoT NPD. Thus, in this section, the application and the role of design in the context of value creation is explored. This section concludes with identification of the knowledge gaps in current design roles in IoT value creation.

2.4.1 What is Design?

Design is originated from the Latin *designo* meaning to mark out, trace, plan; to point out, indicate, signify; and to portray or delineate (Latin Dictionary of the University of Notre Dame). While design as a discipline has a long history with its origins in art, architecture and industrial design, design as a word is considered both a noun and verb, referring to the end product or the process respectively (Glanville, 2015; Steinitz, 1995; Talke, Salomo, Wieringa, & Lutz, 2009). As a noun and the end product, design is used for the final plan of action (a drawing or model), or the result of the NPD process, such as product appearance (Eisenman, 2013). Design as a verb and the process represents the act of developing appealing, usable and functional objects which generally requires substantial research, modelling, iterative adjustment, and redesign (Roper *et al.*, 2016; Nijhuis & de Vries, 2019; Cecilia t al., 2008). Whether design means process or product, scholars' definitions of design is much debated and fluid in literature (Berger, 2009; Sparke, 2004; Walsh et al., 1992).

In the book '*The Sciences of the Artificial*', Herbert Simon defines design as 'the process by which we [devise] courses of action aimed at changing existing situations into preferred ones (H. Simon, 1969)'. Schön (1990) argues that Design is a term that has been used to encompass the entire range of artefacts and made by human beings: from buildings to organizations, behavioural worlds, and theoretical constructs. Aligned with Schön's theoretical foundation about design, Rittel and Webber (1973) assert that design is not solely providing solutions to problems, but should be an argumentative process. Klaus Krippendorf (1989) argues design as 'making sense (of things)'. It underlines the situatedness of the designer in a real-world, and illustrates the combination of roles, practices, and technologies involved in design (Fallman, 2003). Within this strand, design is understood as a hermeneutic process of interpretation and creating of meaning (Fallman, 2003) with which designers have constructive and reflective skills(Cecilia et al., 2008).

There is no single and commonly agreed definition of design as it can be understood inconstantly depending on the purpose, context, and situation. Apart from it, in the framing of this study, the author considers design as an interactive, iterative, and argumentative process of creating meaning through which design acts as an enabler of adding value to the organisation. It involves a dialogue with design materials and primarily amongst different actors, including designers, developers, users, and other stakeholders, as different values are conflicting (Cecilia et al., 2008). With this conception of design, the following section explores existing research on the role of design in the context of organisations' value creation.

2.4.2 The Role of Design within Organisations

In the context of how an organisation utilises design, research identifies different strategies of utilising design. Danish Design Centre propose four different levels of design based on a comprehensive survey which are: 1) non-design, 2) design as form-giving, 3) design as process, 4) design as strategy (Kretzschmar, 2003). The four roles of design identified through a large scale survey of over one thousand companies are widely accepted and considered a solid basis to comprehend the role of design within organisations (Tether, 2005; Heskett & Liu, 2012; Design

Council, 2013; Maffei et al., 2014; Strovang et al., 2014). Buchanan (2001) proposes that the four orders of design; symbols, things, actions and thoughts. Based on the four orders of design, Buchanan elaborates design disciplines within the organisational setting which is graphic design, industrial design, interaction design and environmental design (Buchanan, 2001).

Through a multiple case study methodology, Perks et al. (2005) demonstrates a threefold taxonomy of design strategies for NPD which are: 1) design as functional specialism, 2) design as part of multifunctional team, and 3) design as NPD process leader. Although scholars undertook different research methodologies, it can be categorised into three generic roles of design which are: non-design or design as styling; design as approach; and design as strategy (Table 6). Design as Styling is the conventional role of designers with which they make intangible ideas into tangible artefacts. On the other hand, the design utilised as process and strategy is relatively novel, which means it is not fully recognised as designers' activities in the organisational context. Thus, it is more likely considered the implicit design activities. They will be further explained in the context of value creation later in this chapter.

Table 6 Different role of design for value creation

Role of Design	Four orders of Design (Buchanan, 2001)	Design strategies for NPD (Perks et al., 2005)	Design Ladder (Danish Design Centre 2003)
Design as Styling	Symbols, Things	Functional specialism	Form-giving
Design as Process	Actions	Integrated element	Process
Design as Strategy	Thoughts	Leadership actions	Strategy

Design as Styling

Conventionally, when the design was mainly considered a form and function, the customer value was created with the push economy where linear and segmented NPD processes are dominant. Over the linear NPD process, designers' involvement was negligible or limited to the stages focused on the aesthetic or functional aspects of the product (Perks et al., 2005). When non-design, designers are not involved in any value creation activities, such as product development or marketing initiatives(Kretzschmar, 2003). When the design is considered as styling, the industrial designers contribute to value creation by anticipating and developing best-guessed goods (Speed & Maxwell, 2015) or improving the product and marketing materials at the periphery of the NPD process. The majority of value creation activities are undertaken by non-designers, such as engineers or marketers (Kretzschmar, 2003).

Once the nicely rendered best-guessed products are passed to engineers, designers modify them as manufacturable with little consideration of the aesthetics of human factors of the product (Braham, 1992). They are also involved in branding, designing a logo, improving type styling and colours to stamp a unique identity that secures a place on the shelves of shops (Speed & Maxwell, 2015). Designers' contribution to value creation is realised when the differentiation is perceived by the market (De Mozota, 1998). For example, a new package design may result in a sales increase, or a new product design may lead to cost or time savings to market (Westcott et al., 2013). With the push strategy, companies are able to sell the next product and keep making profits after the product being sold, then becoming obsolete over time (Hui, 2014).

Design as Process

As discussed earlier [section 2.2.3], whilst the economic paradigm has been evolved from a Goods-dominant Logic to Service-dominant Logic, from the push strategy to the pull strategy, the conventional linear NPD approach is gradually replaced with the concurrent, spiral and agile approach which has more emphasis on collaboration of internal and external stakeholders. This is around when companies utilise design as a process over the NPD process (Kretzschmar, 2003). Co-creation (Sanders & Stappers, 2008), co-design (Sanders & Stappers, 2008), and participatory design approaches (Schuler & Namioka, 1993) are integrated into NPD and value creation processes (De Mozota, 2006). In co-design, designers work with diverse experts such as researchers, developers and users (Sanders & Stappers, 2008). They are no longer delivering a marginal role in value creation but encouraged and emerge as key players of a multifunctional team (Perks et al., 2005). Solutions are driven by designerly way of thinking and doing characterised with iterative, user-centric, and participatory process.

Consequently, the way designers work for and design contribution towards value creation has been known as a facilitator (Lorenz, 1990; Wilson, 1995), a co-ordinator (Lorenz, 1990), a collaborator (Thornton, 1987), and a completer (Lorenz, 1990) alongside a skilled industrial designer. These changes lead to new philosophies of design in order to respond to the flow of new information on customer needs and preferences, allowing products to be more tailored, adaptable and desirable to the market. Lehoux et al. (2011) argue that integrating design into multi-functional teams recognises the nature of design as an essentially social process in which various individuals with different skills and functional perspectives 'create opportunities and set constraints which influence the design process'.

Design as Strategy

More recently, scholars from management and design have started to consider design as a strategic approach -often referred to as 'design thinking' (Brown, 2008) and as an alternative approach to conventional NPD processes and innovation (Verganti, 2008; Johansson-Sköldberg et al., 2013; Wardet al., 2009; Gemsera & Leendersb, 2001; Beckman & Barry, 2007; Bessant & Maher, 2009; Seidel & Fixson, 2013; Martin, 2009; Cross, 2011; Liedtka, 2015; Bruce & Bessant, 2002). Design is utilised to create and shape organisational vision as a critical driver for innovation (De Mozota, 1998). In this categorisation, the company can be considered 'design-led' or 'design integrated' by utilising and integrating design at a holistic business level (Bucolo & Matthews, 2010).

It enables designers to drive and support actions throughout the entire NPD process and across a broad range of value creation activities (Perks et al., 2005). Consequently, designers often develop skills to undertake non-design functional activities (Perks et al., 2005) while being retained to mediate value within a complex network of social and environmental connections (Speed & Oberlander, 2016). Extensive research highlights the need of the strategic level of design to innovate and to address users' needs (Chen & Venkatesh, 2013); to reinvent business models and NPD processes (Gruber, De Leon, George, & Thompson, 2015); and to offer unique insights to strategy formation and implementation (Best et al., 2010).

The Actions and Skills of Different Design Strategies in NPD Process

Perks et al. (2005) elaborates on the actions and associated skills undertaken in each phase of the Stage-Gate process (Figure 19). Each strategy is differentiated by the extent of design contributions towards the NPD process. The first category, design as a functional specialism, is associated with the specific design functional role, concentrating on a set of traditional design skills (i.e. aesthetics, visualisation and technical skills) and is excluded from other activities. With the second design strategy, design professionals are involved in diverse NPD activities to integrate functions throughout the development process. Consequently, the ability in effective communication in a cross-disciplinary and cross-functional team setting becomes an increasingly crucial skill for designers (Borja de Mozota, 2003; Mike Press & Cooper, 2003). The last category, design as NPD process leader, is regarded as a fundamental force for innovation. With the strategy, design professionals manage and lead actions throughout the NPD process and other related functional activities.

		Identification of the Needs	Concept Generation	Design and Development	Production	Launch
Functional Specialism	Actions	• Customer contact • Technology Exploration • Idea/Theme Generation	• Receiving Brief Design Research (e.g., Shopping bisits, Color, and Technology Research) • Design Decision-making (E.g., Design Theme and Mood Board)	• Designing Prototype, Packaging, and Launch Material (e.g., Sketch Designs, Colour Decisions, Catwalk Show) Making Prototypes (Use of CAD and Product Samples) • Sourcing & Trial of Materials Testing Prototype	• Transferring Design to Production	• Designing Launch Material
	Skills	• Creativity • Interpretation	• Observation • Visualisation Data • Analysis Creativity • Visual Literacy • Aesthetic Judgement	• Sketching Drawing • Model-Making Design/Ergonomic Analysis • Multidisciplinary Thinking / Creativity • Critical Analysis & Selection	• Design for Manufacture	• Visualisation
Part of Multifunctional Team	Actions	• Interaction with other functions (e.g., manufacturing, marketing)	• Interaction with Other Internal Functions (e.g., Manufacturing, Marketing) • Interaction with External Stakeholders (e.g., Suppliers)	• Detailed Negotiation & Liaison with Internal (e.g., Sales and Technical Staff) and External Functions (Suppliers)	• Organise Tooling Liaison with Manufacturing and Suppliers	
	Skills	• Communication • Diplomacy	• Relationship Management • Diplomacy Communication • Personal Promotion	• Relationship Management • Negotiation Project • Management Communication	• Technical Analysis • Negotiation	
NPD Process Leader	Actions	• Team Assembly • Market Observation & Research • Market Segmentation • Business Case Development	• Market and Technical Research • Informing the Team Trade Show Visits	• Observation of Response to Design • Customer Response Measurement • Consider Business Costs • Visit to Manufacturers and Suppliers Leading the Team and Stakeholders	• Monitoring Production • Quality Dealing with Manufacturing Problems	• Plan & Review • Launch (e.g., Manage Public Relations & Marketing)
	Skills	• Business & Market Analysis Interpretation Research	• Business Analysis • Motivating Others • Relationship Management • Communication Project Management	• Data & Business Analysis Interpretation • Leadership	• Persuasion Motivating Others • Project Management	• Business Analysis • Planning • Motivating Others' Persuasion

Figure 20 Synthesis of Design Actions and Associated Skills in Each NPD Phase

Although the fundamental principles of design remain constant, its application will be continuously evolved in industry and business (Norman & Verganti, 2011). With this understanding of how the company utilises design for value creation, it begs the unanswered question 'how design is utilised in IoT value creation and NPD development'. Consequently, the next section explores emergent research on design and its role and practice in IoT development.

2.4.3 Emerging Design Contribution in IoT NPD

Along with the complex IoT architecture, the unique properties and traits of digitised artefacts challenge organisations to create value. There is an increasing number of literatures that the design disciplines and contributions should go beyond its traditionally agreed consensus within the context of IoT development. For example, design scholars put efforts to resolve privacy, security, trust and ethical issues caused by the high degree of automation, interconnectivity and processing of sensitive private data. Furthermore, they argue designing the hybrid of tangible and intangible products requires a comprehensive understanding and considerations of the invisible elements of IoT, including data, algorithms, network, infrastructure as well as the whole value constellation throughout continuous NPD cycles. The advent of the Internet and the development of IoT, challenges designers with a more complex array of data forms that are mediated in different ways

(Speed & Oberlander, 2016). As such, it requires reframing of how designers design surrounding connected artefacts and datasets. Scholars from HCI and design argue that strategic level of design- often known as design thinking- is to be integrated into data science process, from data capture, data management to user models and data visualisation and analysis (Churchill, 2012; Deutsch, 2015; Speed & Oberlander, 2016).

Design as a Medium of Decoupling Material Properties

Embedding digital technologies into physical products decouples form from function and media from content, which brings opportunities for creating novel products (Yoo, 2010; Tilsonet al., 2010; Jonssonet al., 2009). With these decoupling's, designers are able to provide new digital properties to IoT products and services (Yoo, 2010) basis on the design decisions on what sensors and software to be embedded, how data could be effectively managed and curated. As a result, design activities become more agile (Svahn & Henfridsson, 2012; Yoo, 2010) to have the scope, feature and value proposition of IoT products and services continuously evolved even after being launched and whilst being used (Ng, 2014).

In the domain of HCI, the decoupling could be related to the conception of 'affordance', the meaning or value of something consists of what it affords (Gibson, 1977). Norman (1988) suggests that the role of design is to make affordances easily perceptible to potential users. However, as a single connected device could have the convergence of multiple affordances (Yoo et al., 2012), designing IoT with clear affordances could be more challenging than designing conventional products. According to Norman, affordances are strategically created by designers, and in this regard, an emphasis on the imagination could be a possible solution to designing the IoT.

More Than Human Centred Design

As the term Internet of Things implies that 'things that are connected to the internet (IPSO Alliance, 2008)' communicate to each other and make decisions with a minimum of human intervention, Coulton et al. (2018) identify the interrelated collections of objects as an IoT constellation which is built on top of Object Oriented Ontology (OOO), a philosophical theory that puts objects at the centre of being. The visible part of IoT, a tangible object, is illustrated in figure 8a, but there are invisible elements which exert significant influence in the IoT and are often overlooked, such as data, algorithms, networks, and infrastructure (Figure 20) (Coultonet al., 2018). In IoT development, it is argued that it should be more than human centred design, Consequently, the scope of product design, i.e., 'a complete description of the structural elements of a particular artifact' (Baldwin &

Clark, 2000, p. 42), covers not only the tangible components of the product, but also the digital materiality and value proposition achieved through data.

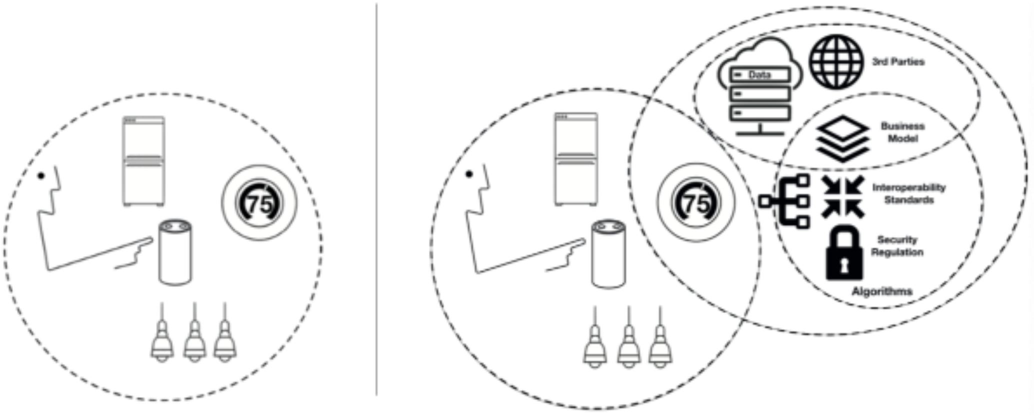


Figure 21 Visible things in an IoT enabled smart home system (Left) Visible and Invisible things in an IoT enabled smart home system (Right)

A Spectrum of Data Centric Design

Data has been the source for designers, architects, and engineers to work with for some considerable time. However, in the digital era, big data is understood to be almost entirely as quantitative data which has not been familiar to designers and also become complex, heterogeneous and ubiquitous (Mayer-Schönberger & Cukier, 2013). In this manner, scholars explore how design intervenes within the data science process.

Table 7 Theoretical framework of different uses of data (Speed & Oberlander, 2016)

Approach Types	Definition
Designing from Data	The use of data as utilising established methods which designers can learn and design 'from' the materials, i.e., ethnographic methods, interviews, cultural probes, technology probes, and contextual mapping
Designing with Data	The use of data as a critical part for designers to understanding and designing 'connected artefacts' while being connected 'with' a user or community, i.e., diverse digital ethnographic methods, including virtual ethnography, netnography, cyber-ethnography, and online ethnography
Designing by Data	The use of data as a system design supported by algorithms, i.e., generative algorithms

Speed and Oberlander (2016) introduces a theoretical framework to support designers to reflect on their conventional practices of working with data in the context of using data-collecting artefacts in the design process. This framework uses the ablative case in Latin in order to differentiate the uses of data to designing 'by', 'with', 'from' data. Designing from data is utilising established methods which designers can learn and design 'from' the materials. The constant connection to the internet between connected artefacts enables designers to stay connected 'with' a user or community to better understand the impact of data-centric products and services. Designing by data is the probability that data, supported by machine learning algorithm, will design the product demonstrating good value.

Table 8 The categories of data and design (King et al., 2017)

Approach Types	Definition
Data-driven	Collected data determines (drives) design decisions
Data-informed	Data is used as one of the inputs in decision-making (among many)
Data-aware	Designerly practices are not only led by data, but also used in data collection practices

King, Churchill, and Tan (2017) identify three typologies of how data and design have been positioned in the design process of digital products and services: Data-driven, data-informed, and data-aware. Data-informed design is a practice in which design professionals utilise data as one of the inputs into their decision-making process. Data-aware design is introduced with an argument that design decisions are not only taken from data but back to data collection as well as system level design. From data-driven to data-informed and data-aware, different levels of design interventions can be identified. With data-driven approach, the types of questions a team asking designers is very precise and clear, thus, designers undertake specific and given tasks. Data-informed approach is useful when a problem space is not fully explored, and further iterations are required. Practice with a data-aware mindset stresses strategic design approach: designers' unique viewpoint on the design of experimental hypotheses for data collection; collaboration with not only data scientists but also a broader group of experts to identify the right data types and address the right questions; and apply a strategic level of designerly ways of thinking.

Although the frameworks are identified from different design professions, architecture, connected products, and digital products and services, they are somehow interrelated in terms of illustrating the various ways of combining data into design practice or the mindset in order to make design decisions with data. Deutsch's spectrum of data-centric approaches (2015) places emphasis on organisations' practice of and relationship to data whereas King, Churchill, and Tan (2017) argue that as a design practice starts from data-aware to data-informed and data-driven, the degree of collaboration and the problems space becomes narrower, and design decisions become less about types of problem to solve but more about design solutions. Speed and Oberlander's framework of different uses of data (2016) are about different design practice depending on the smartness degree of connected objects.

Emphasis on Design as Creating Meaningful Social Value

The emergence of an era of IoT and big data has resulted in the growth of interdisciplinary interests beyond a purely technical perspective (Boyd & Crawford, 2012; Mayer-Schönberger & Cukier, 2013). Specifically, ethical issues underpinning security, privacy and trust concerns are increased, due to the high degree of automation, interconnectivity and processing sensitive private data. In the design literature, research interest on the integration of ethical and moral values into the design of information and communication technologies have recently increased. It leads to considerable scholarly discussion on trust as a topic and how designers increasingly take the role of encouraging user trust (Nickel, 2015).

Although, design has shaped the way people think and behave through creating the man-made objects and environments (Redström, 2006), design research on trust is a relatively under-explored topic and the research landscapes are limited to the functional usability and user interface at the interactional level with the systems (Harte et al., 2014; M. C. Lin, Hughes, Katica, Dining-Zuber, & Plsek, 2011). Despite a paucity of design communities research on design for trust, Bhattcharya et al. (2017) identify three levels of service design approaches towards transaction efficiency; transparency and engagement; and participation and collaboration. They argue that a trust-based service design could relieve the ethical issues and drive a better adoption of novel technology.

2.4.4 Overview

This section explored the role of design within an organisational context. It discussed how design has contributed towards value creation and what emerging roles design takes. Through understanding existing literature, three-levels of design contributions towards value creation are identified: Design as Styling, Design as a process, and Design as Strategy. More specifically, it explored what design activities and associated skills are required depending on the different roles of design in each NPD phase. Although there is research on emerging design practices related to IoT development, they often lack empirical evidence on how design actually intervenes in IoT development processes and if there is a paucity of understanding of design roles between industry and academia. As such, this position supports the research question:

- How does design contribute towards IoT NPD?

2.5 Chapter Summary

This chapter has presented an analytical literature review of value creation activities, NPD practices and processes, and the role of design within an organisational setting. Through a literature review, it is identified that there is a lack of research on value creation activities, NPD process for and design contributions towards IoT. The discussion on value creation, NPD process and design contributions - the key concepts surrounding IoT - are diverse and not fully agreed upon. Here are the key considerations that have been identified through this chapter:

- S-D Logic concept is considered dominant and more appropriate in the digital economy. However, several scholars argue the distinctive perspectives on IoT value creation which can be summarized into three critical points. First, unlike G-D and S-D logic in which human actors leads value creation, the digital components can play a significant role as value creation actors. Secondly, data is a new asset for value creation through recombination, re-contextualisation or re-interpretation of different datasets. Lastly, supported by an S-D logic perspective where value is created within a value constellation, the potential value of IoT arises from the interplay and the value co-creation activities among multiple actors, which can be categorised as ideators, designers, and intermediaries.

- While there are no agreed NPD models and definitions, the current literature adequately addresses valuable insights on the six generic phases of NPD, SDLC, NSD, and PSS, which are: 1) Discovering users and business needs; 2) Defining concepts of and strategies for business and technical solutions; 3) Testing Feasibility of business and technical solutions; 4) Designing, Prototyping, and Testing solutions; 5) Manufacturing, Marketing and Releasing solutions; 6) Evaluating and Planning the next phase. These phases will be compared with the IoT NPD phases and critically discussed for the conceptual model development.

- There are four types of NPD approaches identified which are: Sequential Approach, Concurrent approach, Spiral approach, Agile approach. Each approach has distinctive merits and limitations of developmental activities. Moreover, the attributes of the NPD process are identified, which are: a) Reviews and Iterations; b) Simultaneous running with a cross-functional approach; c) Emphasis on external network interactions; d) Iterative, rapid, and lightweight processes; e) Hybrid of different development processes.

- As the economy paradigm progresses, the role of design has evolved from the focus on the aesthetic or functional aspects of a product to strategy and process. With the advancement of technology alongside a number of development challenges, design scholars propose where design could bring value in IoT development, for example, creating meaningful social value by resolving critical ethical IoT issues, engendering a more user-focused system with a data-centred design approach, and achieving business goals, understanding invisible elements including value constellations, data, and algorithms.

CHAPTER 03

Research Methodology

3. Research Methodology

3.1 Introduction

In Chapter 1, a research aim and research questions were identified based on the research background. In Chapter 2, literature on value creation, NPD, and the role of design in NPD has been critically reviewed and analysed to comprehend the foundational knowledge. Chapter 3 sets out the appropriate philosophy, approach and strategy used to address the research problem, aim and questions (set out in Chapter 1, Section 1.3 and below).

Table 9 Research Problem, Aim and Questions of this thesis

Research Problem	**The research problem addresses that the lack of theoretical understanding of IoT NPD process, practice, and value creation**
Research Question	What are the conceptual IoT NPD process and the design roles which aim to create value propositions for organisations?
Research Aim	This research aims to develop a conceptual model of NPD process for IoT products and services and investigate the role of design for value creation within IoT NPD process
Research Questions	According to the research aim, sub-questions are addressed: • RQ1: What are the existing and emerging theories on value creation, NPD process, and design roles in the organisational setting? • RQ2: How is an IoT system developed with the aim of creating value propositions for organisations? • RQ3: How does design contribute to IoT development and value creation? • RQ4: What is the conceptual model of IoT NPD practice and process reflecting value creation strategies and challenges?
Research Objectives	• RO 1: To understand existing and emerging theories on value creation activities, NPD models, and the role of design in the business context • RO 2: To identify how IoT systems are designed and developed, aiming to create value propositions for organisations • RO 3: To develop a conceptual model and identify design interventions for value creation within IoT NPD process

To address the defined research questions, it is required to understand how to design the research in terms of philosophical assumptions, approach and strategy. The research design is defined as “a logical plan for getting from here to there, where here may be defined as the initial set of questions to be answered, and there is some set of conclusions (answers) about these questions" (Yin, 2008, p.26). In short, it refers to decisions about how to achieve research aims, linking theories, questions and goals to apt methods and resources (Flick, 2018). In research design, a strong emphasis should be placed on the analysis and selection of the research methods as the research methods are the basic guidelines of knowledge creation (Arbnor & Bjerke, 1997). The choice of research design was achieved through careful considerations of the multiple research options available, the aim and questions of the research, and the implications of the epistemological stance. In order to initiate and develop a research design, Michael Crotty's (1998) four basic questions are considered for a comprehensive approach toward making adequate decisions regarding overall research design. The key questions for research design include:

- What philosophical stance, epistemology and ontology will support the research?
- Which research approaches will be adopted for the reasoning of this PhD research?
- What research strategies and methodology will be employed for this PhD research?
- What research methods will be used?

This chapter outlines the most effective approach to answer the research questions, considering the benefits and drawbacks of different research paradigms, approaches, and methods. Section 3.2 discusses the research philosophies, approaches (deductive and inductive), strategies and methods from the rationale for undertaking this PhD research. Section 3.2 describes case studies in terms of research design and data collection. It also states the rigorous approaches involved in the chosen research methods. Lastly, Section 3.4 provides how data is analysed and how reliability and validity of research is achieved.

3.2 Rationale for Research Approach

3.2.1 Research Philosophy

Undertaking research begins with having a philosophical orientation about ontology and epistemology. Ontology is related to the nature of social reality, and epistemology is the nature of knowledge (Creswell, 1998; Easterby-Smith, Burgoyne, & Araujo, 1999). Research philosophy is defined as a shared worldview that represents the beliefs in a discipline and that guides how problems are solved (Schwandt, 2001). Understanding the philosophical position is a significant strategic decision as it is the foundation of the research design, helping researchers clarify the research design and recognise which designs will work and will not (Easterby-Smith et al., 1999). The terminology of research philosophy is referred to variously depending on the researchers, for example, the worldview (Creswell, 2009), paradigms (Guba & Lincoln, 2005; Mertens, 1998) or broadly conceived research methodologies (William L. Neuman, 2000). Regardless of its terminology, positivism and interpretivism/constructivism (sometimes they are used interchangeably) are regarded as two main views of research philosophy (Wisker, 2008) (Table 10).

Table 10 Comparison of Positivism and Interpretivism (Constructivism). Integrated from studies by Lincoln & Guba (2005), Creswell (2009), Gray (2014), and Bhaskar (1979)

	Positivism	**Interpretivism (Constructivism)**
Ontology: What constitutes reality	Naïve realism/ Realism: 'real' reality but apprehendable There is only one single truth	Relativism: local and specific constructed realities and co-constructed realities Reality is subjective and differs from person to person
Epistemology: What constitutes acceptable knowledge	Objectivist: Finding truth The world is external and objective; thus, truth is a matter of the authenticity of an experiment and its factual results	Subjectivist: Creating truths The world is subjective; thus, truth is a matter of the authenticity of interpretation and its reconstruction
Research Approach	Deductive approach : Identifying phenomena : Constructing and testing the explanations for the phenomena : Describing the generative mechanisms	Inductive approach : Understanding previous knowledge/ theories : Collecting and analysing real world phenomena or practices : Developing new theory or model

Positivism adopts the philosophical stance of the natural scientist (Saunders et al., 2006). Subsequently, positivists are likely to use a highly structured methodology with a deductive approach to producing generalizations known as scientific laws (Gill & Johnson, 2002). They assume that social entities exist in reality external to social actors. The stance of positivism asserts there is only one true, objective knowledge that transcends time and cultural location (Potter, 2006). With an objectivist stance, reality is observable, stable, and measurable. Therefore, knowledge gained through studying this reality has been labelled 'scientific' and included the establishment of 'laws'

(Merriam, 2009). Within the positivism, it is believed that 'the researcher is independent of and neither affects nor is affected by the subject of the research' (Remenyi *et al.*, 1998: 33).

In contrast, interpretivism is a manor anti-positivist stance that looks for 'culturally derived and historically situated interpretations of the social life-world (Crotty, 1998: 67). Interpretivism, often used interchangeably with constructivism, advocates the necessity of the researcher to understand differences between individuals in our role as social actors (Saunders et al., 2006). Truth and meaning are created by the subject's interaction with the world (Creswell, 2009; Gray, 2014). With the inductive approach, interpretivism accepts that multiple knowledge exists and is highly contingent on time and cultural location (Potter, 2006). In other words, they assume that multiple realities exist concerning a single event, and the realities are reported based on the researchers' opinion or interpretation of informants that the researcher interacts with. The researcher is part of the findings shaped by their own experiences and background (Creswell, 1998).

This thesis is based on constructivism as it aims to understand NPD processes for IoT products and services based on the interpretation of multiple participants' points of view. The author believes there is no objective 'truth' in the practice and process of new product development. There are complex factors interrelated to the nature of NPD, which can hardly be reduced to a set of observable 'laws'. Thus, IoT development and the role of design within the development process can be socially constructed based on different participants' experiences and knowledge on the investigated projects. This thesis aims to look for 'thick descriptions', through the collection of qualitative data. In the next section, the research approaches for different research philosophies are reviewed to identify the appropriate research strategy for this PhD research.

3.2.2 Research Approach to Theorising

John Dewey (1933) outlines a general paradigm of enquiry that supports the scientific approach, consisting of inductive discovery (induction) and deductive proof (deduction). The deductive approach begins with a universal view of a situation and works back to the particulars; on the contrary, the inductive approach moves from fragmentary details to a connected view of a situation. Deduction involves the construction of a hypothesis (or hypotheses), and a research strategy is designed to test the hypothesis. In comparison, the inductive approach is a "research-before theory" strategy that allows new problems or phenomena to emerge from empirical research (Nachmias & Nachmias, 1996). Positivism underpins deductive reasoning, and interpretivism underpins the inductive approach. The nature of this research tends towards an inductive approach because it will explore the relative subjects of NPD, the role of design and value creation for IoT development. Each research approach has its own strengths and limitations and will be reviewed through table 11.

Table 11 Comparison between research approaches. Integrated from studies by Merriam (2009), Creswell (2009) Easterby-Smith et al. (1999) Gray (2014), and Saunders et al. (2006)

	Deductive	**Inductive**
Goal of Investigation	Explanation: prediction, control, description, confirmation, hypothesis testing, generalisation	Understanding: discovery, meaning, Hypothesis generating, interpretation, reconstruction and description
Research Strategies	Experimental/Manipulative; Verification of hypotheses; Chiefly Quantitative methods	Hermeneutic; Phenomenology; Ethnography; Grounded theory; Naturalistic/ Chiefly Qualitative methods
Research Design	Predetermined, Structured	Flexible, evolving, emergent
Type of data	Mainly quantitative data: large, random, representative samples	Mainly qualitative data: Small, non-random, purposeful samples
Mode of analysis	A range of data can be numerically analysed (Deductive analysis by using statistical techniques)	A range of data can be hermeneutically interpreted (Descriptive, text analysis by interpretation of data)

The deduction approach is originated from what we think of as scientific research (Saunders et al., 2006). It is the dominant approach in the natural sciences. Laws present the ground of explanation, enable the anticipation of phenomena, predict the occurrence of phenomena, and permit them to be controlled (Collis & Hussey, 2003). It could be explained as an experimental approach that employs either a hypothesis to be tested or a research question (Gray, 2014). A theory is developed through a highly structured methodology (Gill & Johnson, 2002). The process of deductive reasoning begins with examining existing theory or an abstract relationship between concepts. It moves towards concrete empirical evidence through testing the hypotheses or the abstract against hard data (W. Lawrence Neuman, 2006; Robson, 2002). The hypothesis is deduced by being confirmed or rejected with research findings; therefore, the theory is modified in the light of findings (Bryman & Bell, 2011). A range of data collected are mainly quantitative which are large, random and representative samples that could be numerically analysed.

Being wary of deduction, inductive approach has gained interests by the researchers in social science (Saunders et al., 2006). In general, the inductive approach is regarded as a suitable way of building theory when limited theories address the given research questions adequately. This tradition is also called grounded theory. Within this context a theory is built from the ground up based on a close iterative investigation of the data (Bryman & Bell, 2011; William L. Neuman, 2011). The purpose of inductive reasoning is to understand the nature of the problem. Thus, it is particularly relevant to the context where such events were unfolding (Saunders et al., 2006). Researchers in this tradition are more likely to work with qualitative data by employing various methods for data collection to create meaning and establish different views of phenomena (Easterby-Smith et al., 2002). The process of this approach consists of the four stages: existing theories related to the research aims and questions are obtained; the events or phenomena are understood throughout qualitative data collection; the facts are analysed, compared, and classified to identify regularities; and new theories are developed (Potter, 2006).

Based on reviewing two general paradigms of enquiry, the author considers that the nature of this research tends towards an inductive approach. Within the process of reasoning, the related texts and pieces of data are gathered and synthesised in order to propose theory such as concepts, hypotheses or propositions. The approach towards real-world IoT system development emphasises the nature of value creation and development practices rather than numerical aspects of it. The research aim can be realised through inductive reasoning and qualitative field research into real IoT system development projects rather than controlled statistical experiments. Moreover, qualitative data collection sounds adequate in understanding the attributes of IoT development which will be accomplished through the voice of the project manager or leader.

3.2.3 Research Strategies and Methodologies

Qualitative and quantitative methods are the two main streams of data collection and analysis. Qualitative methods are regarded as research strategies that primarily emphasise texts, rather than quantification, in collecting and analysing data (Bryman, 2004). Qualitative methods are helpful to investigate the deeper meaning of discoveries and gain an in-depth understanding of a circumstantial social phenomenon. It is apprehended by people’s words and behaviours as a result of how they interpret the complexity of their world (Creswell, 2003). Thus, these types of methods play a significant role in presenting potential relationships, causes, effects, and dynamic processes in design development (Brannen, 1992). The most fundamental qualitative methods are interviews, observation, focus groups, case studies, and simulation (Yin, 2009). Quantitative methods emphasise objective measurements and numerical analysis of data, which means that researchers may mostly handle hard data in the form of numbers for testing theories. Quantitative methods have its strength in providing relevance to decision, particularly when statistics of large examples are involved. It is limited in terms of effectively understanding the process or significance of actors.

When comparing the qualitative and quantitative methods related to the research paradigm, the former, generally taking a subjective approach, is referred to as constructivism, whereas the latter is often referred to as positivism as it most likely takes an objective research approach. Qualitative methods aim to achieve a depth of the research with a small number of instances, while quantitative methods aim to achieve the breadth of the research with comprehensive coverage of different situations (Blaxter et al., 2010). It is commonly understood that quantitative methods tend to adopt the deductive approach, whereas qualitative methods tend to use the inductive approach. However, researchers have not agreed on which research strategies belongs to which research approaches and philosophies. For example, certain researchers recommend applying the coding scheme development method commonly used for qualitative data analysis under the positivism worldview (Yazan, 2015; Yin, 2013).

These are a few examples of methodologies:

- **Experimental research**: A researcher manipulates the independent variable to confirm its effect on the dependent variable (Gray, 2014).
- **Survey research**: A researcher attempts to test a theory in the field by exploring the association between variables. With the careful random selection of samples, the results of this approach can be generalised to other situations or contexts (Gray, 2014).
- **Grounded theory**: A substantive theory is devised inductively from data through an iterative process of comparing collected and analysed data until the saturation of theory (Creswell, 1998).
- **Case study**: Case study research refers to an 'empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not evident' (Yin, 2009). A case study is argued as one of the best means of investigating a contemporary phenomenon within a bounded system (a single case) (Yin, 2009; Stake, 1995, 2005) or multiple bounded systems (cases) (Yin, 2009; Eisenhardt, 1989; Stake, 1995).
- **Ethnography:** People's daily lives are closely observed while a researcher is participating in their lives and interviewing them to explore a cultural and social group during a prolonged time (Creswell, 1998).
- **Action research**: The world is investigated while a researcher attempts to change or improve it by participating in the whole process as an agent of change (Gray, 2014).

In this research, qualitative research is more appropriate than quantitative research. It is because qualitative research is primarily more concerned with understanding the meanings of given events, phenomena, or the relationships between particular variables, focusing on exploring "how people interpret their experiences, how they construct their worlds, and what meaning they attribute to their experiences" (Merriam, 2009, p.5). Moreover, qualitative methods could provide a more profound understanding of NPD practice with an emphasis on the process (how) and contexts (when) (Murphy, Dingwall, Greatbatch, Parker, & Watson, 1998). Although some scholars consider case study is controversial to data collection due to the lack of robustness as a research tool (Zainal, 2007), it is the most appropriate data collection and analysis method for this research.

First, from the philosophical stance, constructivism, this study attempts to understand the practice of IoT value creation and NPD based on the interpretation of different participants' perspectives on the IoT projects. Second, case study research is especially appropriate if current perspectives seem inadequate (Kathleen M. Eisenhardt, 1989), which aligns with the research problem, the lack of theoretical understanding of the NPD process for IoT systems. Third, the research question of 'How' for this study is most likely to be appropriate and be answered with the case study strategy (Yin, 2003, p.22). Finally, considering the complexity and ambiguity of IoT development practice and the scarcity of prior research in the field, case study methodology enables the study of the particularity and complexity of IoT development activity within essential circumstances (Stake, 1995).

In order to determine the type of case study, authors use different terms to describe a variety of case studies: For example, single, holistic and multiple-case study (Yin, 2009) and intrinsic, instrumental, or collective (Stake, 1995). A single case study similar to an intrinsic case study can be helpful to elaborate on a peculiar or rare phenomenon at a deep level (Siggelkow, 2007) In contrast, multiple or collective case study enables to explore differences within and between cases (Kathleen M Eisenhardt & Graebner, 2007; Yin, 2008). Among the types of case study, multiple case study design is selected for this research. The goal is to replicate findings across cases by drawing comparisons with generalizable and robust results (Yin, 2009). Each case would serve to "confirm or disconfirm the inferences drawn from previous ones" (Eisenhardt & Bourgeois, 1988, 739).

3.2.4 Qualitative Methods

A research method is a strategy of inquiry that moves from the underlying philosophical assumptions to research design and data collection. Each research method affects not only the way of how data should be collected but also implies different skills, assumptions, and research practices. There are several different approaches to qualitative research methods. In this section, observation, interview, document review and graphic elicitation are explored for the data collection instruments in qualitative case study research (Merriam, 2009; Stake, 1995).

Interview

The Interview is referred to as a process in which a researcher and participant engage in a conversation focused on questions related to a research study (Demarrais, 2004, p.55). From the perspective of the interpretive constructionist researcher, the key aim of an interview is to find out how people perceive an occurrence or object and the meaning they attribute to it. It is a useful approach when a researcher cannot observe how people interpret the world around them or is interested in past events that are impossible to replicate (Merriam, 2009). Depending on research questions, it can be used for intensive case studies of a few selected participants or representing a broad range of ideas from numerous people. In terms of the level of structuration, the interviews can be categorised into three different types (Merriam, 2009; Myers, 2009):

- Highly structured interview: Questions and the order of the questions are predetermined and strictly regulated. The format in qualitative research may not allow a researcher to access participants' perspectives and interpretation of the world.
- Semi-structured interview: Questions are more open-ended than structured and in a range of specific topics to understand how individual respondents define the world in unique ways. This approach enables the researcher to respond to the emerging worldview of the interviewees and new ideas on the topic.
- Unstructured interview: The set of questions are not predetermined or a few if any pre-formulated questions; thus, the interview allows the researcher to explore a phenomenon. It is often used following participant observation in the early stages of the study.

Observation

Observation is referred to as a method that involves the systematic selecting, watching, and recording of observable phenomena, objects or behaviour in a natural setting (Gorman & Clayton, 2005). In terms of a researcher's role in observation, four different types are classified, including complete observer, observer-as-participant, participant-as-observer, and complete participant (Gold, 1958). With this method, 'who, what, where and when' questions should be critically considered to get rich and in-depth information (Baker, 2006). Logs and field notes are the most common type of data collection (Polit & Hungler, 1987). The issues of validity, reliability and ethics, are the major factors associated with observational studies.

Document Reviews

Multiple sets of secondary data are often used in combination with other methods for case studies (Owen, 2014). This method provides additional questions, information on background and context, supplementary data, a way of tracking change and development, and verification of findings from other qualitative data sets (G. A. Bowen, 2009). Various types of documents, including industrial reports, strategic planning reports, annual reports, newsletters, technical or non-technical documents and project reports, enable a researcher to discover meaning and understand the research problem (Merriam, 1998). Document analysis is specifically applicable to qualitative case studies to support detailed descriptions of a phenomenon (Stake, 1994; Yin, 1994). It is regarded as a cost-effective method and resources with exactness, coverage (Yin, 1994) and stability (Merriam, 1998). Moreover, as major primary sources, multiple secondary sources help to triangulate the questions under examination (Jick, 1979; A. Strauss & Corbin, 1990). Contrary to its advantages, insufficient detail, biased selectivity and validity concerns are identified as limitations (Yin, 1994). In this regard, Bryman and Bell (2011) identify four criteria for accessing the quality of documents:

- Authenticity (Is the evidence genuine and of unquestionable origin?),
- Credibility (Is the evidence-free from error and distortion?),
- Representativeness (Is the evidence typical of its kind, and, if not, is the extent of its untypicality known?), and
- Meaning (Is the evidence clear and comprehensible?)

Graphic Elicitation

Graphic elicitation techniques ask research participants to draw or diagram visual representations of a concept, experience, network, or behaviour (Copeland & Agosto, 2012). The terminology of graphic elicitation techniques is alternatively called 'image-based research (Prosser, 1998) ', 'creative visual methods' (Buckingham, 2009), 'diagramming (Goulding, 1999)', 'visual elicitation (Varga-Atkins & O'brien, 2009)'. Despite a range of broad terms, these techniques are instrumental in qualitative research studies by enabling participants to express complex or abstract thoughts that are difficult to capture via interviews alone (Crilly et al., 2006). The drawbacks of using this method is a subjective interpretation and the issues of decontextuality when used alone (Copeland & Agosto, 2012). Another issue using visual data in qualitative research is that each participant's diagrams may vary due to different abstraction levels (Anselm. Strauss & Corbin, 1998). To maximise the potential benefits and reduce the potential drawbacks of using visual data, Varga-Atkins and O'brien (2009) address three elements of researcher control in the design and implementation of graphic elicitation: the intended research purpose; the subject of visualisation; and structure.

It is assumed that the concepts regarding IoT development can be constructed based on different participants' points of view on the investigated project. Therefore, the author undertakes field research exploring IoT development practices by setting up the semi-structured interview, graphic elicitation technique and document reviews. Selected methods are considered appropriate to achieve research objectives as some of the case studies started before the period of study and some of the design phases were completed after the research period. For the similar reasons, the observation method is not considered for the data collection tool: first, some of the projects are ten years old and not observable; and second, the nature of the IoT NPD process is complex and continuous, so the sole researcher is unable to collect profound data. As each participant has distinctive experience and interpretation within the context of the given project, the interview can be utilised to comprehend diverse perspectives and opinions, which could inform a holistic understanding of the NPD process for IoT systems, thereby contributing to existing knowledge. Alongside the semi-structured interview, participant-led graphic elicitation is selected for two reasons. First, it helps participants to express ideas that would be difficult to articulate with spoken words only. Second, it stimulates the participant to recall practices and experiences of their IoT development process. Document reviews are selected as a supplementary means of gathering data for past events or when informants have forgotten the details (G. A. Bowen, 2009). This thesis presents a rich insight into the IoT NPD process with descriptions of the phenomenon.

3.2.5 Role of The Researcher

In quantitative studies, theoretically, the researcher's role does not exist or can be described as 'independent of and neither affects nor is affected by the subject of the research' (Remenyi *et al.*, 1998: 33). On the contrary, in qualitative research, the researcher is the primary instrument of data collection and analysis, shaping the findings by their own experiences and background (Creswell, 1998); thus, they rely on skills and intuition through an interpretive lens. Their roles are influenced by the research philosophy and the approach. Within constructivism, the spectrum of the researcher's involvement in the research subject is varied between the insider-outsider stance. The insider fully participates in the activity, program, or phenomenon, whereas the outsider is an objective viewer (M. Simon, 2011). Although the researcher should get inside the participants' perspective in qualitative research, full participation is not always feasible, and there are no right answers of which stance should be selected (Merriam, 2009).

This thesis is based on constructivism with the attempts to understand IoT development and value creation practices. Despite close contact with the entities through semi-structured interviews, the researcher's role in the research is an outsider stance as understanding the participants' point of view towards IoT development and value creation is fundamental. Having enough distance with participants, the researcher can explore and ask real questions, not share assumptions (Seidman, 1991). Although this PhD research started as part of the bigger research team (PETRAS project [see the section 1.1]), it has been fairly individual and involved little outside influence. Thus, having an outsider stance is appropriate for this research.

3.3 Designing Case Study | Research Design

One of the critical benefits of case study methodology is that the research design is flexible in the adaptation of research so that multiple methods can be employed for data collection and analysis (Kathleen M Eisenhardt & Graebner, 2007; Stake, 2005; Yin, 2008). In order to underpin this study's epistemological stances, three qualitative methods in the case study methodology are involved: semi-structured interview and graphic elicitation as the primary data sources, and a diverse variety of document reviews for the additional data source, such as industry reports, business papers, consumer reports and the user forums' website. The pilot study was conducted not only to collect data but also to refine the research design (Figure 21). The University ethics approval forms regarding the case study are included in Appendix A.

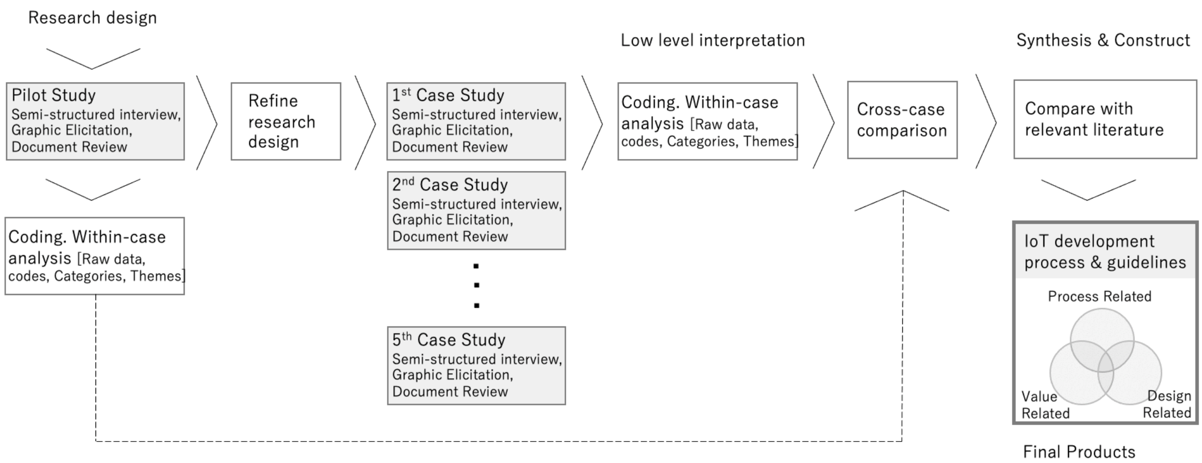


Figure 22 Methodological structure of this thesis

3.3.1 Choice of The Bounded System | Case Unit

A bounded system means a boundary in time and place, which can be any special unit of analysis, such as a program, an event, an activity, or individuals (Creswell, 1998). In case study methodology, one of the critical epistemological issues is where to draw the boundaries, for example, what to include and exclude; thus, what is the claim to knowledge being made (S. Stark & Torrance, 2005). drawing the boundaries of a case ensures the study remains reasonable in scope. However, it is not straightforward and involves crucial decisions informed in diverse ways by different disciplinary assumptions. Several authors suggested how to bind a case: a) by time and place (Creswell, 2003); b) time and activity (Stake, 1995); and by definition and context (Miles & Huberman, 1994).

As this study's objective is to investigate NPD process for IoT, the case is bound by definition and context. Consequently, the 'IoT development project' as the analysis unit sounds more appropriate than other options for this study. IoT system is developed through organic interactions among competitors and customers. Therefore, the analysis unit for the case studies is the 'IoT development project' rather than a company. Considering the complicated nature of IoT development with value co-creation ecosystem (Mazhelis et al., 2012; Rymaszewska et al., 2017; Aivalioti *et al.*, 2018), data collection is undertaken mainly around a leading company who is identified as the intermediary in IoT ecosystems [see the section 2.2.2.3 IoT Ecosystem for Value Co-Creation in Chapter 2] (Lusch & Nambisan, 2015; Smedlund & Toivonen, 2005; Ikävalko et al., 2018). It is because the intermediary is responsible for coordinating and managing the whole development activities and process.

3.3.2 Case Selection

Sampling Methods

Sampling methods are categorised into probabilistic and non-probabilistic sampling (Table 12). Probabilistic sampling methods are most likely used to ensure findings' generalisability, which sounds more appropriate in quantitative research. In contrast, non-probability methods are more appropriate in qualitative research. It is commonly agreed that whether the research approach employed is quantitative or qualitative, a researcher should select a certain sampling method to maximise efficiency and validity (Morse & Niehaus, 2009). The case was selected based on purposeful sampling(Merriam, 2009), among other samplings in Non-probability sampling methods. The rationale for selecting purposeful sampling for this qualitative case study is that it allows the author to select a certain interesting case that illustrates some feature of the process (Silverman, 2017) and yield rich information in cases (Patton, 2014).

Table 12 Methodological structure of this thesis

Probabilistic Sampling	**Random:** It totally takes random sample of population. Each individual has an equal opportunity to be selected. It requires a complete list of population.
	Systematic: Similar to the random sampling but, it has an unordered list of complete population. The sample selection is by a systematically regular gap from the unordered list.
	Cluster: The sampling choice to be like geographically spread. For example, a number of hospitals could be selected from the list of all hospitals in a country and then the identified through a random sampling strategy.
	Multi-stage: This is an extension of cluster sampling in detail. For example, the same percent of sample can be chosen by country, county, city and town.
	Stratified: It requires having one or more certain element choice from the same percentage of subgroups of either random or systematic sampling strategy.
Non-probabilistic Sampling	**Quota:** it is similar to stratified sampling; but people are selected to fill quota for specific research purpose.
	Available: the sample is a group of available people around a researcher. This method is usually used for a pilot test.
	Purposeful: Individuals or groups of individuals are identified and selected as they are knowledgeable about or experienced with a phenomenon of interest.
	Snowball: Small group of people are selected to represent a population with selected characteristics. Selected samples refer similar others for the research.

The author adopted two non-probabilistic sampling methods: 'available' for the pilot study and 'purposeful' for the main case study. The sample for the pilot study was 'available' to the author introduced by the author's supervisor, thus, sampling the interview went efficiently. The author intended to adopt criterion-based case sampling and maximum variation sampling as purposeful sampling strategies (Patton, 2014). The criterion sampling strategy is common in quality assurance efforts by reviewing and studying all cases that meet the predetermined criterion of significance (Patton, 2014). The following criteria were considered for case sampling:

a) The project should aim at developing a new IoT product and service (or products and services);

b) The IoT product and service must be commercialised to the market to investigate the subsequent NPD process. As it provides a fruitful setting in which the emerging practices and value creation of IoT systems are investigated; and
c) The geographical location of the IoT project should be based in the UK. It is to consider not only the accessibility and resources but also PETRAS IoT Research Hub, of which the research scope is limited to a domestic context.

To purposefully select a wide range of cases to maximise variation on dimensions of interest, the author established the protocol framework for the case study based on the typology of IoT sectors (IoTUK, 2016). The candidate cases were identified through three different approaches:

a) a critical review of a limited number of leading industry white papers on IoT businesses;
b) partner organisations of the PETRAS project; and
c) further internet searching on the specific website including 'theiotmagazine.com', 'iotworldmagazine.com', and 'iot-now.com'.

Thirty-one companies were initially listed and invited to participate in the case study via email from January to April 2019. Among thirty-one invitations, twenty-six did not respond, three organisations declined because of their unwillingness or urgent business, and five showed their interest (Table 13). In order to obtain a comprehensive understanding of the IoT development process and practice, the participants have to satisfy the following three criteria: the experts who have the knowledge and practical experience over five years; the experts who have a detailed understanding of the whole process of IoT products and services development; and who hold the authority to drive the project and make strategic decisions. Users were not considered as the interview participants for this study due to the scope of value creation. As this study investigates organisations' practice and process to develop and deliver a particular bundle of products and services to the customers', how the products and services were perceived and used was not the scope of this research.

Table 13 A list of the candidate cases depending on the typology of IoT Sectors

	Home	Industrial	Urban/City	Office	Transport	Maintenance	Agriculture
Contacted	12	2	5	2	4	2	4
Declined	1	-	-	-	1	1	-
Not responded	9	3	6	2	3	-	1

Responded	1	-	-	-	-	1	3

Although the author intended to employ a diverse variety of samples across sectors, the participants initially showed their interest in the research was not evenly distributed across sectors nor belonged to one sector. A paucity of candidates results in heterogeneous sampling being more difficult because the IoT businesses are relatively novel, and many start-ups have failed to survive before launching their IoT systems. Thus, participants' availability and willingness become prioritised in the case selection for this research (Bernard, 2002; Spradley, 1979). It is widely agreed that careful case selection could raise the reliability and robustness of the findings; it could lead to the study's practical constraints. Moreover, Stake (1994) stresses that a flexible design and case selection is acceptable when the case study is conducted based on constructivism.

Sample Size

The literature talks about attaining data saturation (Gummesson, 2000) to ensure the research questions can be answered. However, it is regarded as controversial in qualitative research because the concept of saturation is difficult to define (G. A. Bowen, 2009). Moreover, the depth of the data is often more significant than the numbers (Burmeister & Aitken, 2012). Holloway (1997) explains that the number of participants can be relatively small in interpretive research. Similarly, Yin (2009, p.162) advises researchers to begin 'with a simple and straightforward case study' due to the intricacy of managing and processing large amounts of data. Although an ideal number for cases is not agreed upon, there are several recommendations:

- Eisenhardt (1989, p.545): A number between four and ten cases but no more than ten as it may cause complexity from too diverse data sets.
- Crabtree and Miller (1992): A sample size of six to eight subjects for homogenous samples.
- Curran and Blackburn (2001): The number of cases in business research is often fewer than ten.

Considering the recommendations and the balance between theoretical saturation and practical constraints (Kathleen M. Eisenhardt, 1989), six cases were selected including one pilot study: healthcare, smart home, drain maintenance, dairy, vertical farming and tropical farming.

3.3.3 Pilot Study Design and Setting

Data collection techniques were employed with the semi-structured interview, and graphic elicitation technique and document reviews were utilised as a complementary tool. Graphic elicitation techniques were designed to help the informants articulate broad concepts of the NPD process and practices and value constellation of the project. These are developed in conjunction with the semi-structured interview to minimise the issues of decontextuality of this method (Copeland & Agosto, 2012).

Semi-Structured Interview

The initial interview questions for the pilot study were developed based on the literature review with two aims: to collect data for analysis and refine the questions for the main case study. The graphic elicitation tools were coupled with the semi-structured interview to help the informants articulate the broad concepts of value creation and the NPD process. In order to generate interview questions which, stay focused on the substantive research problem areas, the researcher followed a couple of qualitative interview guidelines:

- Questions should be clear, comprehensible, relevant and short to participants, which can lead to detailed responses and specific events or experience in asked questions could encourage respondents to deliver fuller narratives (Bryman & Bell, 2011; Myers, 2009)
- A few broad, open-ended, and alterable questions are better than close-ended questions. For that reason creating a certain amount of order on the topic areas is useful for a reasonable flow of interviewing (Bryman & Bell, 2011; Myers, 2009)
- Questions should be asked to lead specific intended responses (Bryman & Bell, 2011)

In line with the recommendations of Myers (2009) and Bryman & Bell (2011), an interview protocol was developed for the pilot study, which includes three types of questions: Introduction & Project background, main questions (NPD processes, Risks in NPD, and Creating value for IoT) and summarising (Table 14). The interview was carried out for two hours in July 2018.

Table 14 Interview protocol for the pilot case study

	Semi-Structured Interview Questions	Graphic elicitation
Introduction & Project background	1. General introduction of the interviewee, including the interviewee's background, expertise and particular role in IoT development 2. General information of the project and their IoT system	

NPD process and practice	3. An overview of the NPD stages and activities by illustrating the IoT development stages within the whole process 4. Opinions on the generic NPD process identified from literature compared to their IoT process. 5. Opinions and reflections on their NPD process 6. The critical differences between traditional product development and IoT product development	Illustrating NPD Process
Value creation activities	7. The role and the nature of the involvement of any collaboration with the external organisations in the stages 8. An overview of the value constellation by illustrating how stakeholders are involved in IoT development 9. Activities of and opinions on continuous defining and redefining value proposition in their IoT development 10. Frequency of defining/redefining value proposition of IoT	Value constellation Map
Design Contributions	11. Activities in identifying customers' needs before and after launching IoT products and services 12. Opinions on the designers' contributions towards NPD 13. Opinions on the designers' capabilities(competencies) that is critical in the IoT NPD process and how it was different from its counterpart in the 20th century	
Summarising	14. Appreciation and following stages on post-interview	

Graphic Elicitation

The participant-led graphic elicitation technique was designed and formatted based on the three elements of researcher control in visual tasks: the intended research purpose, the subject of visualisation, and the structure (Varga-Atkins & O'brien, 2009). The intended research purpose was to help the participant depict their knowledge and experience on how their IoT products and services are developed through the activities of the process, who the actors are and how they constitute the value constellation. Accordingly, the visualisation subjects were identified as IoT NPD process and value constellation (Figure 22).

Figure 23 Graphic elicitation tools for NPD Process, IoT value constellation, and organisation involvement (from the left)

Each of graphic elicitation tools was paired with the interview questions. For example, the diagram of the NPD process was followed by interview question 3. The diagram of organisation involvement was followed by interview question 7 and the relational map of the IoT value constellation was followed by interview question 8 (Table 14). In this way, the informant could provide rich insights whilst simultaneously depicting the diagrams and continue deeper interview discussions. Data collected through graphic elicitation techniques were used to triangulate and extend the data collected from the interviews.

Document Reviews

A range of archival documents was obtained for a comprehensive understanding of the project and triangulation. All of the data sources were electronic materials, varied from peer-reviewed academic papers to the project website (Table 15). The secondary documents were searched in pre-and post-interview situations. A total of 162 peer-reviewed papers on the SPHERE project have been found between 2014 to 2019, including journals, conferences, posters, and workshop papers. The majority of the papers were about the technical development of the IoT system, which is less relevant to this research subject. By skimming the title of the paper, 13 papers were selected for the analysis. Data sources are reliable as academic papers are peer-reviewed. The project report, newsletter, and project website aim to archive their project progress, including activities and events.

Table 15 Sampling of Documents

	Overview of the project	**Value Creation**	**NPD process & Practice**	**Design Contribution**	**In Total**
Peer-reviewed paper	1	1	1	10	13
Book Chapter	1	-	-	-	1
Project Report	-	-	1	-	1

Project Newsletter	-	-	1	-	1
Project website			21		21
In Total	2	1	24	10	**37**

3.3.4 Recommendation for Main Study

Semi-Structured Interview

Q8, which is about Identifying value constellation and organisation involvement, seemed too complicated to answer within a limited time. Q9 and Q10 were not able to draw profound and rich information. Therefore, the questions about value constellation and re-identifying value propositions (Q8- Q10) have been removed. Instead, the informant is asked about the significant activities and what challenges they had for value creation. Also, the informant found it challenging to illustrate the map of the value constellation. His response echoed it by saying, '*The University of Bristol and the University of Reading work together for the research, but I do not know how to draw the arrow. There is an information value exchange, but about the social value, I am not sure which way the arrow should direct to (Refer to the code number. SP_103).*'

Graphic Elicitation

The graphic elicitation was formatted to help the informant depict the visualisation subjects easier. However, it was not helpful as the process is not linear, and some stages run parallel. Consequently, the informant asked for a blank paper to freely illustrate their unique process as a diagram (Figure 23 Left). Thus, a blank paper is provided to all informants in the main case study instead of a pre-formatted tool. Moreover, having the informant illustrate value constellation and organisation involvement was identified as complicated and not an effective way of finding answers (Figure 23 Centre and Right). Thereby illustrating a diagram of value constellation and organisations mapping have been removed.

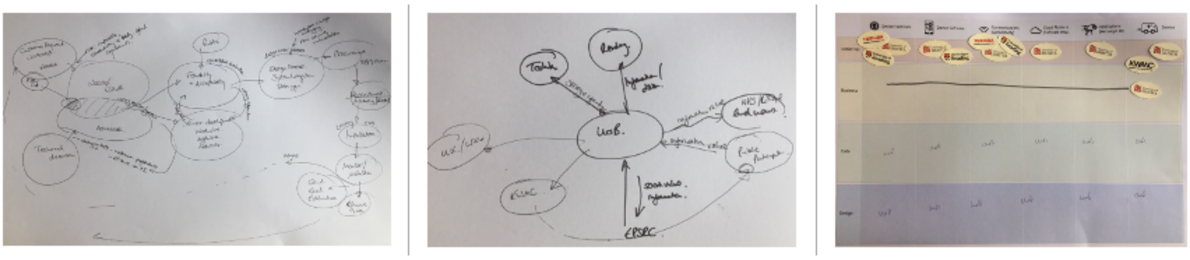


Figure 24 IoT NPD process, value constellation, organisation involvement of SPHERE project illustrated by the informant (From Left)

Reflecting the limitations and recommendations drawn from the pilot study, the main study design was refined more effective way. The following section will present the main case study design and settings.

3.3.5 Main Study Design and Setting

Semi-Structured Interview and Graphic Elicitation

The main study design is refined according to the insights from the pilot study. The interview is designed to ensure that the respondents' diverse perspectives and opinions inform a holistic understanding of how IoT products and services are developed and what values they create through the entire NPD process (Table 16). Data analysis ran concurrently with data collection for the researcher to seize an opportunity for flexible data collection (Kathleen M. Eisenhardt, 1989). Whilst early interviews were being analysed, minor alterations were made to the interview questions for the following data collection. For example, the question on designers' contribution toward the NPD process was likely left out for two reasons.

First, the informants have limited understanding of design, mostly remained traditional visualisation role of design. Second, a few cases had internal designers or worked with external designers at the point of data collection. Thus, concerning data collection on design contribution, the researcher had to rely on document reviews. The interviewees were asked only to illustrate the NPD process but value constellation. A blank paper was provided to the informants to illustrate their own unique IoT NPD process instead of providing the pre-illustrated and structured paper.

Table 16 Interview protocol for the main case study

	Semi-Structured Interview Questions	**Graphic elicitation**
General Questions	1. General introduction of the company 2. General introduction of the interviewee, including the interviewee's background, expertise and particular role in IoT development	
NPD practice, issues, & process	3. An overview of the NPD stages and activities by illustrating the IoT development stages within the whole process 4. The role and the nature of the involvement of any collaboration with the external organisations in the stages 5. Activities in identifying customers' needs before and after launching IoT products and services 6. Opinions and reflections on their NPD process 7. The key differences between traditional product development and IoT product development 8. Issues that they encountered in each stage of the NPD process against value creation	Illustrating NPD Process
Creating Value for IoT	9. The most significant activities in NPD process in terms of creating value propositions 10. At which stage of the process, the value of IoT products and services are created and offered to the customer	
Design Contributions	11. The way of the designers' contributions towards NPD	
Closing Questions	12. Various closing questions 13. Appreciation and informing following stages on post-interview	

The author contacted the informants by invitation emails with the purpose of this study. Once they agreed to participate in the research, a follow-up email was sent, containing the interview details, including the information sheet and consent form, but the interview questions. The university ethics approval forms regarding the case studies are included in Appendix A. They responded to the email by stating the preferred date and time for the interview. One interview per case was undertaken as the sources of empirical evidence from the experts have strategic- and operations- level knowledge and experience in IoT development. However, two interviews were undertaken for the anonymous case. The rationale behind this is to avoid the lack of evidence in profound operations-level knowledge and experience. Thus, the supplementary interview with the project manager was conducted after the interview with the managing director.

Table 17 The list of informants

	Case	Informant and Affiliation	Interview Number	Tenures of IoT NPD
Pilot Study	SPHERE	Project director, University of Bristol	1	5 years
Main Study	AlertMe	Co-Founder, DevicePilot	1	9 years
	Anonymous case	Founder & Product Manager	2	10 years respectively
	Silent-Herdsman	Co-Founder, University of Strathclyde	1	13 years
	LettusGrow	Co-Founder, LettusGrow	1	5 years
	ClimateEdge	Co-Founder, ClimateEdge	1	5 years

The informants were five Founders (72%), one project director (14%) and one product manager (14%) of their respective organisations (Table 17). The interviewees' tenures with their IoT development project varied thus had a breadth of experience: 4 people had been with the firm between 5-9 years, and three people between 10-15 years. In-depth semi-structured interviews were carried out over three months between 21st February and 4th April 2019. All interviews were one-on-one sessions ranging from approximately one to two hours in length, with an average of 1 hour 15 minutes at the informants' workplace. Prior to starting the interview, the researcher introduced the research background and the purpose of the study, followed by an explanation of the informed consent, including confidentiality, anonymity, voluntary participation, the option to withdraw and the details on the university's approval of the research. The interviews were recorded upon the consent of the interviewees and transcribed by the researcher for later coding. Coding of the early interviews was conducted alongside the later interviews were undertaken.

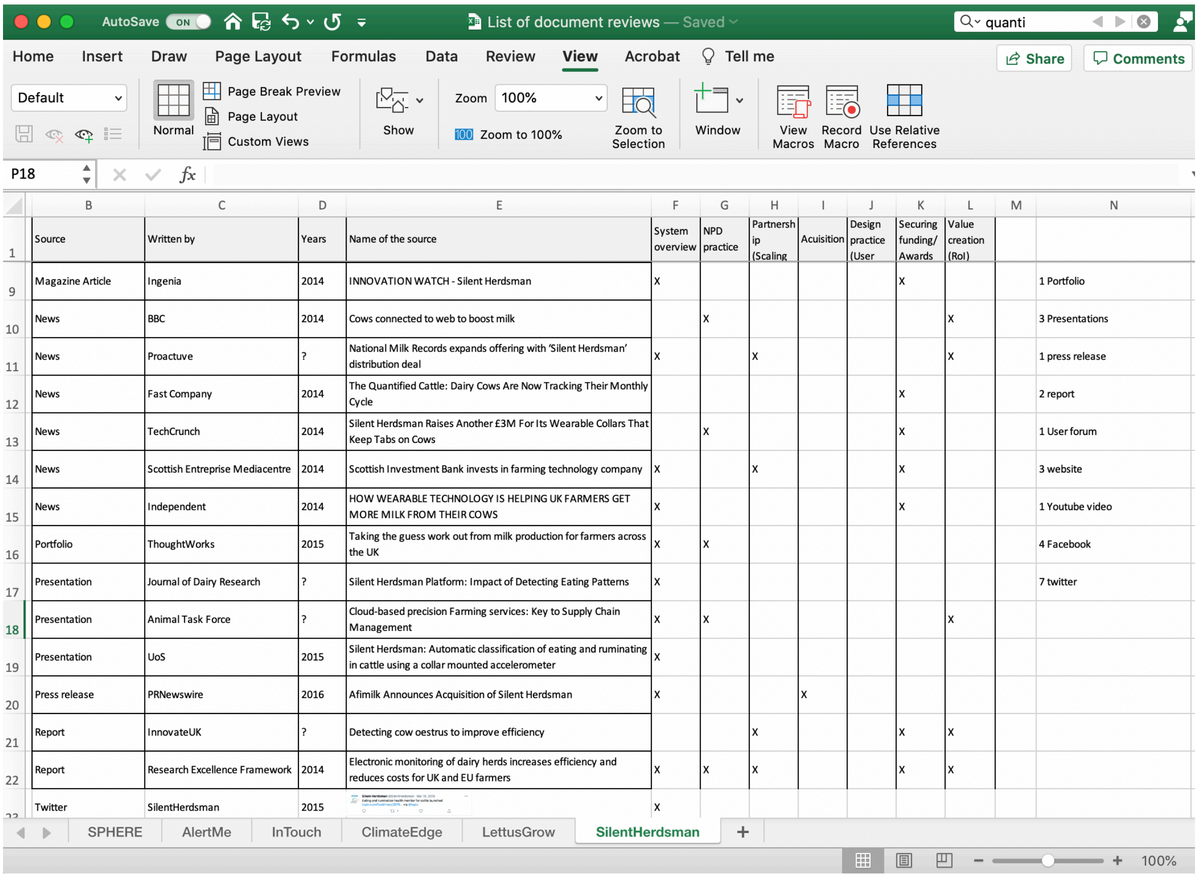
Document Reviews

Various electronic documents were obtained before and after the interviews to supplement and triangulate the informants' evidence (Table 18). Internal archival records were not used in this study for different reasons, including project confidentiality, the nonexistence of the documents, and the informants' furlough due to pandemics. In SilentHerdsman and AlertMe, internally archived documents were unavailable as the companies were acquired by others in 2015 and 2016, respectively. In the case of LettusGrow and ClimateEdge, the organisational documents were not shared due to confidentiality. The informant in the anonymous case was furlough because of the pandemic, so it could not obtain the internal archives. Document reviews are only used to support the primary data as the NPD process, and value creation activities could not be understood through a specific type of documents. Moreover, the time taken for IoT development varied from 4 years to 13 years, so it was not easy to obtain and review four years of archived documents.

Table 18 The List of Documents Categorised by Sources

	AlertMe	Anonymous case	SilentHerdsman	LettusGrow	ClimateEdge
News	11	5	6	19	2
Product Brochure	-	-	2	-	-
Presentation	-	-	3	-	-
Press release	15	-	1	-	-
Interview Article	-	-	-	3	6
Magazine Article	1	2	1	1	1
Website	8	7	3	11	8
Video Clips	2	-	1	-	-
SNS Platform	-	-	11	-	43
User Review	5	-	-	-	-
Project Report	-	-	2	1	-
Portfolio	3	-	1	1	-
User Forum	1	-	1	-	-
Sum	46	14	32	36	60

In document reviews, rigorous, systematic and transparent approach (Higgins & Green, 2011) was adopted in the following steps: 1. Obtaining all materials which help to understand the project development; 2. Extracting relevant data; 3. Analysing data, and 4. Synthesising data. In the case of searching data on each case, the projects and companies' names were used as the keywords input into the search engine. In general, all articles and sources relevant to the study's key themes were obtained, including IoT system overview, NPD practice and process, value creation, design practice and contribution, partnership, and company acquisition. The electronic data was skimmed and archived on Excel spreadsheets by categorising source, informants, years, name of the source, and the relevance to the theme (Figure 24). Data sources comprise: organisational or funders' websites, including UKRI or InnovateUK, which provide a broad set of information about the projects; news sources, including start-up-focussed online journals such as TechCrunch or EUStartups; traditional news media and magazines such as BBC, Independent, or Forbs; and academic news article released from CambridgeNetwork, Imperial College, University of Bristol.



Source	Written by	Years	Name of the source	System overview	NPD practice	Partnership (Scaling	Acuisition	Design practice (User	Securing funding/ Awards	Value creation (RoI)		
Magazine Article	Ingenia	2014	INNOVATION WATCH - Silent Herdsman	X					X			1 Portfolio
News	BBC	2014	Cows connected to web to boost milk		X					X		3 Presentations
News	Proactuve	?	National Milk Records expands offering with 'Silent Herdsman' distribution deal	X		X				X		1 press release
News	Fast Company	2014	The Quantified Cattle: Dairy Cows Are Now Tracking Their Monthly Cycle						X			2 report
News	TechCrunch	2014	Silent Herdsman Raises Another £3M For Its Wearable Collars That Keep Tabs on Cows		X				X			1 User forum
News	Scottish Entreprise Mediacentre	2014	Scottish Investment Bank invests in farming technology company	X		X			X			3 website
News	Independent	2014	HOW WEARABLE TECHNOLOGY IS HELPING UK FARMERS GET MORE MILK FROM THEIR COWS	X					X			1 Youtube video
Portfolio	ThoughtWorks	2015	Taking the guess work out from milk production for farmers across the UK	X	X							4 Facebook
Presentation	Journal of Dairy Research	?	Silent Herdsman Platform: Impact of Detecting Eating Patterns	X								7 twitter
Presentation	Animal Task Force	?	Cloud-based precision Farming services: Key to Supply Chain Management	X	X					X		
Presentation	UoS	2015	Silent Herdsman: Automatic classification of eating and ruminating in cattle using a collar mounted accelerometer	X								
Press release	PRNewswire	2016	Afimilk Announces Acquisition of Silent Herdsman	X			X					
Report	InnovateUK	?	Detecting cow oestrus to improve efficiency			X			X	X		
Report	Research Excellence Framework	2014	Electronic monitoring of dairy herds increases efficiency and reduces costs for UK and EU farmers	X	X	X			X	X		
Twitter	SilentHerdsman	2015		X								

Figure 25 Archives of the documents on spreadsheet

In total, 188 different electronic documents and video clips were collected for analysis. Most of the electronic data were qualitative and descriptive, covering the development activities and business events within the development period of each case. Texts and images were archived on the word document for analysis. The author attempted to be objective and obtain factual data when reviewing press releases and the company's website, such as data on the investment amount. Each case has different sources and amounts of available documents. For example, AlertMe had a significant number of Press releases and user reviews compared to other cases. LettusGrow has several news and interview articles on the business activities from agriculture centred media such as Farmweek, Agri Investor, Horti Daily, Agritecture.

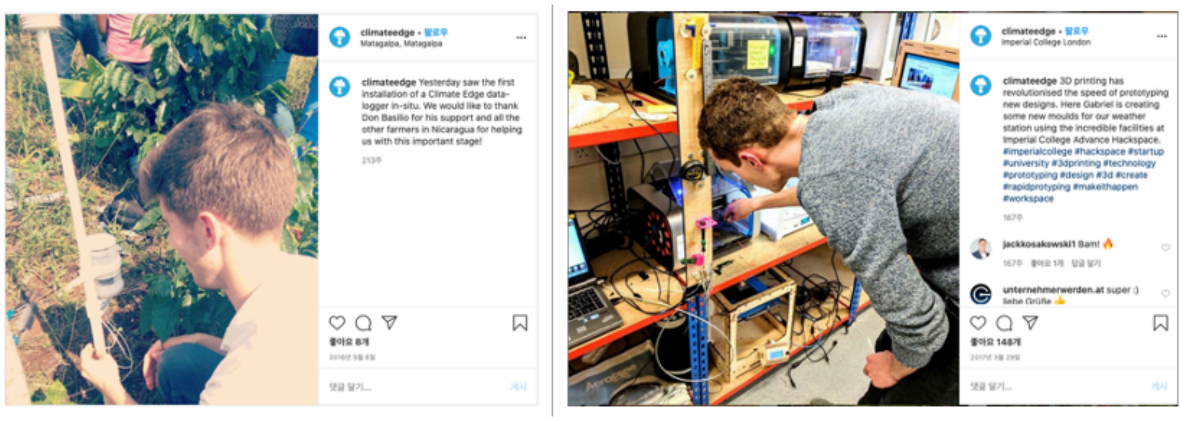


Figure 26 Instagram posts of ClimateEdge

ClimateEdge has used Instagram to communicate with its customers and stakeholders by uploading photos and describing development activities. This source of data was as beneficial as a logbook (Figure 25). SilentHerdsman also used Twitter and Facebook but as a marketing and promotion tool. The IoT ecosystem actors' online portfolios helped understand the design contributions to IoT value creation. For example, for LettusGrow's IoT project, a design consultancy's online portfolio was referred. For the SilentHerdsman case, a video clip and a portfolio of a software consultancy were referred. Also, three documents from engineering consultancy and design consultancies were referred to comprehend the design intervention to the AlertMe project. In the next section, how the documents were analysed and synthesised with interview data will be described.

3.4 Data Analysis

There is a range of data analytical approaches in qualitative research, including ground theory, narrative analysis, interpretative phenomenological analysis, discourse analysis, thematic analysis and qualitative content analysis. Grounded theory and hermeneutic phenomenology require a higher level of interpretive complexity (Vaismoradi et al., 2013). On the contrary, it is argued that qualitative content analysis and thematic analysis are helpful when employing a relatively low interpretation level. This research aims to comprehend the phenomena focused on the 'lived experience' of the participants. The researcher's role in the research is an outsider stance; thus, the approaches using a low level of interpretation are more suitable. The content analysis uses a descriptive approach in data coding and interpretation of quantitative counts of the codes (Wamboldt, 1992; Morgan, 1993), whilst, thematic analysis enables a purely qualitative, rich, detailed yet complex account of data (Braun & Clarke, 2006).

This multiple case study research adopted thematic analysis, which is more appropriate to search for and identify common threads spread out across a single interview or set of interviews (Desantis & Ugarriza, 2000). Thematic analysis is utilised for the transcribed contents, graphic elicitation and obtained documents throughout within-case analysis (Braun & Clarke, 2006; Vaismoradi et al., 2013). Then the codes and themes of each case are compared and critically analysed through a cross-case study (Kathleen M. Eisenhardt, 1989). Thematic analysis is led by the data-driven coding process, appropriate for studying a phenomenon with no previous context (Braun & Clarke, 2006; Tuomi & Sarajärvi, 2006). Thematic analysis process follows the stages identified by Braun and Clarke (2006), which consists of six stages: familiarising with data; generating initial codes; searching for themes; reviewing themes; defining and naming themes; and producing the report. When generating codes for the phases and activities of the NPD process, graphic elicitation is utilised to interpret it into and illustrate the NPD process with more accuracy. In this process, process-oriented coding was applied to compare and synthesise the graphic elicitations and the transcriptions.

3.4.1 Within Case Analysis

The analysis starts with the interview transcription. The recorded interview was manually transcribed through a denaturalistic transcription style in which 'idiosyncratic elements of speech (e.g., stutters, pauses, nonverbal, involuntary vocalisations) are removed' (Oliver, Serovich, & Mason, 2005). Then the author familiarised with data, reading the transcript, comparing with the graphic elicitations and a set of collected documents iteratively (Patton, 2002). By familiarising with data, the researcher began the process of organising and structuring the data and increased her awareness of the patterns, themes, and categories in the data (Figure 26). Then the initial codes were generated with focused coding, based on the research questions and the interview protocol: NPD process and practice, value creation activities, and project background. Then the open-coding procedure was followed by focused coding, investigating emergent core categories in the raw data with key themes. Over the focus and open coding, excel spreadsheets were utilised for manual thematic coding. This stage enabled not only to refine the initial codes but also to have another core category appeared: barriers, challenges, and tensions in the IoT NPD process.

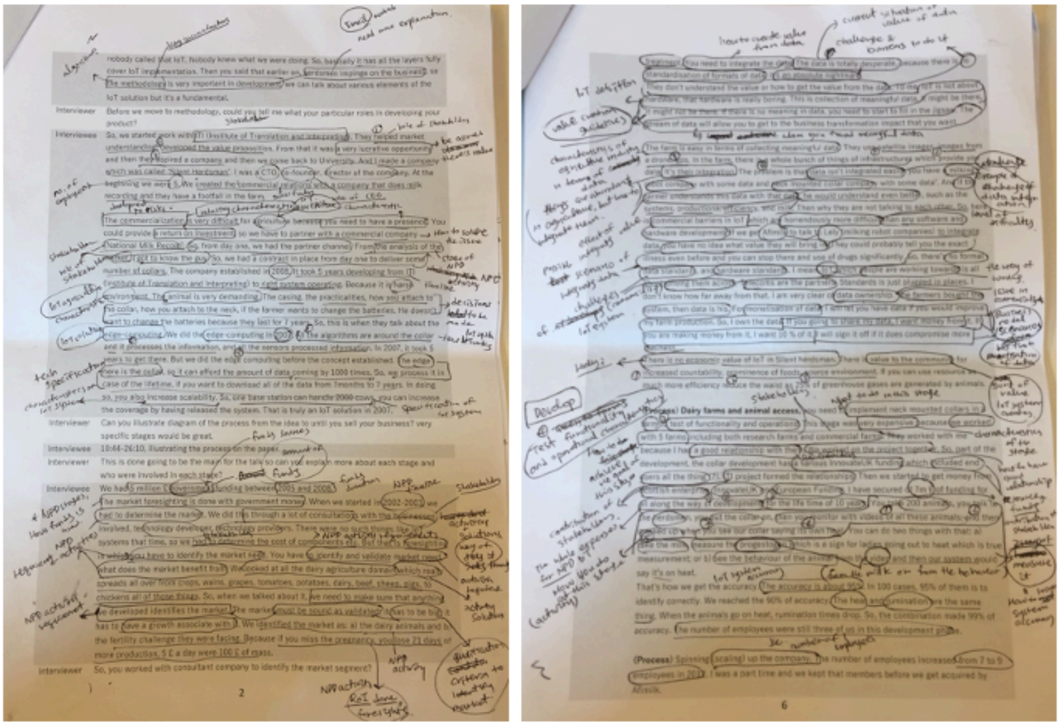


Figure 27 Reading transcriptions iteratively to familiarise with data

Whilst identifying patterns and themes in the data set, process-oriented coding was conducted to comprehend each project's NPD process and practice. In the interview transcripts and document data, the text segments for describing the development process were selected and categorised to the constituents of the process. They include critical phases of the process, the aims of each phase, key activities, and challenges. The NPD process diagrams illustrated by each informant were compared and compiled with the results of the process-oriented coding. The results were presented in 'event flow network' as one of the variations of the time-ordered display, which is helpful for the analysis of flow and sequences of a project (Miles & Huberman, 1994). The level of interpretation was varied in developing an 'event flow network' for each case as some informants illustrated their process with great abstraction (Anselm. Strauss & Corbin, 1998). For example, the interviewee stated a large cycle of NPD process from the company growth perspective. Thus, a considerate level of interpretation was required for AlertMe's NPD process, supplementing relevant information from the transcriptions and document reviews (Figure 27). Full details of each case NPD process illustrated by the informant and interpreted by the author can be found in Appendix D.

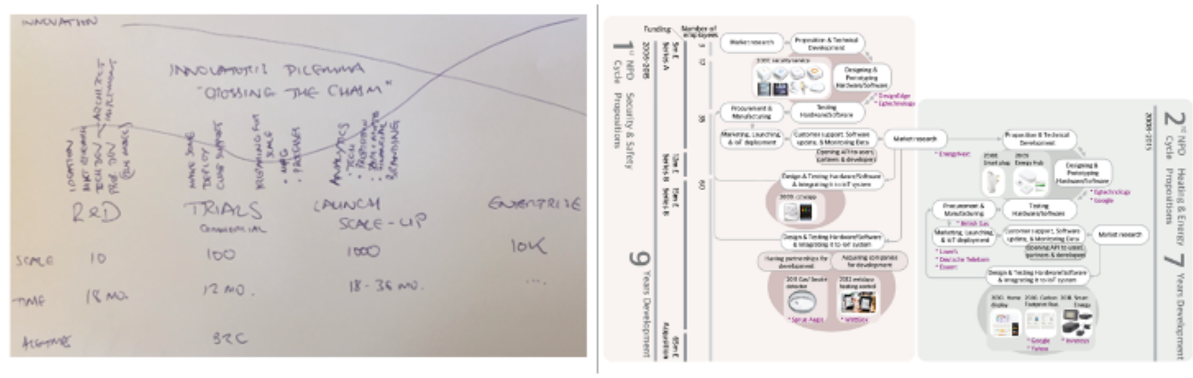


Figure 28 AlertMe IoT NPD process illustrated by the informant (Left), AlertMe IoT NPD process interpreted by the author (Right) [Appendix D]

The author attempted to reflect the distinctive characteristics of each IoT NPD process upon the event flow network. For example, the interviewee of LettusGrow emphasised that their NPD process consists of three sprints in the R&D phase and two V-models which are visualised in Figure 28. Thus, the essence of the LettusGrow IoT NPD process was interpreted and reflected upon their NPD process (Figure 29). Not only these two cases but other cases were represented at a different level of detail and complexity by the interviewees. In this regard, Miles and Huberman (1994) suggest that the researchers decide what level of details they will have when using the event flow network. Consequently, certain levels of interpretations were made to provide a clear picture of the phases of the IoT NPD process, which includes the images of the IoT system, the years of development, the systems' value propositions, various actors, and the source and amount of funding.

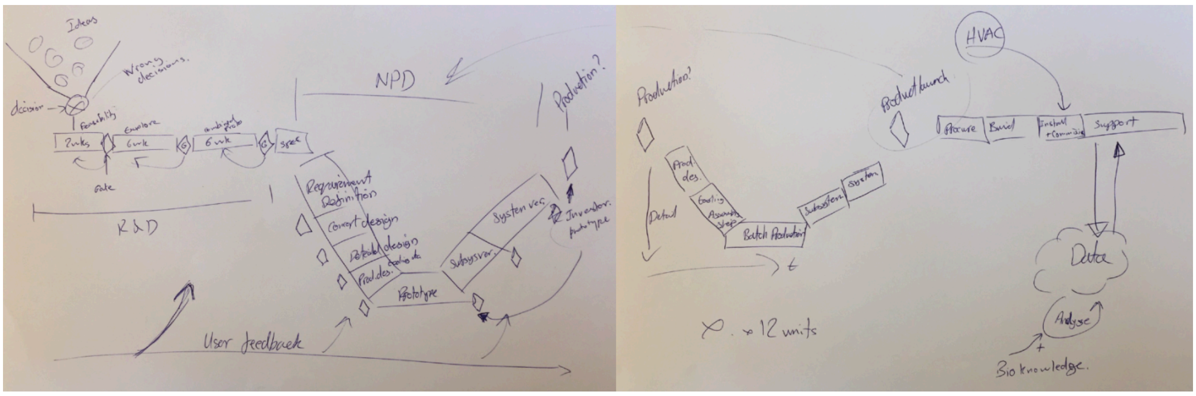


Figure 29 LettusGrow IoT NPD process illustrated by the informant [Appendix D]

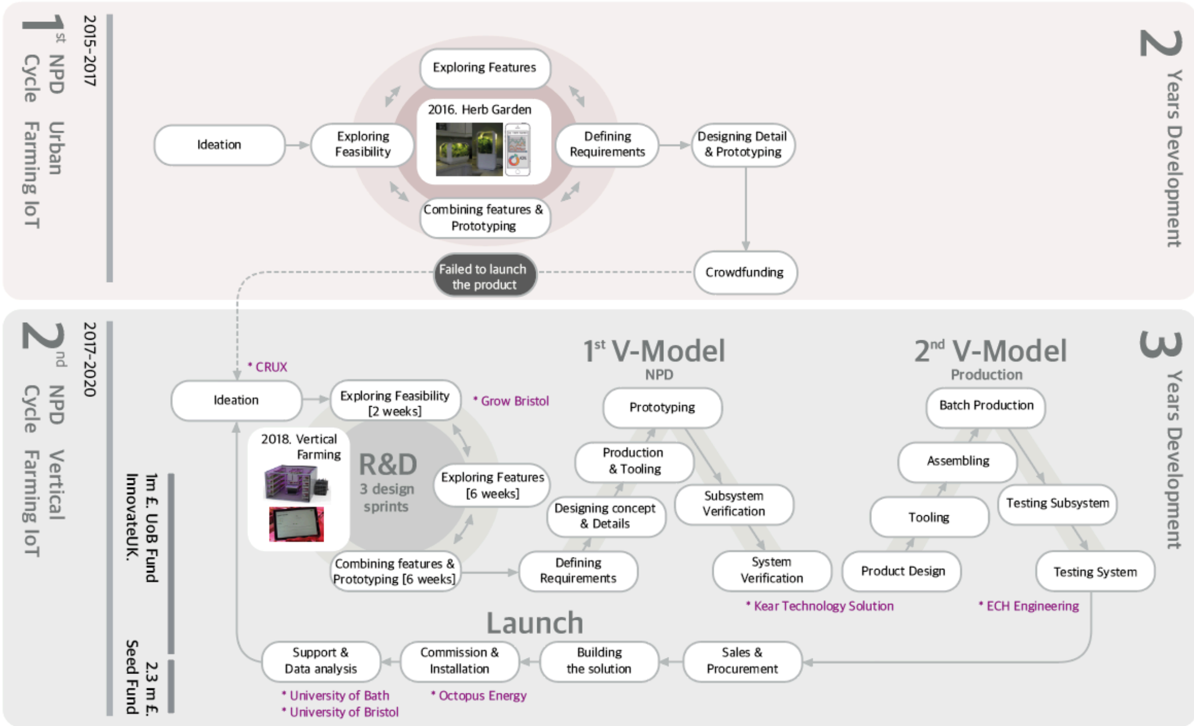


Figure 30 LettusGrow IoT NPD process interpreted by the author [Appendix D]

The thematic analysis helps identify patterns and themes in the data set (Corley et al., 2004) and enriches the author's understanding of the topics. Through iterations of the coding process, codes, categories and themes of each case was developed. Within case analysis report of each case was generated through the last phase of thematic analysis. They were three pages long with about 1,200 words, containing the interpreted IoT NPD process. These case descriptions were used to validate the case analysis through the member checks (Merriam, 2009) described more in detail in the section 3.4.4 Rigour of the research.

3.4.2 Cross Case Analysis

A cross-case analysis was carried out along with the within-case analysis to recognise emerging patterns across the six case studies. Within *case-oriented approaches* (Ragin, 1997), *Multiple methods* (Stake, 2006) was adopted for this study as it facilitates a greater understanding of a common focus for a set of case studies. With regard to the multiple methods, selected dimensions or categories were compared across cases, and commonalities and uniqueness were identified (K. M. Eisenhardt & Bourgeois, 1988). The tactics used for the cross-case analysis was 'Noting patterns and themes' and 'Clustering' (Figure 30). While utilising the tactics, themes were refined across the cases, and a codebook was developed.

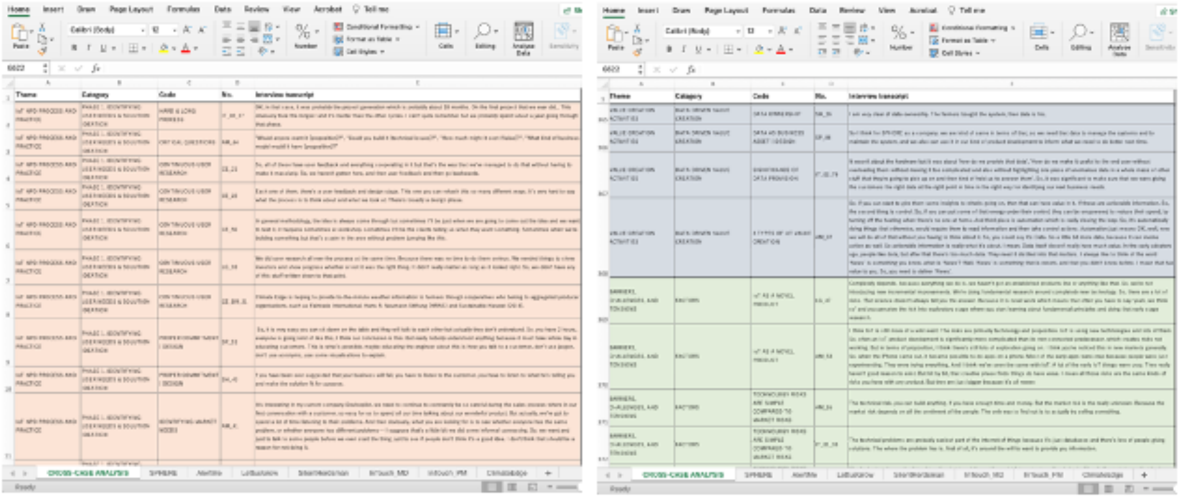


Figure 31 screenshots of a codebook

The codes were organised into a hierarchy with the following top-level categories:

- IoT NPD process and practice (e.g., Phase 1. Identifying user needs and solution ideation, Phase 2. Requirement identification and feasibility test, Subsequent cycle of IoT NPD process)
- Attributes of IoT NPD process (e.g., Developmental consideration, Generalisable phases of NPD process, Continuous and emergent process)
- Value creation activities (e.g., User-driven development, The critical focus on value co-creation, Data-driven value creation)
- Barriers, challenges and tensions (e.g., issues of trust, security, privacy, adoption and acceptability, value co-creation barriers, commercialisation issues, costly and lengthy AI development)
- Project overview (e.g., Aim of the project, business nature, business value, partner contributions)

3.4.3 Theorising from Case Studies

It is a common criticism that the case study results cannot be generalised and therefore are useless due to the absence of randomness and the limited number of participants (Gerring & McDermott, 2007; Hillebrand et al., 2001). However, some methodologists argue that case studies generate theory within some spectrum of simple descriptions of cases or are more analytical and display cross-case or interstate comparisons (Creswell, 1998, p.195). Chetty (1996) emphasises that theory building from case study methodology is helpful when existing theoretical and conceptual frameworks are insufficient. In this case, case study research can be used as hypotheses or propositions in further research, thus plays a significant role in advancing a field's body of knowledge (Merriam, 2009). Moreover, a multiple-case design provides a more substantial basis for theoretical generalisation than a single-case design (Tsang, 2014). Thus, multiple-case design for the research scantiness in the IoT NPD process justifies that this study could contribute to a body of knowledge with some degree of generalisability.

Under the necessity of a deeper level of understanding of how to theorise from case studies, several methods of theorisation in case studies are identified (Ridder, 2017; Tsang, 2013; Welch, Piekkari, Plakoyiannaki, & Paavilainen-Mäntymäki, 2011). Based on the conception of theory as a continuum, Ridder (2017) describes three phases of theorisation in a case study: building, developing and testing theory. Welch et al. (2011) specify four methods of theorising from case studies: inductive theory building, natural experiment, interpretive sensemaking, and contextualised explanation. Based on Welch's four theorising typologies, Tsang (2013) develops an alternative typology depending on the degree of contextualisation and theory development (Figure 31). Interpretive sensemaking aims to comprehend the singularity of the phenomenon, contributing to the theory or concept development. The contextualised explanation has its stand-alone value and legitimacy in theory development without sacrificing contextualisation. A researcher draws on existing theories to strengthen the explanation of the specific cases (Tsang, 2013; Welch et al., 2011). Identification of empirical regularities is a way to discover empirical regularities from case study findings, though partially. Theory building and testing is a method to explain the phenomenon by developing a theory or testing an existing theory.

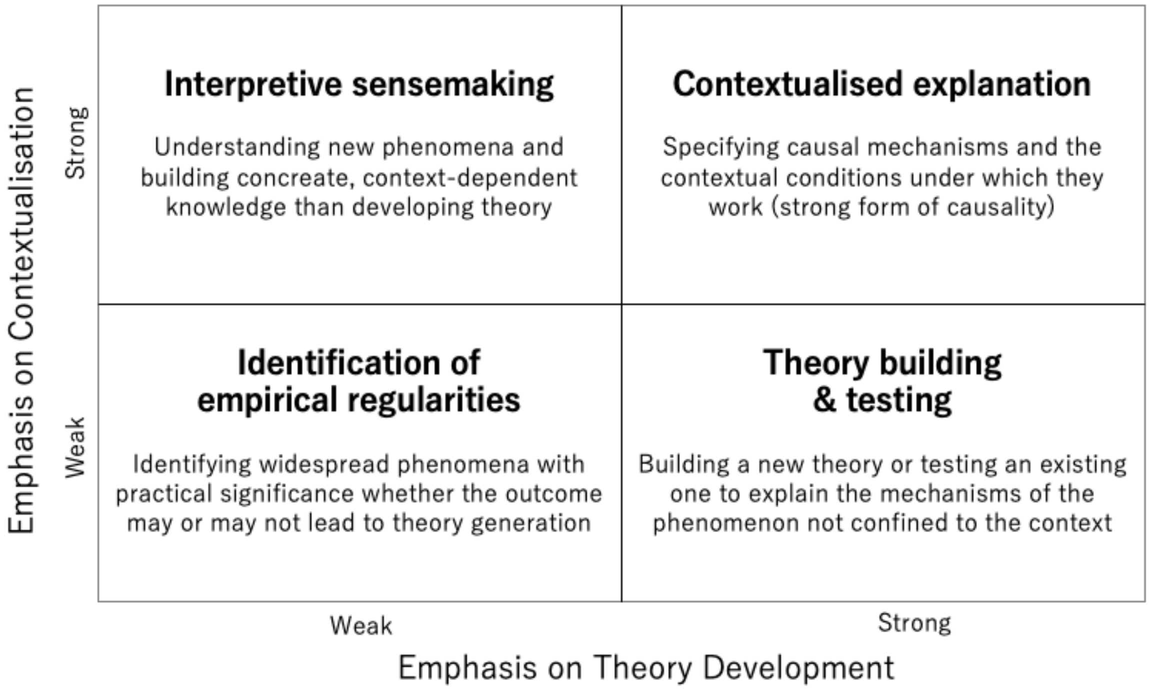


Figure 32 Typology of theorising from case studies adapted from Tsang (2013)

In building theory, this thesis adopted the identification of empirical regularities. Adopting this type for theorising from the case study is justifiable concerning the primary purpose of the case studies, which is to develop a conceptual IoT NPD process. Thus, the theorising process was more focused on identifying regularities of the IoT NPD process, practices, and value creations rather than emphasising the case's uniqueness in its entirety. While the multiple cases demonstrated the variety of IoT NPD processes and value creation, partial regularities of IoT NPD process across the cases were observed and developed as a conceptual NPD process model. Thus, the research outcome, a conceptual IoT NPD process, and the attributes underpinning IoT development practices and value creation can provide initial insights which can be tested built as a theory in the broader context.

3.4.4 Rigour of The Research | Validity and Reliability

In principle, research should be designed and implemented to convey trustworthy answers to the question in a credible and justified manner (Jaakkola, 2020). Depending on the research approach, qualitative and quantitative studies use different strategies to enhance the quality of research (Firestone, 1987). For the quantitative study, the procedures that have been followed faithfully must be convinced by the reader. For the qualitative study, on the other hand, making sense of the author's conclusion must be convinced with a depiction in enough detail (Firestone, 1987, p.19). Regardless of the type of research, scholars use different perspectives and concepts on the quality of research. However, reliability and validity are commonly used amongst others. Methodology literature identifies reliability as the repeatability of the results, whereas validity refers to the truthfulness of the results. Although the two concepts are treated distinctively in quantitative research, they are not considered separately in qualitative studies (Golafshani, 2003).

Methodologists doing qualitative research have devised varied criteria to improve overall study quality or trustworthiness (Gray, 2014): frameworks to assess the trustworthiness of qualitative data (Guba, 1981; Y. S. Lincoln & Guba, 1985); guidelines for obtaining the rigour of qualitative research (Mays & Pope, 2000); and strategies for building credibility, transferability and confirmability (Krefting, 1991). A degree of validity is considered variously depending on the epistemological stance of methodologists. For instance, Yin (2003) considers rigour and the application of logic in research significant as a generalisation is made through the limited number of cases. On the other hand, constructionist scholars such as Stake (2005) and Siggelkow (2007) are less strict about the rigour of the research. Merriam (2009, p.229) introduces several strategies to enhance validity and reliability, summarised in Table 19. The strategies are more categorised explicitly into internal and external validity.

Table 19 Strategies to enhance validity and reliability adapted from Merriam (2009)

Validity	Strategy	Description
Internal validity or credibility *How congruent are the findings with reality?*	Triangulation	Using multiple methods, sources of data, investigators, or theories to confirm emerging findings.
	Member checks or respondent validation	Taking the preliminary analysis and tentative interpretations back to the participants asking whether the interpretation 'rings true'.
	Adequate engagement in data collection	Spending adequate time to collect data enables the data to become 'saturated'.
	Researcher's position or reflexivity	Reflecting critically on the self as a researcher, the 'human as instrument' regarding assumptions, worldview, biases, theoretical orientation, and relationship to the study which may affect the investigation.
	Peer review/ examination	Discussions with colleagues regarding the process of study, the congruency of emerging findings with the raw data, and tentative interpretations.

External validity /Transferability *How generalisable are the research findings?*	Rich, thick descriptions	Providing a detailed description to contextualize the study such that readers will be able to determine the extent to which their situations match the research context, and, hence, whether the findings can be transferred.
	Maximum variation	Seeking variation or diversity in sample selection to allow for the possibility of a greater range of application of the findings by readers.

Internal validity is related to how research findings match reality, while external validity concerns how are the findings transferable to other situations (Merriam, 2009). Creswell (1998) recommends that qualitative researchers engage in at least two strategies in any given study. This research study utilised four strategies: triangulation and member checks to improve internal validity or credibility; rich, thick description and the expert audit review to enhance external validity.

Document Reviews

The author adopted triangulation to improve internal validity (Merriam, 2009). Triangulation through multiple sources of data enabled to increase the validity of the study constructs (Yin, 1994) and the trustworthiness of findings (Grandy, 2010; Stake, 1994). Combining participant-led diagramming with semi-structured interviews and digital documents, including public marketing material, industrial reports, business papers, consumer reports and the user forums' website, helped establish the internal consistency of the data on the NPD process.

Member Checks

Member checks are used as they are considered the most critical technique for establishing credibility (Lincoln & Guba, 1985, p.314). Once data was collected and analysed, within-case analysis has been written in the format of a case study report that illustrates the NPD process. Then the interpretations were shared through email in which discussions on or opportunities of any omitted or inaccurate information can be raised. Out of six case studies, five informants responded to the email, correcting some parts of the preliminary case report. The corrections were then checked thoroughly and applied to the final case descriptions. Two informants were not available to read the case report as they were furlough and extremely busy amid the COVID-19 pandemic.

Rich, thick descriptions

The author attempted to enhance external validity through *rich, thick descriptions*. In chapter 4 detailed description of six cases was provided, including the adequate contexts of the development, business circumstances, the approaches towards IoT development, and the smartness level of the system so that the findings. Moreover, Chapter 5 provides a detailed description of the main findings with sufficient evidence presented in quotes from participant interviews and documents.

Expert Audit Review

Although an expert audit review (Patton, 2014) is not introduced in Table 20, the author conducted it as a strategy for ensuring external validity. The conceptual model was developed through the case study methodology, which might have some limitations in generalising the results due to the small sample size apart from its contribution to a comprehensive understanding of the IoT NPD process and practice. Thus, the expert audit review was designed to overcome the limitations and validate the conceptual model. The findings related to the conceptual model were summarised in a three-page long report, including three questions at the end (see Appendix C).

The questions below were designed to assess the validity of the findings.

- Q 1. To what extent you would agree on the conceptual model, value creation strategies and attributes of the IoT NPD process considering your knowledge/experience?
- Q 2. Do you have any critical elements or point missing in this conceptual process, value creation strategies and attributes of the IoT NPD process?
- Q 3. Do you find any critical insight missing from this report?

Originally 39 experts in academia and industry were contacted via email, being asked whether they could provide their feedback or opinions on the research findings. As 9 experts agreed to review the conceptual model and research findings, a report and consent form was sent. In the end, 8 in total (5 academics and 3 professionals) provided their feedbacks and consent forms via email. One of the challenges in expert audit review is to get the right expert (Patton, 2014). Due to the complexity of IoT system development and value creation, some academic experts showed their concerns on partially valid expertise in reviewing the conceptual model. The professors' expertise varies from innovation management, marketing and service systems, design strategy, and engineering. The professionals' length of work experience was reported to be over ten years. The profiles of the selected experts are listed in the Table below. The expert audit reviews are summarised in section 6.4 Validation of the Mobius strip model of IoT NPD in Chapter 6.

Table 20 Profile of experts

Expert	Position
Academic Expert 1	Full Professor of Innovation Management, Management School
Academic Expert 2	Full Professor of Design Engineering and Innovation, Business School
Academic Expert 3	Full Professor of Marketing and Service Systems, Manufacturing School
Academic Expert 4	Assistant Professor of Design Strategy, Management School
Academic Expert 5	Full Professor of Electronic & Electrical Engineering, Engineering School
Industry Expert 1	Founder of IoT business (One of the interviewees)
Industry Expert 2	Project Manager of IoT system development (One of the interviewees)
Industry Expert 3	Consultant in Innovation and Digital Transformation

CHAPTER 04

Case Study Descriptions

4. Case Study Descriptions

4.1 Introduction

This chapter summarises the six IoT development projects in the layout of within-case description. The factual description of each case is based on the interview, graphic elicitation, and document reviews. To allow understanding of the project, the descriptions of the individual cases are organised in a set of sub-section categories as follows:

- **Project overview**: This sub-section outlines the given project focusing on particular contextual conditions of the project, such as project background, scope, period, aim, and stakeholders, and IoT products and services. It encompasses the illustration of IoT NPD process to provide comprehensive understanding of the IoT process.
- **IoT development process**: This section describes how each of the projects are unfolded in terms of detailed phases and specific activities across the NPD process. It also provides the aim of each phase, considerable events and stakeholders involved.
- **Value creation strategies**: This section outlines how organisations attempted to create value through the IoT system. The value creation strategies are mainly related to new product development practices.
- **Development challenges and design contributions**: This section summarises the development challenges, barriers and tensions and design interventions within IoT development process. Distinctive challenges are identified depending on the project background, context, and value creation activities. The findings of design contributions are limited due to the limited access to data collection which is more specifically described in section 7.4. The research Limitations.

4.2 SPHERE | Healthcare IoT

Project Overview

The project has initiated within the context of an increasing number of people living longer with one or more chronic diseases in the UK. Thus, the project explores how future healthcare services should be set for conversion from clinical setting into the home. SPHERE stands for Sensor Platform for HEalth in a Residential Environment, a smart home system for monitoring inhabitants' physical and mental well-being. The project aim is to measure the value of the system and the cost and value of acquiring data. Funded by the EPSRC for five years from 2013 to 2018, Bristol University led the project with the project partners, including Universities of Southampton, Universities of Reading, Toshiba, IBM, Bristol City Council, and Knowledge West Media Centre.

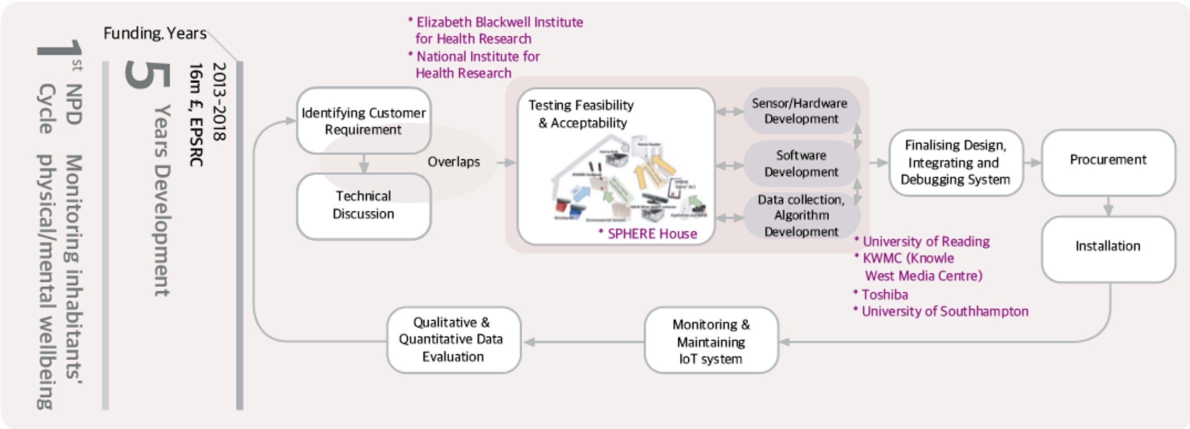


Figure 33 The eight phases of SPHERE IoT NPD Process

SPHERE's IoT NPD process (Figure 32) is distinctive to other cases as it did not aim to commercialise the product due to the scope of the project. Subsequently, the SPHERE NPD process omits some phases, including manufacturing and marketing. Considering it did not aim to commercialise the system, the IoT process does not reflect the characteristics of continuous design and development iterations. It was a government-funded project, and thus there were fewer challenges from the budget, and had internal design capabilities.

IoT NPD Process

The SPHERE project's development process consists of eight phases: Identifying customer requirements; Technical discussion; Testing feasibility and acceptability; Finalising the design, integrating and debugging system; Procurement; Installation; Monitoring and maintaining IoT system; and Qualitative and quantitative data evaluation. The process began with 'Identifying customers' requirements'. In the SPHERE project, it was required to meet clinical researchers' needs who use the system to collect patients' data. Beyond its primary objective of identifying and understanding future customer requirements, this first phase was crucial for building strong relationships with future customers which helps to prepare for scaling up by deploying the IoT system and collecting data to verify and refine algorithms. The next phase was 'The technical discussion' which revolved around the need to explore appropriate technology for the system. This phase aimed to discover the overlaps between customers' needs and what was, ultimately, achievable.

After the Technical discussion phase, the IoT system was installed into the living lab called the SPHERE House [Section 5.2.1]. 'Feasibility and acceptability' were tested through a combination of traditional ethnographic methods and participatory techniques. This phase took over a year, through which the sensors, hardware, and software were developed, and data were collected for algorithms development. Once the SPHERE system was 'finalised, integrated and debugged', the phases moved to 'Procurement and installation'. This phase did not have many issues as their system was not being commercialised. While 'Monitoring and maintaining IoT system', three kinds of data were collected, data on users, environment, and the system itself. The collected data were then used to evaluate and improve the IoT system over the final phase, 'the qualitative and quantitative evaluation'.

Value Creation Strategies

Alongside other IoT system development, the SPHERE system was highly complex and inter-sectoral with various sensors, devices and algorithms. Consequently, it required value co-creation with device manufacturers, software developers, and service providers. Also, as the data collected from the sensors were utilised to diagnose obesity, depression, diabetes, stroke, falls, respiratory conditions, cardiovascular and musculoskeletal disease, working with a certain level of healthcare experts outside the technology domain was imperative. In value creation through IoT systems, having external experts' opinions was considered significant to understand the meaning and insights from the data. Moreover, building strong relationships with customers had to be emphasised from the beginning of the process not only to identify their needs and requirements but also to commercialise the system at a later stage. Over the final phase involving qualitative and quantitative evaluation of the system and users, continuous NPD activities were critical, identifying customer requirements and redefining value proposition.

Development Challenges and Design Contributions

Several challenges were identified through the IoT NPD process. Over the first phase, identifying users' requirements was challenging as customers generally were not trained to articulate and define their needs. Although they defined the requirements, it could have been impossible, contradictory or poorly defined. Critical questions were raised over the technical discussions, including what kind of system to develop, whether the system would rely on AI, and whether to use labelled data. Another technical issue was not knowing system performance until the system was developed and deployed. The sensor prototype and development stage must have been followed quickly to understand if the right decisions had been made. The small sample size was insufficient to make decisions and a consensus upon designing a nationally scalable IoT system when testing feasibility and acceptability.

To test and evaluate the system thoroughly without completing the product and service ecosystems was incredibly challenging with the continual pressure of never being able to fix the design and integrating the system. The system integration was highly complex and often required strategic alliances with device manufacturers, software developers, or service providers, which occur various issues over the physically distributed value co-creation. Special attention to quality control should have been paid during the procurement phase. Particularly, being unable to procure specific hardware components may have led to the whole system being re-designed and searching for new suppliers.

As described earlier, SPHERE had an internal design researcher over the early stage of the project. Thus, there was a strong emphasis on design input in identifying users' needs and testing feasibility and acceptability. The user-centred design approach was utilised with the living lab. One of the critical activities was to understand diverse users' experiences of technology and healthcare through ethnographic interviews and walking interviews. Design contributions lay in organising a series of workshops and meetings with clinical researchers and patients for rich conversation and brainstorming ideas. The quick sensor prototype and design activities were underlined, making things real before full production.

4.3 AlertMe | Home Security/Safety & Energy IoT

Project Overview

AlertMe aimed to develop an IoT hub that improves energy efficiency, security and safety at home with multiple devices and applications. Safety and security features were firstly launched in England in January 2007; then, the business propositions were extended to the energy service by launching SmartPlug in January 2008. From its foundation in 2006 to its acquisition by an energy provider in 2015, diverse actors and partners were involved in value creation through several cycles of the IoT NPD process (Figure 33). Value creation was critically focused on connecting different devices and services and scaling up a number of IoT systems.

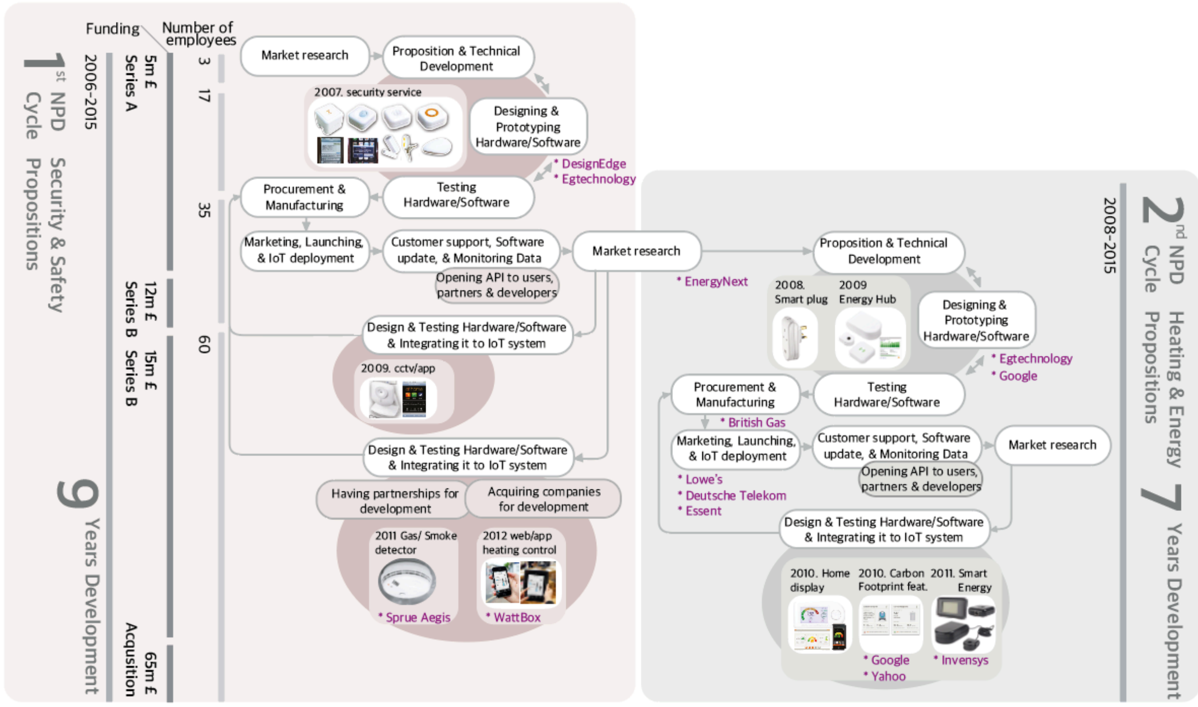


Figure 34 AlertMe IoT NPD Process

The degree of system intelligence was not advanced as the system did not utilise machine learning technologies. Thus, data contributed to value creation primarily to tighten customer relationships and increase brand loyalty, providing them rich information on energy usage. AlertMe's NPD process could be characterised by numerous development cycles and a customer-centric process by continuously improving the system more intuitively. Since launching the IoT system, the entire process was fuzzy as new features, and value propositions were constantly realised, developed, and added to the system whilst the IoT system was being used.

IoT NPD Process

AlertMe's development processes were iterated until the energy provider, British Gas, acquired it in April 2015. The process was more likely to be six breakdowns of development activities with several variations: Market and technical research to identify user needs and suitable solutions; Designing, prototyping, and testing hardware and software; Procurement and manufacturing; Marketing, launching and IoT deployment; Customer support, software update and monitoring data. The project was started with 'the market and technical research' to identify key market and channel partners through which safety and security service was initially identified. The 'Design, prototype, and test' phase, which took 12 months, aimed to develop actual 'things' whilst developing, integrating and testing hardware and software. Over this phase, the appropriate price point was tested in the market.

The 'Procurement and manufacturing' phase aimed to effectively tool up for volume production of the scalable IoT system and assure the quality of components. When the security and safety IoT system was first 'marketed, launched and deployed', there were few employees and channel partners. The team manually 'monitored and analysed' user data until the number of products sold and deployed grew exponentially. Then, AlertMe hired an extensive customer service team early on to solve many technical issues and comprehend user behaviours.

After launching the security and safety products and services in 2008, AlertMe started working with a research partner, EnergyNext, in an attempt to identify the subsequent value proposition. The team extended the software services through various co-creation, including obtaining the technical solution on heating control by acquiring Wattbox and launching the carbon footprint tracking service through partnerships with Google and Yahoo. AlertMe also worked with several design consultancies and heating providers as hardware development partners, including DesignEdge, Egtechnology, Sprue Aegis, Invensys, and British Gas, not only to improve existing products and packages but also to develop the subsequent IoT solutions.

Over the procurement and manufacturing stage, the practices and processes became more formal and efficient. Over the marketing, launching and deploying the heating and energy IoT system, British Gas committed to installing the smart meters in 10,000 homes and re-branding AlertMe's IoT system. In later phases of the NPD process, AlertMe focused on scaling up directly and through channel partners. Telecommunication business (Deutsche Telekom), retailer (Lowe's), and energy providers (British Gas and Essent) had enormous numbers of customers to reach into the market and potentially extend their propositions. AlertMe continuously attempted to satisfy the customers by fixing the technical faults and pushing updated software.

Value Creation Strategies

There was no machine learning technology in the system, but data played a crucial role in creating value propositions. For example, data on how customers use energy enabled AlertMe to develop a compelling piece of PR (Public Relations) materials and to have a deeper relationship with customers, providing them insightful information and customised services. AlertMe actively involved a diverse variety of partners in new product and service development to maximise value propositions, such as technology companies, web service providers, energy providers, retailers and telecommunication businesses.

Having partnerships with Google and Yahoo, AlertMe expanded their service access through partners' platforms, such as energy services through Google's Powermeter, carbon footprint service through iGoogle gadget and Yahoo Widget. AlertMe also broadened their target market to Germany, the US, and the Netherlands directly and indirectly through the retail partners. Acquiring or partnering with companies was critically helpful when they wanted to add novel technologies that were highly specialised and strictly regulated. For example, acquiring Wattbox and partnering with Sprue Aegis saved AlertMe's time and money on development of smoke detecting technology.

Development Challenges and Design Contributions

When AlertMe was founded, it was the early days of the IoT market in which the team had to develop most of the hardware from scratch. Having no ecosystem or products to interact with the AlertMe platform made the process expensive and slow. One of the critical activities in the early phase of the IoT process was to get the technical architecture right and pull all the different IoT architecture layers together whilst considering the possibility of globally scaling up the system in the future. The IoT complexity resulted in substantial development risks around the technical and business development and test. Developing a secure IoT system was challenging as there was often tension between security and usability.

Managing supply chain and quality control was critical as most IoT components were manufactured at relatively low volume, which led to component shortages. Cash flow was another primary risk after committing millions of pounds to produce. As AlertMe IoT systems were self-installable, they had to be designed intuitively to install, resulting in the company's significant effort in user-centric design. This issue led the team to improve the IoT system deployment more straightforward and easier continuously. While IoT systems were deployed and used, many issues were found, such as providing accurate information to the customers across interfaces, and ensuring data security, privacy, and trust. Even though the team measured energy accurately at the design stage, technical faults caused nonidentical information on energy consumption across the different interfaces.

Instead of having internal designers, AlertMe worked with a couple of external design consultancies. It was emphasised to have a user-centred mindset for the customer service team as they often visited customers' houses to fix the technical problems. Despite no internal designers, having a partnership with external design consultancy, Egtechnology enabled improving package design and developing various products range for energy and heating technology. EnergyNext conducted a series of surveys and ethnographic research to understand how IoT products and services were used and identify future value propositions. While testing the working prototypes with user, the team had concerns regarding protecting the company's Intellectual properties. AlertMe's early customers were advanced and active on the AlertMe users' forum on which they voluntarily reported, discussed and resolved the technical issues.

4.4 Anonymous Case | Drainage Maintenance IoT Systems

Project Overview

The case company has supplied two-way radio rental systems for 35 years and has become the UK's largest supplier within the quarrying industry. As the business paradigm shifted from voice communications to digital communications in the early 2000s, they brought up IoT solutions to reduce costs and improve gully and drainage management efficiency, informing when it should be cleaned and inspected. The business has developed SmartWater, a gully management solution in highways first, then applied the same technology to the rail sector called TrackWater. Several government fundings from UKRI (UK Research and Innovation) initiated the IoT system development, including Faith, SmartStreets, SmarClean I, II, SmartWater, PETRASHub, and TrackWater.

The IoT NPD process consists of two cycles: the first is a gully management solution development for highways, and the second is a variation of the first solution, a drainage management solution development for railways. From the beginning of the process various actors were involved, including, government’s innovation agency, local authorities, construction and facilities management company, university, and railway company. The data models and decision support system were embedded in both the SmartWater and TrackWater IoT hubs. Consequently, it created value by predicting gullies and drainages management and offering live insights to the customers. The company attempted to create value by curating data that was critically challenging from technical and business perspectives. The role of design was reasonably limited as the design consultancy worked as a subcontractor.

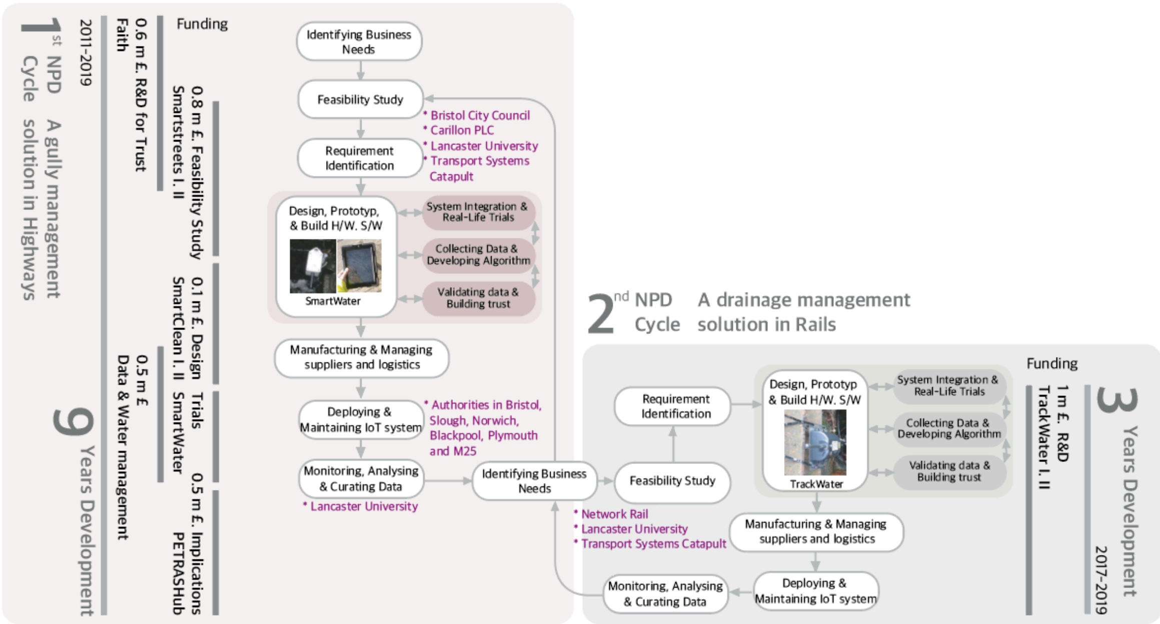


Figure 35 Anonymous case's IoT development Process

IoT NPD Process

The IoT NPD process of the smart drainage maintenance system consists of two separate cycles, each consisting of seven stages (Figure 34). The cycle on the left-hand side indicates the initial IoT development process for SmartWater (a gully management solution in highways), and the one on the right-hand side indicates the subsequent NPD process for TrackWater (a gully management solution in railways). While the first IoT solution was being deployed, the process continued to the second cycle of IoT NPD. The 1st NPD process began with 'Identifying business needs', which took 18 months. Through several informal discussions with the company's main partners, the business need was identified. To make the business idea tangible, they applied for government funding at the feasibility study phase.

Lancaster University committed to a feasibility study with a small number of demonstrators to confirm the economic value. Then the requirements were identified through a series of workshops. Although the consensus on the 'system requirements' was reached between stakeholders, it ceaselessly changed until the system was manufactured. The design subcontractor mainly led 'designing, building and prototyping IoT system' through which the case company was an intermediary to refine the product and application designs. After confirming initial low fidelity prototypes focusing on the looking and functioning, the working prototypes were tested in the labs and the gullies for quality approval. Real-life trials with highway customers were ongoing as data had to be collected and algorithms must be validated.

After 'the system manufactured and released', it was monitored and maintained through which the technical faults were reported and fixed. The system security was directly related to customers safety, so that the team had a subcontractor to manage the infrastructure and constantly monitor the system security. Over this stage, the company shared data with customers to discover values that a data analyst from the university supported, which naturally led to the continuation of the 2nd cycle of the NPD process. While maintaining the IoT system, the development cycle becomes less defined, smaller, and shorter with minor tweaks to the IoT system. However, when SmartWater was identified as a subsequent value proposition over the 2nd NPD process, a complete redesign of hardware was required, which characterised the process with considerable loops and reviews. While developing and deploying TrackWater in the rail sector, SmartWater solutions were being deployed to other sites and improved by updating software, improving algorithms accuracy, and fixing technical failures that characterised the IoT NPD as an ongoing process.

Value Creation Strategies

Value co-creation was critical in this case throughout the NPD process. Users and stakeholders were involved in the whole process to identify business needs, what value to create, and how. The stakeholders were Connected Places Catapult, Carillion PLC, Network Rail, Lancaster University, and the local authorities including Bristol, Slough, Norwich, Blackpool, Plymouth. IoT is a complex system; having the suitable partners who could direct them in the right way with more experience in the field was critical in value creation. Specifically, Lancaster University was committed to technological development with a critical focus on system and machine learning development.

The value was created through scaling up IoT application domains, offering the prediction of how gullies and drainages should be managed, and improving the system and prediction accuracy. The team also attempted to create value by integrating and curating multiple data sources, which was unsuccessful because the stakeholders had a lack of economic drivers to make data meaningful. The organisations that had freely available data were not interested in driving value creation. The adoption of the system was critical in realising economic value of the system which was critically related to trust issues with end-users. Thus, the team regularly validated data and system accuracy even if that was time-consuming.

Development Challenges and Design Contributions

IoT development transformed the company's strategic directions into entirely novel ones. Thus, securing funding was critical to steer the traditional business to IoT business. Value co-creation risked the business with regard to the competitiveness of the business partners. Having requirements identification agreed upon was a painful process as each stakeholder had different interests, such as the duration of the product lifetime guarantee and system maintenance cost. In the design phase, prototype and test IoT system, key challenges were laid in managing the quality of the product as the team lacked knowledge and experience in designing hardware. There was a conflict between getting something to market quickly and trailing against the fact that it was full of technical failures. The system integration was one of the most significant challenges for two reasons: not knowing what issues they had to deal with until they started to integrate things; and having IoT system integrated into the company's legacy system.

Validating algorithms and building trust with the end-users was critical for commercialisation and the acceptability and adoption of the IoT system. While maintaining the system and monitoring data, the team focused on increasing the system accuracy and ensuring data security, privacy, and ethics which were significant to the highways customers. Monitoring, curating, and transforming data into something useful was closely related to designing a user-friendly front-end interface with the appropriate kind, level, and amount of data. System maintenance and commitment were vital financial and technical issues related to data reliability, availability, storage and standardisation. Over the NPD process, HR risks were always the most significant challenge as the company was located in the northwest of England and lacked hardware development skills.

Although there was limited design contribution identified over the company's NPD process, the team were aware of the significance of the design phase and approaches (co-creation, fail fast, and iteration) due to the complexity of the IoT system. The team well acknowledged that innovation was driven by needs. To identify and translate problems into appropriate technical and business solutions, they held innovation workshops and spoke to customers on a regular basis. During the feasibility study, repetitive ethnography research was conducted with the University to understand how they operate the original gully emptying system.

4.5 SilentHerdsman | Dairy IoT Systems

Project Overview

Whilst UK dairy exports are growing, and the long-term outlook for the industry is optimistic, UK Farmers have faced financial challenges caused by low milk prices. The solution came up while the interviewee was working for the ITI (Intermediary Technology Institutes) Scotland Ltd, set up by

Scottish Enterprise. With this context, it was required to satisfy the increasing worldwide demand for high-quality animal products in combination with responsible farming, including reducing environmental impact and resource use and improving animals' welfare. It was initiated as part of a three-year project co-funded by the Technology Strategy Board from 2006 to 2009. Then it continued to commercialise SilentHerdsman by establishing the University of Strathclyde spin-out company, Embedded Technology Solutions (ETS) Ltd. SilentHerdsman was a decision support platform for herd management.

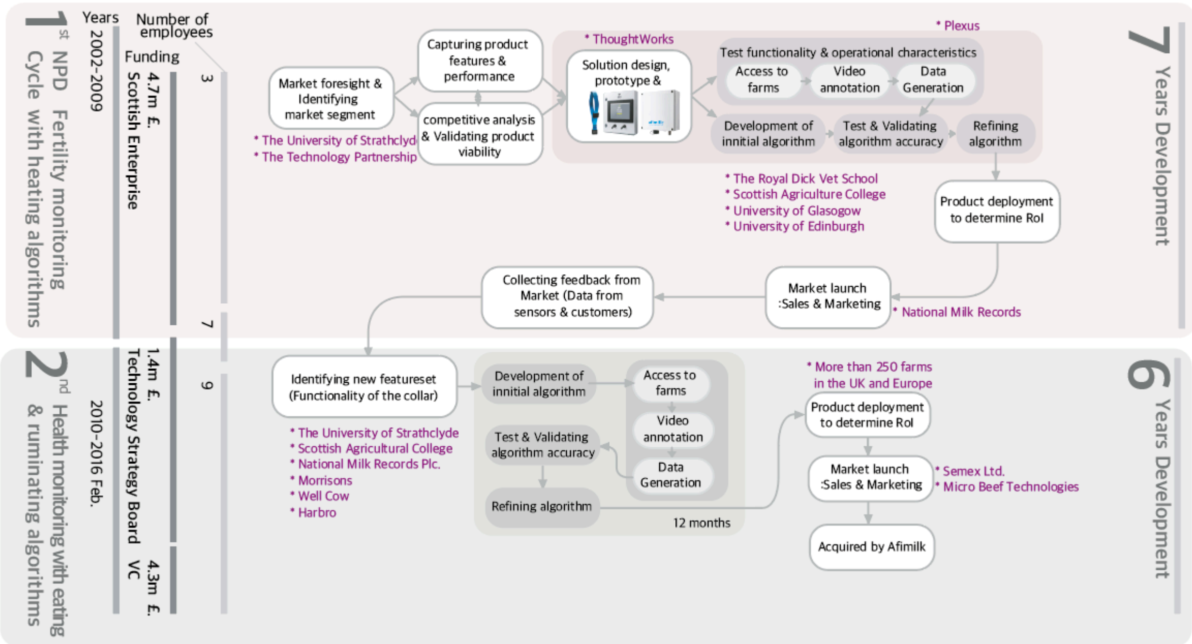


Figure 36 IoT NPD process for SilentHerdsman

Over the two cycles of the NPD process, seven and six years respectively, the neck mounted collar, software and machine learning algorithms were developed (Figure 35). The first value proposition was developed primarily aiming to automatically monitor the behaviour of livestock, thus increasing fertility. Then the second value proposition, the health management feature, was developed through the later cycle of the NPD process. It was provided through the same platform by developing different algorithms. For 13 years of IoT development process from 2003 to 2016, two cycles of the NPD process were identified with the award of £ 10 million of funding, involving a diverse variety of stakeholders.

IoT NPD Process

SilentHerdsman's NPD process comprises two development cycles with slightly different subphases (Figure 35). The process began with 'market foresight and identifying market segment'. At this phase, a series of consultations was conducted with the supply chain actors, such as farmers, herdsmen, main retailers, logistics, milk recorders, artificial inseminators, nutritionists, animal scientists, and technology providers. The team secured the partner channels from day one to test the collars and collect data. Once the market was identified, the project team 'validated the product's viability' by specifying the solution features.

At the solution design and prototype stage, the high-level features and performance requirements were specified. Over this phase, the farmers' current practice was understood through ethnographic methods. 'Designing and prototyping a solution' was achieved through a series of lengthy iterations with primary stakeholders. The initial hardware prototype was evaluated in partnership with both the commercial and research farms. While developing and testing functionality and operational characteristics of the hardware, data was collected to create and validate the algorithms for identifying the onset of heat (to optimise pregnancies), and the Return of Investment (RoI) of the system was validated.

For launching and deploying the system, a commercial company partner progressed the sales and marketing strategy. Over this phase, market feedback and data were collected and utilised to identify farmers' latent needs in monitoring animals' health. The end-users need was identified as achievable with embedding novel algorithms into the same hardware. After understanding how the veterinary doctors and farmers judge when the animal is unwell, they accessed the farm environment to record the muscle movement.

Developing and refining the algorithm for the additional solution took a further 12 months. On top of the funding from Scottish Enterprise, they succeeded in securing £1.4 m from Technology Strategy Board and £4.3 m from Scottish Equity Partners, Albion Ventures and the Scottish Investment Bank. As a result, the team deployed the solution to more than 250 farms in the UK and Europe. For market launch and sales over the 2nd NPD cycle, the world-leading solution providers in Germany and the US committed to scaling up the system globally. Finally, the IoT system had subsequently been acquired by an established business in 2016.

Value Creation Strategies

Through the IoT NPD cycles, SilentHerdsman created value by increasing the number of IoT system deployments and improving the accuracy of predictions. However, what made SilentHerdsman's subsequent value creation and development activities distinctive was a critical focus on embedding additional intelligence within the existing system to provide additional service. Over the process, several critical value creation activities were identified, such as understanding the users, having a good relationship with future customers from the beginning of the process, system integration, translating data to the appropriate features, validating system accuracy, building trust, and determining RoI for market penetration.

Having diverse value chain actors involved was emphasised through the process, including data specialists, nutrition management technology developers, vets, geneticists, software developers, engineers, supermarkets, milk recording services suppliers, animal feed businesses, and universities. It was because the system's value was driven by the experts' practice which had to be appropriately translated into the complex IoT system and value constellation. Value co-creation was no longer recommendatory but compulsory. Customers' involvement was even more significant in the value creation of IoT for identifying needs and deploying the system, collecting data, and testing algorithms. Trust building was closely related to market penetration, so the RoI of the system had to be determined.

Development Challenges and Design Contributions

There were complicated development challenges such as: identifying users' needs accurately and translating them into the right solution; misunderstanding the market and the competitive landscape; developing solid physical casing considering the environmental sustainability as the cows hack against the wall, rains, and the water trouble; the long journey of developing, testing, validating and refining algorithm; discovering an algorithm not fitting for purpose or system; managing different development pace of the feature set and algorithm; unknown product performance; limited budget to access to the future customers and prove the solutions; building trust with the customers in the entrenched market; failure of the system commercialisation; and time and resource constraints. With regard to data-driven value creation, despite easy access to the meaningful data from the whole infrastructure in the farm environment, data integration was critically difficult for business opportunities. Also, there were more complicated issues around the standardisation of data formats, data ownership, and monetisation of data.

There were no internal design capabilities throughout NPD process but the design mindset was emphasised. The team spent decent time on the farm to understand the farm environment and observe how farmers use the system. Testing and monitoring constant feedbacks from the farmers enabled a usable system for the farmers and stakeholders. Thoughtworks, a software development company, helped to design SilentHerdsman solution over the later cycle of NPD, particularly the UI of the system. The critical design contribution was to work with users iteratively, starting quickly from making low-fidelity paper prototypes to develop the actual software with more efficiency.

4.6 LettUsGrow | Vertical Farming IoT

Project Overview

LettusGrow's IoT system integrates vertical farming hardware, sensory data, software system (Ostara), and access to network-sourced data optimisation. The software automates and controls the entire indoor growing system, collecting data on plants, overseeing inputs to crop growth and allowing farmers to trace crops from seed to sale, making operations more efficient.

After the failure of the Herb Garden, B2C urban farming IoT system development (the first IoT NPD cycle), they re-identified the target market with the help of a design consultancy through the design support program invested by InnovateUK. The team targeted the vertical farming industry and developed the solution to reduce labour costs of which its development journey was primarily investigated for the study (Figure 36). Thus, this case study mainly focuses on the second IoT NPD cycle which can be characterised as a mix of sprint approaches and two V-models. As the system does not embed high-level intelligence, the value was mainly created by increasing the IoT system deployment.

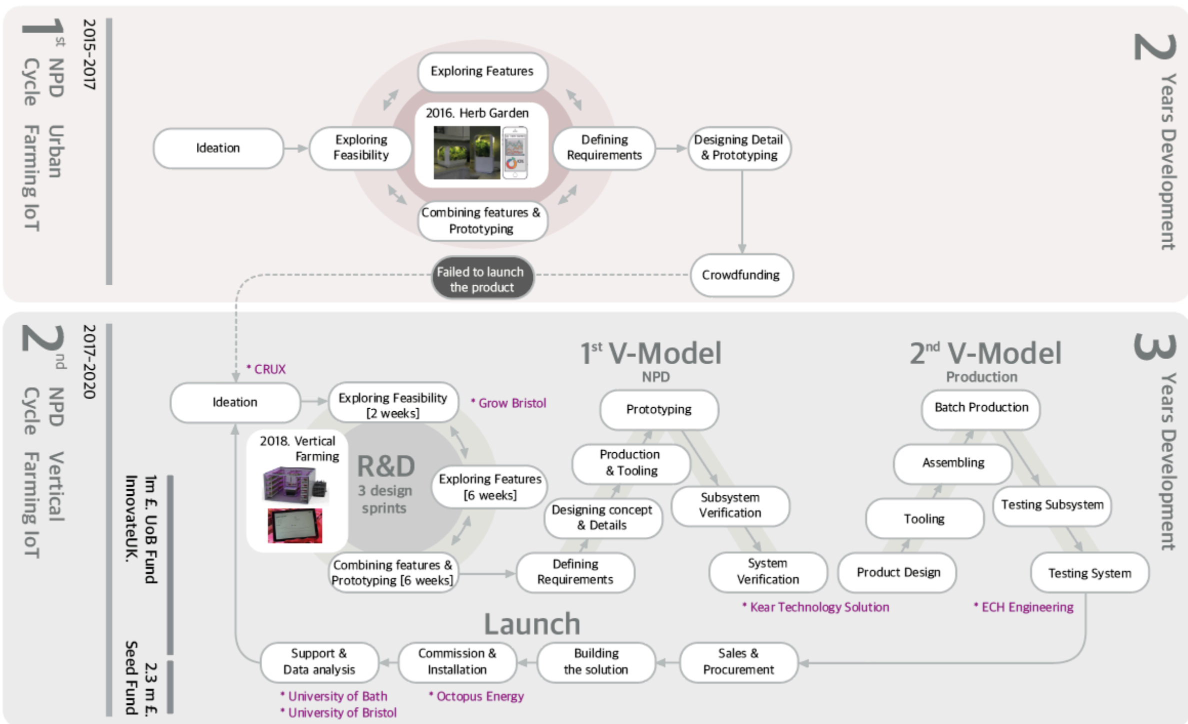


Figure 37 NPD process for LettusGrow

IoT NPD Process

LettusGrow's NPD process comprises five units: Ideation, R&D, 1st V-model, 2nd V-model, and Launch. It is a mixture of different NPD approaches. For example, the team goes through three design sprints over the R&D phase and two V-models for NPD and production. The gate reviews between the discrete stages of the process were critical to review progress set against KPIs. The development begins with ideation, The team searched for the new market opportunities in which their technology application could flourish. Thus, with the help of the external design experts, they aimed to discover where their unique technology could significantly impact saving labour costs and the use of resources. Identifying users' needs is characterised as continuously ongoing activities, working with the internal farmers.

R&D was fundamental to identifying value proposition and demonstrating the technical specification of 'How the technology works'. This phase consists of three design sprints: two weeks of feasibility exploration, six weeks of features exploration, and six weeks of combining features and prototyping. The 1st V-model NPD phase aimed to translate technical specifications of 'how does technology work?' into 'how do we need to package it as a commercial product?' This phase consists of requirement definition, concept and detail design, production and tooling, prototyping, subsystem and system verification.

The production began over the subsequent V-model, which was to have suppliers in line and mass-produce the components. The phase consists of sub-phases of product design, tooling, assembling, batch production, testing subsystem and system. Product launch included sales, procurement, building solution, commission, installation, after-sales support, and data analysis. The systems were supported and shared data with the farmers while scaling up the IoT deployment over the launch phase. The development ideas for a new product or improving the existing system popped up over the development process were explored at the ideation phase.

Value Creation Strategies

Unlike traditional product manufacturing companies creating value from a physical product and their physical capability, the value of LettUsGrow has been based upon data and the knowledge on how the physical products are working and having the system fit on the broader farming context. Specifically, tacit knowledge on how to grow crops and vegetables only existed in the learned experience of the farmers. As a start-up, utilising a wide range of programs and having partnerships with external experts in strategic design, data science, engineering, and farming were the critical value creation activities for LettusGrow. Each organisation contribute to NPD differently, for example: Grow Bristol, urban farming experts helped the team to give user-feedback; ECH Engineering supported to design, build and test the systems; the University of Bristol researched indoor farming; the University of Bath reviewed the software architecture with data science, and Octopus Energy offered vertical power to save energy costs.

Development Challenges and Design Contributions

Through the R&D stage, ideas should have been transformed into the right product in a short time. Since IoT is a complete novel technology, NPD was very conceptual in nature, not knowing if the system would work as intended. Consequently, the feasibility was hardly identifiable unless it was physically built, integrated, and rigorously tested. In the first V-model, the small number of customer samples possibly affected decisions, particularly bias and specific ways, not reflective of the entire industry. One of the main risks in prototyping was a conflict between making enough prototypes and the cost of materials. Over the system and subsystem verification stage, unexpected interactions or emergent behaviours were challenging. The different pace of software and hardware development was another critical challenge as the hardware with the additional complexity slowed software development and reduced performance. The uncertainty of the system performance continued with the investor prototype, with which if the team could convince the investors to secure funding. Unknown maintenance cost was critical in business as to whether the solution would last 20 years, the maintenance contract.

Without internal designers, LettusGrow worked with CRUX, a design consultancy over the Ideation and R&D phases. The external design experts committed to identifying the customer and business needs and discovering where the technology fits in and offers the most value. While identifying customer and business needs, design played a significant role in encouraging the team to work with farmers, biologists and end customers, in order to understand the complex multivariable system. Design intervention also reconfigured the existing NPD process with more rigour and gave the team a competitive advantage.

4.7 ClimateEdge | Tropical Farming IoT

Project Overview

The impact of climate change on smallholder farmers' ability to grow crops has been crucial, but there is nothing much to support them. Many farmers, particularly in the tropics, are isolated from high-tech services that improve efficiency, financial management software, and up-to-date agronomic models - all of which are mainstays of European and US agriculture. Several factors affect crop quality which makes farming incredibly complicated, and climate change makes it even more unpredictable. In this context, ClimateEdge started its IoT system development in 2015. A tailored IoT system aimed to deliver agronomy at scale in crop agriculture by supporting smallholder farmers and cooperatives with access to knowledge.

The value was created through optimising the system for specific farming environments and various crops, including coffee, cacao, tea, and bananas. Nevertheless, the intelligence has not been embedded in the system; it is composed of the NEXO weather station, the analytical software and the FieldGuide application. The IoT NPD process consists of several agile development iterations until it is manufactured. Alongside the NPD process, the team has consulted farmers and cooperatives that distinguished its business approach from other cases. It enabled the team to understand the clients better, have access to the farmers, and generate revenue early in the NPD process. Different needs were identified through the workshops, interviewing people, observing their practice, and eventually, the system was released. Despite limited intervention only in product design engineering, ClimateEdge was one of the few cases with internal design capabilities.

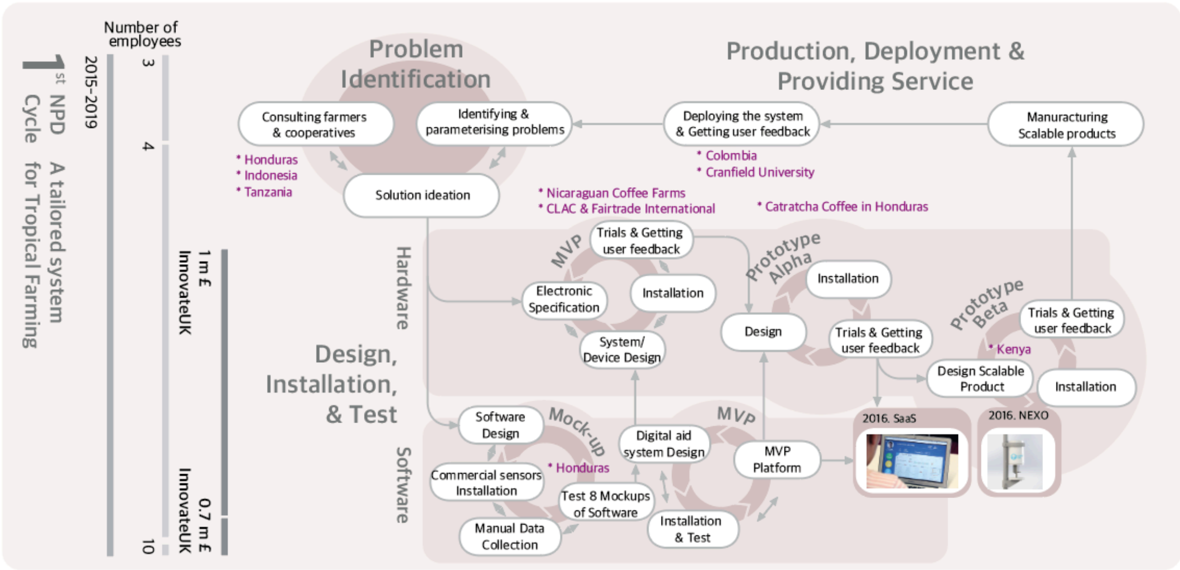


Figure 38 ClimateEdge's IoT NPD process

IoT NPD Process

ClimateEdge's IoT NPD process consists of 3 units: Problem Identification; Design, Installation, and Test; and Production, Deployment and Providing Service (Figure 37). Although the process is illustrated in regular sequence for the reader's convenience, the interviewee stressed two significant attributes of their NPD process. First, each phase is not in a particular order as the system developed through an agile approach. For example, the loop of problem identification could be undertaken across the process, and system design and trial never end even after the products were manufactured and scaled up. Second, Sales, Marketing and business activities were not considered as part of the NPD activities. The project started with the unit of problem identification. As the ongoing activities, problems were identified through workshops, observations, surveys, and while building the system on farms.

The unit of design, installation and the test contained several iterations of designing mock-up, MVP (working prototype), prototype alpha and beta, through which the system could be refined. Getting the feedback fed into the phase of system design was the infinite loop of never-ending design activities. Through mock-up, MVPs, Alpha, and Beta prototypes, the system had been manufactured, which means it was redesigned and replaced by the manufacturable components. The systems were deployed and distributed by leveraging existing networks of cooperatives from consulting services. While the service was being provided, the team tried to understand the user feedbacks on technical issues, which was reflected in designing the next version. After the 1st cycle of development activities, the team continuously improved and tested hardware and software design to scale up with more deployment and expand the service area.

Value Creation Strategies

The system creates value by gathering affordable data from smallholdings focusing on climate and feeding data into an intelligent decision support system whilst providing farmers with tailored advice on farm management. Linking the farmers' challenges to the right solution was the critical practice in value creation. Through a number of prototyping iterations, the team reduced the price of the weather station and made the system easily adapted to measure and monitor conditions for several different crops. Having the system designed affordable and accessible while delivering real-time data effectively was also well thought through practice to ensure the farmers using the system efficiently. With Cranfield University as a scientific partner, the team works on data-led soil management to help irrigation which is the key to service delivery.

Development Challenges and Design Contributions

When identifying problems, the clients were often not aware of what they were struggling with, why they wanted it. At the proof-of-concept phase, manual data collection on air and soil by temperature sensors was a tedious process. When testing the concept with the MVP (Minimum Viable Product) in the farm environments, the MVP was not good enough to make people comprehend what a solution looks like and how it works. To explain the concept verbally to the farmers was not enough to get feedback, even though the conversation was carried through the working prototype. Thus, the team did not get enough feedback on the UI and UX of the system at this stage. The critical issues in testing the weather station were to make it more user-friendly, well thought through to withstand tropical weather conditions while being cost-efficient and easy to service and upgrade. Accessibility was a key priority in IoT development as each region, and the individual farmer had different needs and requirements. The risks over the production, deployment and providing service phase were mainly related to cash flow. There were tones of risks while scaling up the system, including secure funding.

Climate Edge has had an internal designer from the early stage of the NPD process. A product design engineer made the system more user-friendly, cost-effective, and proof against tropical weather conditions. The user-centred approach was applied overall process, which resulted in designing the affordable and accessible solution. The IoT NPD process emphasised iterative and agile design delivering extensive user testing, which was crucial to differentiate ClimateEdge's system from competitors. Considering the regional infrastructure of the internet and farmers' accessibility to the system, the team developed different types of applications from web software to SMS and voicemail.

4.8 Chapter Summary

This chapter describes the six IoT development cases based on primary and secondary data, including interviews, graphic elicitation, and document reviews. Each case is summarised into four categories: project overview, IoT development process, value creation activities, development challenges, and design contributions. The project overview of each case is summarised below in table 21. IoT development processes are varied depending on value creation activities. However, the overall phases and activities can be generalised, which will be further discussed in the next chapter. The case studies demonstrate a range of value creation strategies with different focuses: for example, interconnecting various devices and services (AlertMe and Anonymous case), diversifying services through machine learning technologies (SilentHerdsman), and scaling up IoT application domains and refining IoT systems (ClimateEdge, LettusGrow, and SilentHerdsman). The exploration of the IoT value creation strategies enables the groundwork or support for establishing knowledge on the subject area. Whether there are internal capabilities or not, the role of design in IoT value creation is reasonably limited over the IoT NPD process. Development challenges are categorised into technical or business risks, some commonly found between the cases, for example, limited resources, lack of development, and management skills.

Table 21 The IoT development overview of six cases, with various context

Categories	***SPHERE***	***AlertMe***	***Anonymous case***	***SilentHerdsman***	***LettusGrow***	***ClimateEdge***
Project period	2013-2018 (5 years UKRI project)	2006-2015 (Being acquired in 2015)	2011-present (2020, at the point of the research)	2003-2016 (Being acquired in 2016)	2015-present (2020, at the point of the research)	2015-present (2020, at the point of the research)
Form of Commercial Transactions	Not aim to commercialise	B2C	B2B	B2B	B2B	B2B
Type of organisations that led IoT development	A University	A Private VC-funded company	A private company	A Private VC-funded company	A Private VC-funded company	A private company
Market Segment	Healthcare	Home	Drain maintenance	Dairy	Vertical Farming	Tropical agriculture
IoT products and services	A SPHERE wearable, a charging pad, up to 30 sensors and an application	A smart hub with several securities, safety, energy products/services	IoT hub including sensor network, data models, and decision support system	Smart neck mounted collar, Touch screen PC, and Data gathering station	Vertical farming hardware and software system	Weather station, the analytical software and the application
Value(s) delivered through IoT systems	Measuring cost of acquiring data on residents' physical and mental health	Improving: a) Energy efficiency; and b) Security and safety	Reducing costs and improving efficiency in gully/drainage management in: a) Highways; b) Rails	a) Increasing animal's fertility b) Improving animal's health	Improving crop productivity, making operations more efficient	Empowering smallholder farmers to succeed, providing them the insights & services
The number of IoT value proposition	1	2	2	2	1	1
Value creation strategies	Developing scalable IoT system, Providing insights on residents health	Developing scalable IoT system, Interconnecting various devices,	Developing scalable IoT system, Providing prediction service on gully management,	Developing scalable IoT system, Providing prediction service on animal's health and fertility,	Developing scalable IoT system, Providing insights on farm management, Improving and updating system	Developing scalable IoT system, Providing insights on farm management, Improving and updating system

		Providing insight on energy usage, Providing customised service	Improving and updating system	Improving and updating system		
Use of machine learning	Yes	No	Yes	Yes	No	No
Design Contribution	*Internal Design Researcher*	External Designers (Branding, & Product Design)	External Designers (Product Design)	External Designers (Software Development)	External Designers (Strategic Design)	Internal Designers (Product & Engineering Design)
Interviewee	*A Project leader with* electronic *engineering background*	A founder with computer engineering background	A managing director & a project manager with business background	A founder with electronic engineering background	A co-founder with engineering background	A co-founder with environmental technology background

CHAPTER 05

Cross Case Analysis and Main Findings

5. Cross Case Analysis and Main Findings

5.1 Introduction

Chapter 5 presents the analysis and findings arising from the empirical data of each case study in order to compare across the cases. The collection of data used in this section includes information from different sources used for subsequent analysis. This is mainly primary data collected from the interviews and second source diagrams, and complementally the secondary data of electronic documents and video clips. Based on the research objectives and interview protocols, four critical dimensions for cross-case analysis are established: IoT NPD processes and practice, common aspects of IoT NPD process; Value Creation strategies; Barriers, Challenges and Tensions. In the process of drawing out the initial research findings, the six cases are compared and contrasted with one other against these dimensions. The findings are thus presented, and the outcomes are elaborated as follows:

- IoT NPD process and practice (Section 5.2): This subsection combines and compares each project development activities, phases, and process. Mainly referring to the diagrams and interview transcriptions, the phases of IoT development are displayed, and the activities of each phase are discussed. In identifying the phases when the diagrams omit detailed aspects of the process, interview transcriptions and digital documents were used as supplementary resources. Through comparing the processes of the six cases, the five phases of IoT NPD process are organised and the subsequent IoT NPD process are described.
- The common aspects of IoT NPD process (Section 5.3): In this subsection, the common characteristics of the IoT NPD process observed across six cases are discussed in detail. Five primary facets are identified in total, most of which are distinctive from conventional NPD practices. These are also interrelated to value creation activities and the challenges of IoT development.
- Value Creation Strategies (Section 5.4): This subsection represents how companies create value throughout the NPD process. Five critical value creation strategies are identified. Although value creation strategies are covered within the same overarching term, the specific ways by which each company create value may be distinguished and are described in detail.
- Barriers, Challenges and Tensions (Section 5.5): Summarises the obstacles for the companies to create value over the NPD process. The barriers may differ in each case depending on the

context of the project, industry, and development environment. The interview questions were designed to focus on connected device development, conventional business challenges and barriers were minimally touched upon, such as supply chain management and manufacturing challenges.

Each data set referred to this chapter has unique code system, 'The name of case_##' from the primary data, and 'The name of case_DR_##' from the secondary data. For example, in LettusGrow case, if the source is from interview transcription, it has the designation of [LettusGrow_##]. If the source is from the secondary data, it has the designation of [LettusGrow_DR_##]. For the anonymous case, the designation is slightly different as two interviews were conducted within the study. The interview with managing director is designated as 'Anonymous case_01_##' and project manager's interview is designated as 'Anonymous case_02_##'.

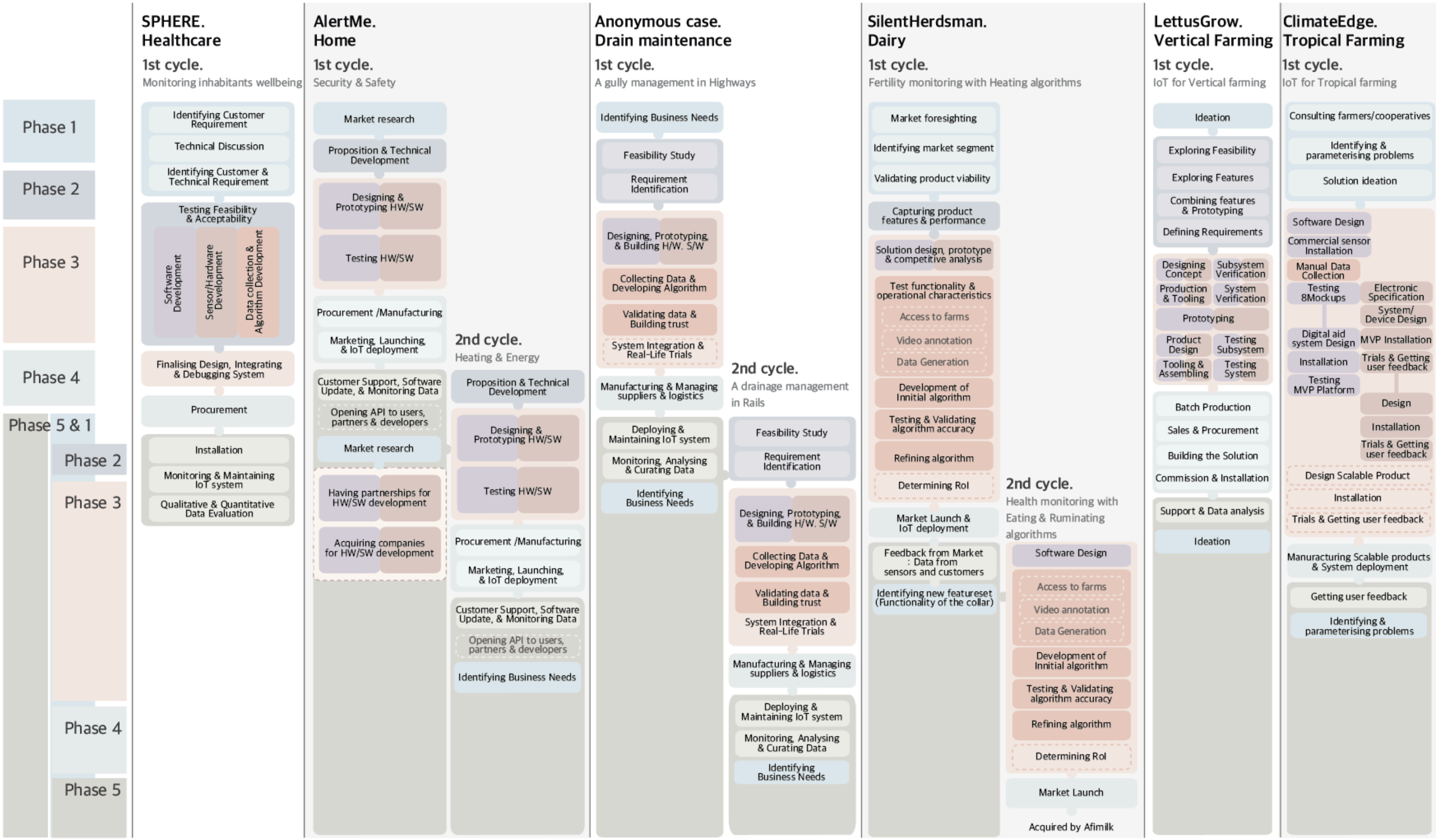


Figure 39 IoT NPD process of the six featured cases

5.2 IoT NPD Process and Practice

Based on the interview transcriptions, graphic elicitations and digital documents, the full extent of development activities and processes of six cases are mapped and compared to comprehend the generalisable phases. The NPD activities are grouped into five phases differentiated by the colour blocks on the left-hand side (Figure 38). The subsequent NPD process is illustrated as being overlapped with the fifth phase of the first NPD cycle. It is because while supporting the customers and sustaining a long-term relationship with them, the companies collected market feedback whilst identifying their needs. These lead to the minor update of current IoT system as in LettusGrow and ClimateEdge cases or the major change of the novel value proposition in AlertMe, SilentHerdsman, and the anonymous cases. The flow of the IoT NPD process activities is largely similar across the cases.

The phases differentiated by the colour blocks can be critically debated. For example, there is no clear phase of feasibility test and requirement identification in the ClimateEdge case (Right hand side column in figure 38). However, these activities are included in phase three. Furthermore, some cases contain more specific IoT development activities, whereas other cases omit the activities for the following reasons: first, it was a lengthy period of development, 9 and 14 years for AlertMe and SilentHerdsman respectively. And second, each informant's diagrams vary due to different abstraction levels (Anselm. Strauss & Corbin, 1998). For example, the interviewees of SPHERE, AlertMe, and the anonymous case illustrate the phase three more simple even than those of SilentHerdsman, LettusGrow, and ClimateEdge.

5.2.1 First Cycle of IoT NPD Process

The phases of the first cycle of IoT NPD process are generalisable which are: Identifying user needs and solution ideation; Feasibility test and requirement identification; Designing, prototyping, integrating and testing hardware, software and algorithms; Manufacturing, marketing, launching and installing IoT system; Customer support, data monitoring, and software update. The development activities in each stage will be described in more detail in the following sections.

Phase 1. Identifying User Needs & Solution Ideation

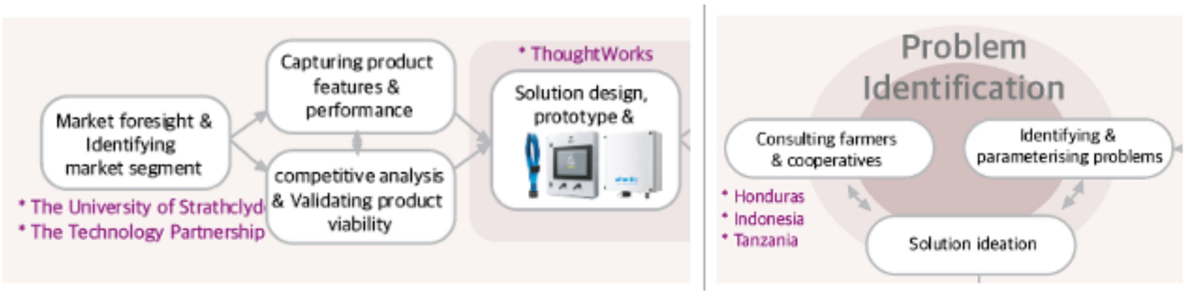


Figure 40 Early stages of NPD process of SilentHerdsman (Left) and ClimateEdge (Right)

Although the terminologies of activities that the six companies used to start their IoT development are slightly different, the first phase is summarised as 'identifying user needs and solution ideation'. This phase includes activities such as market research, proposition and technical discussion and development, identifying market segment, parameterising problems, searching for partners for trials and ideation. To create a tailored system for the target market, they involve a diverse variety of value chain actors throughout a series of discussions. It is an iterative process of different activities, as displayed in SilentHerdsman and ClimateEdge's IoT process [Figure 40]. This first phase often overlaps with the next phase, feasibility testing and requirement identifications. One example is the SilentHerdsman case, in which the interviewee explained that the first three phases from identifying user need to solution design and prototype are not sequential but parallel. ClimateEdge has a slightly distinctive approach towards this first phase. They have been delivering the consulting service which enables the team to access the farmers and understand their issues more deeply [Figure 41].

Figure 41 ClimateEdge's workshop as a part of consultancy services to the farmers in Indonesia and Tanzania

The methods of identifying user needs and developing solution ideas are varied between the cases. However, the commonalities of the methods are that they use qualitative methods in a co-creation context, including workshops, conversations, meetings, discussions, and observations. The team observed farmers, interviewed healthcare providers and researchers, held workshops with councils and other related customers. The project leader of SPHERE specifically described how to commit to identify user requirements effectively. For example, educating the engineers to use visualisations but not jargon and acronyms helps to communicate with the customers [Figure 42]. LettusGrow is the only case in which they explicitly deployed a design approach at a strategic level for identifying value proposition with the help of a design consultancy through the InnovateUK design foundation programme [LettusGrow_DR_04]. SPHERE and ClimateEdge went through another activity, which is to reframe and parameterise issues and subsequent challenges. This additional activity is required as users are often unaware of what they want, and this activity was directed towards uncovering their latent needs.

> OK, like generally there is a process of identifying what the problem is. Sometimes that comes from ourselves **observing** something. It's sometimes about **assembling** whether it's we're in the farm or we're like 'oh, that's an absolute pain.' 'Why is that person doing that job and that person doing this job.' Like **conversation**, more like operational consulting. Sometimes we see things as a problem, but then they may not see that's a problem. At some point, it's very easy to get **caught up in the symptoms** rather than necessarily the causes. So, just because someone's spent a lot of time doing something that may be the problem that actually the issues stamp back. [ClimateEdge_47]
>
> So, first stage is for **customer requirement**, **lots of workshops and meetings** and again we are not trying to sell but we are trying to do research but people you put down here is kind of business partners that heart institute, NHS organisations, clinical researchers, and pharmacy companies. They may not be able to tell you what they need so the method here is just a meeting but you need something like brainstorming or conversation. It is process of an interview, but we don't have methodology, just taking time to understand them in detail. [SPHERE_49]

Figure 42 SPHERE one day workshop (Left) and user research (Right)

One of the common activities observed between the cases is developing a good relationship with customers. They see it as one of the must-dos in the early phase of IoT development as it enables to secure partners for trials, minimising waste of time because the IoT system trial with a certain number of customers is inevitable. The companies had to collect a large amount of data to validate algorithms and systems once the hardware and software development activities were completed.

> The way of doing this is that you have to **have a good enough relationship with your customer** that you can really develop **a proper understanding of what they need**. My advice here is fundamentally proper commitment to do it in detail and take some time. You can mitigate this risk by just doing it very well. It means making time to do it and talking to lots of people and making sure that you are listening to them and having a conversation. [SPHERE_50]
>
> So, from day one, we had the partner channel. From the analysis of the market, I got to know the guy. So, we had a contract in place from day one to deliver some number of collars. [SilentHerdsman_42]
>
> All the hard work in terms of **getting the trial arranged** and adopted has been done right at the start. The councils were expecting to try equipment. So, we worked with them to identify some places when they helped us in terms of actually getting the kits out there. [Anonymous case_02_36]

Although the identification of user needs is argued as the first phase of IoT development, companies perceive it as continuous activity throughout the whole NPD process. In LettusGrow and ClimateEdge, speaking to the users is a continuous ongoing activity to satisfy the customers. The LettusGrow interviewee described that their IoT NPD process does not contain a separate stage of ‘identifying user needs’ but review gates between the stages in which the team continually talk to their customers to make strategic decisions. Once ClimateEdge deployed the weather station, there were possibilities of the technical faults to be managed.

> We did **user research all over the process at the same time**. Because there was no time to do them serious. We needed things to show investors and show progress whether or not it was the right thing. It didn’t really matter as long as it looked right. So, we didn’t have any of this stuff written down to that point. [LettusGrow_16]
>
> So, all of these have user feedback and everything cooperating in it but that's the way that we've managed to do that without having to make it massively. So, we haven't gotten here, and then user feedback and then go backwards.[ClimateEdge_21]

Phase 2. Feasibility Test & Requirement Identification

Once the business and solution ideas are selected, the companies identify system requirements and conduct a feasibility test. Apart from AlertMe, the second phase, requirements identification and feasibility testing, are explicitly or implicitly indicated over the entire IoT NPD process. Regardless of consisting different activities, fundamental activities aim to identify value proposition and the technical specification of 'How the technology works.' SPHERE conducted their feasibility testing at a physical house for a year, which runs parallel with sensor/hardware, software and algorithm development. LettusGrow's second phase is based on three design sprints: a) 2 weeks of feasibility exploration, b) 6 weeks of features exploration, and c) 6 weeks of combining features and prototyping. There is an interim review period between the discrete stages to review progress set against KPIs, then they could potentially go back or into the next stage (Figure 43).

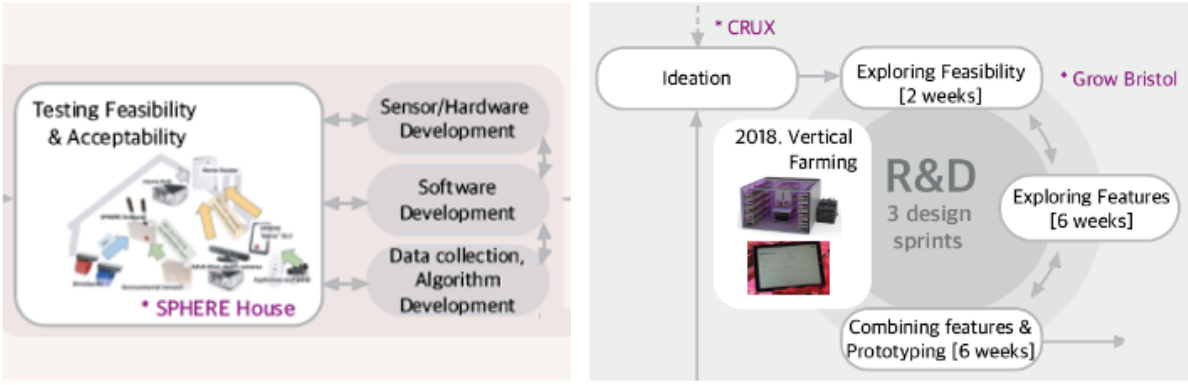


Figure 43 The second phase of IoT process of SPHERE (Left) and LettusGrow (Right)

Over the second phase, the companies seek to answer crucial questions such as:

- What is the market landscape?
- When could we have our product launched?
- Does the science say if it should work?
- Does the science say that the combination should work?
- What is the product?
- What is the feature set of the product?
- How should it look; what is the form factor?
- What is the products' lifetime requirements; can we make the technology work?
- Can we integrate them to work together?
- Is the product profitable; how does it get deployed?
- What is the overhead and the maintenance costs etc?

Companies have workshops and discussions with stakeholders, conduct comprehensive technical and business research activities, and more significantly they develop a demonstrator and test feasibility. However, to obtain all the answers at this point is challenging because the system is not fully built, integrated, and rigorously tested. Moreover, IoT is a complete disruptive technology that is very much conceptual in nature.

> But there’s always risk around R&D stages, like ‘Does the technology work’, ‘Can we make the technology work’, ‘Can we make it work together’, and there is always the risk of product market fit. But that’s what we use the user feedback to assess each stage. [LettusGrow_50]

> We learn a lot in this stage as well. So, first attempt to **identify requirement** was literally it was **a workshop**. So, we all sat around the table people who'd been involved in all the stages previously that we had the design partner there and we all sat down, and we thought through what we could possibly do with. [Anonymous case_02_48]

In the ClimateEdge case, the feasibility test is critical [ClimateEdge_49]. At the phase of proof of concept, visiting farms in Honduras for 6 weeks enables the team to manually collect data, by setting the sensors on the coffee farm and speaking to farmers. Although manual data collection is a tedious process, visiting farms at the early stage of the NPD process was beneficial to the team as they were able to better identify farmers’ issues and be guided which directions the system should be designed. Another critical activity observed during the feasibility testing is the IoT acceptability study. SPHERE and the anonymous case contribute tremendous efforts and time to confirm if their IoT system is acceptable to the end users. The anonymous company conducted a series of ethnography research projects with Lancaster University. By doing this, they understood not only how the gully cleaners are operating the original gully emptying systems but also the level of IoT system acceptability. They also held innovation workshops, and liaised with customers on a regular basis. To test the acceptability, SPHERE tried to make it as real as possible for the users. They invited individuals to stay at the university house where the commercial sensors were deployed [Figure 44]. Theoretically, once the feature of technical files and specifications is identified, the process moves to the next phase. However, in reality, the requirements were continuously changing [Anonymous case_02_47].

> We do some feasibility and acceptability. So, we have **house universities and numbers of public coming here** and we see, at this point we didn’t have any technology so maybe we just bought things. Imagine **put them in the house to see how they feel about it**. So, they come and stay in the house of university for **about two weeks with the sensors**. So, if you think about that, even if we could do this every single week of the year, we can maybe get 25 people to give their opinions. That is absolute top end of this now… [SPHERE_65]

> So, **we did a feasibility study and then we built the sensors**. It was research and we did lots of **ethnography reports** with the University where we went into industry to understand how they did the work and **how they would accept change**, so **we did it around what we were building at the time** which was worked all the system. And they were interviewed, the people who were using paper. We interviewed them once we’ve started to introduce the technology. [Anonymous case_01_50]

Figure 44 A photo of participant is cooking as part of feasibility study taken with a head-mounted camera in SPHERE house

Phase 3. Designing, Prototyping, Integrating, and Testing Hardware, Software and Algorithms

In the third phase, companies build prototypes, translating technical requirements into an end product. They integrate all different IoT architecture layers together, considering scaling up and commercialising the system in the future. From low-fidelity prototypes, MVP to manufacturable products, companies iterate prototyping, integrating, and testing several times [LettusGrow_51]. Over these development activities, they involve diverse actors with different values and fresh perspectives that would enable the team to build the right system fast and easy.

> This is really when you build something people sometimes call it a 'MVP' (minimum viable product). That's the first time you have actually get it, not just a theory. You're not just talking to people saying 'Would you buy something, if it is?' You are actually getting stuff into people's hands. [AlertMe_74]

> All activities we've done for solution design and prototype is based on a **dynamic conversation with the various people involved**. Now you involve the technology providers and make up IoT systems, sensors, microprocessors, and wireless chipsets. [SilentHerdsman_45]

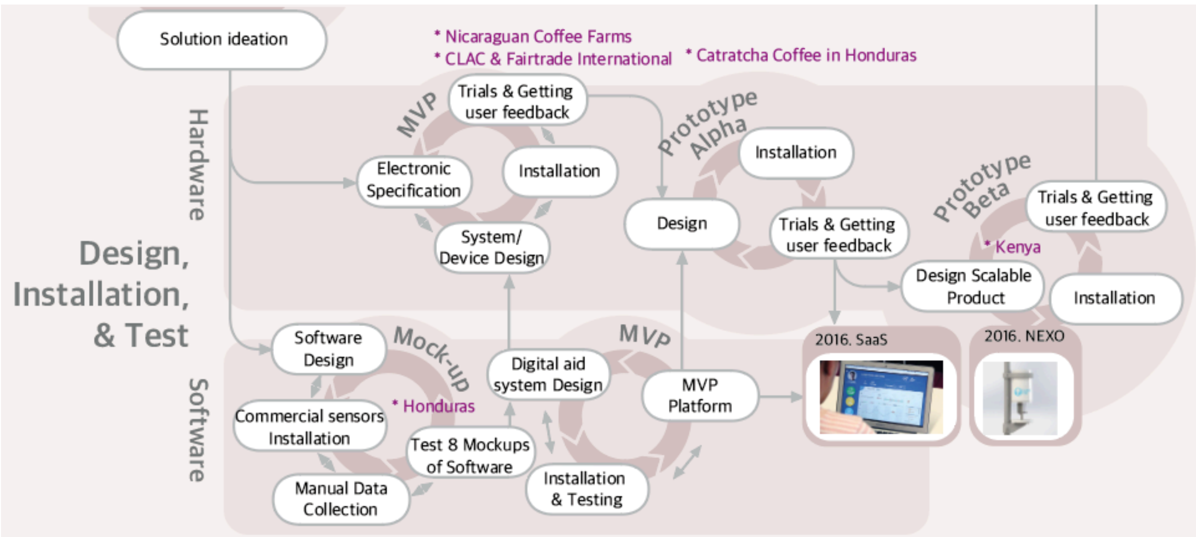


Figure 45 The third phase of IoT process of ClimateEdge

The design activities of this phase are varied between the companies depending on if AI development is involved or not. Those that involve algorithm development like SilentHerdsman, Anonymous case and SPHERE takes longer period of this phase involving algorithms development. Although ClimateEdge does encompass machine learning technology in design phase, its NPD process is distinctive to others in terms of illustrating the explicit separation of software and hardware development and the iteration cycles (Figure 45). From the proof of concept to the scalable product, ClimateEdge's IoT system has gone through several agile development cycles with trial partners. Each mock-up, MVP, Prototype Alpha and Beta improves the system gradually over time. For example, the eight software mock-ups used for the feasibility test help identify the MVP features and individual components. In prototype Alpha, a PCB (Printed Circuit Board) was replaced by the Arduino based board so that data could be sent remotely. The 3D printed weather station was replaced by vacuum-formed UV stable HIPS (High Impact Polystyrene) parts to protect the sensors (Figure 46). The application was developed in different forms to provide users with better accessibility, including web, app, SMS, and voicemail. The prototype Beta was improved with a focus on modular and scalable designs.

> Our weather station is designed and **iterated based on extensive user testing.** We **tested our first prototype** with Fairtrade International on 10 farms in Nicaragua in mid 2016. Built from 3D printed parts of the shelf material and Arduino based electronics we successfully collected the data for several months and learned a lot from this first version. Since then we have built many iterations slowly making our way **from rapid prototyping methods to more scalable manufacturing methods** like vacuum forming or liquid moulding… [ClimateEdge_DR_47]

Figure 46 ClimateEdge Prototyping its weather station

On the other hand, SPHERE, the anonymous case, and SilentHerdsman involved AI development, resulting in additional design activities and issues related to building algorithms, data validation and trustworthiness. To incorporate the understanding of the users' knowledge into the algorithms, the anonymous case and SilentHerdsman conducted ethnography and interviews additionally. The companies created, validated, and refined a software algorithm with data collected while testing the functionality and operational characteristics of the hardware and software during real-life trials. Thus, the time spent for this phase was double and triple compared to those without an AI embedded system. For example, it took two and three years for the anonymous case and SilentHerdsman, respectively, whereas it took one year for AlertMe.

> I have seen a farmer looking at his animal and counting the number of times of rumination a minute. And if the rumination is below 70 a minute, it means the cow's not well. Based on this, we **build the algorithm to understand and give automatic indication** of when rumination stops. [SilentHerdsman_56]

SilentHerdsman's NPD process specifically illustrate the complexity and challenges of algorithms development (Figure 47 Left). In the anonymous case, four sub-activities consist of the third phase of the NPD process (Figure 47 Right). The anonymous case, as a software development specialised company, the design subcontractor was in charge of hardware designing, building, and prototyping, and Lancaster University mainly built algorithms. In this context, the case company played a critical role as an intermediary to integrate the prototype of the system. Although SilentHerdsman and the anonymous case had access to the farms and highways for trials respectively, assembling reliable data against the algorithms was time-consuming and costly. After they released the sensors in different places in the country, the only way to validate data accuracy was actually to have someone across the country manually check it. This internal data modeller had to go through and remove superfluous data. Having the customers adopt the system, they both had the trust issue, but the approach to it was somewhat different. SilentHerdsman built trust by proving RoI (Return on

Investment), and the anonymous case company had the end-users understand that the system is trustworthy.

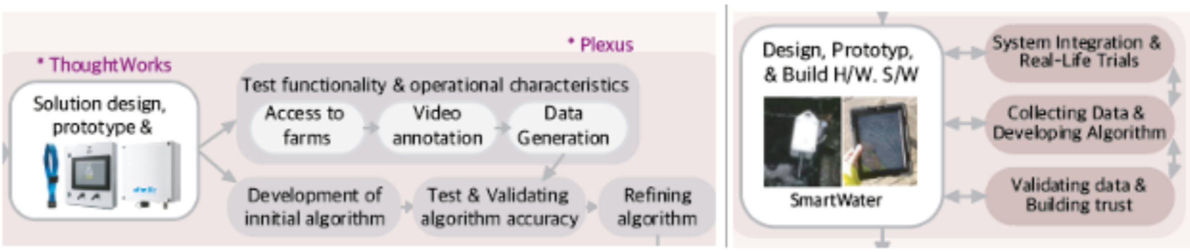


Figure 47 The third phase of IoT process of SilentHerdsman (Left) and the anonymous case (Right)

Before releasing the system, companies have a test plan to ensure not only the quality but also security of the system is effective. The functionality and operations of hardware and software are tested through real-life trials. The reviews collected from the tests are saved for the following value propositions. The security of the system is tested by penetration testers, the so-called 'ethical hackers', to perform vulnerability assessments. The stage of Subsystem testing aims to check nothing's changed in the interaction of everything at the point of the final product launch phase. The system trial is an ongoing process as the system is continuously updated and adapted to. The system is required to be modified and customised depending on where it is applied.

> So, we've **deployed the kit** to one early customer, one internal customer, and one partner experience grower and we do **regularly usage interviews** with those people, we do reviews at certain frequencies as to sort of feedback on what they are doing… **We also write it all down, store it for future**. So, doing things like that, we **understand real priorities and then quite a lot of broader market research**. [LettusGrow_83]

> So, it's the same **security and privacy**, through best practices. You can try and make your product as secure as possible by design. You can then test to see whether it is secure. You can h**ire penetration testers to come and try and hack it**, **and to audit your code**. And we did all those things. [AlertMe_81]

> It's kind of been an ongoing process. So, if I look at it from that point of view, when we first identified it, I would say it's still undergoing now. So, this is we're still trialing these here. And I would say this is the longest phase because this has probably been going on. It probably took us 2 years to. [Anonymous case_02_66]

Phase 4. Manufacturing, Marketing, Launching and Installing IoT Systems

Once the system is integrated and tested, it is then ready to be manufactured, commercialised and installed. Apart from SPHERE, all of the companies subcontracted manufacturers for volume production. At this stage, the manufacturers helped answer critical questions on the way of building and deploying IoT systems while the companies assured the quality controls. Alongside manufacturing the products, their number of customers increased, the companies had to tool up the process and teamwork made more effectively and efficiently. SilentHerdsman had channel partners for market launch and sales. They could focus primarily on IoT system development as the channel partners progressed the sales and marketing strategy.

> Very last step is **to design for scale and manufacturer** which is 'How do you take this and do this at scale?' So, we know 'How the system works?' 'With sensors what data you want to collect?' 'How do you make that happen?' After getting through mock-up, MVPs, Alpha and Beta prototypes, the system is being manufactured and then you like 'Right. Now how difficult is that actually to build', 'how difficult is it to actually install' like that, 'is it installation' or 'do we have someone abroad?' [ClimateEdge_75]
>
> We go through couple of other stages, it's kind of the **production tooling, another production design phase that is suitable for batch manufacturing** things like that. And then in the tooling and assembly shop, preparation, then we get the first batch product made. So, **we don't manufacture in-house where we can avoid it**. We'd like to avoid it because it's the **capital cost to small business**. We can't afford the tooling, and extra people to do all… [LettusGrow_78]
>
> **We didn't want to do any marketing and sales** but only develop eating and rumination algorithm. So, NMR (National Milk Records) became the engine for marketing to us. NMR have been established for many years. [SilentHerdsman_65]

Phase 5. Customer support, Software update, and Data monitoring alongside Phase 1

The fifth phase is customer support, software update, and monitoring data. Once the systems are deployed, companies are able to collect and aggregate data in cloud, which are then processed for analysis (Figure 48). While LettusGrow, ClimateEdge, and AlertMe provided customers insights on plants growing or energy usage, the anonymous case and SilentHerdsman supported the customers' decision making with the prediction using algorithms. In particular, the anonymous company looked at a wider range of datasets and sensors to make an attempt to create additional value propositions. LettusGrow identified the fifth phase of the NPD process critical as it is the moment where a lot of value around data and biological knowledge was collected by internal farmers and biologists. The team aimed to create enhanced value by combining and analysing different types of data, such as Co2, airflow, and substrate moisture.

> So, if you're collecting information electronically that's where the data comes from and then what you are doing is you're **changing that data into something useful**. [Anonymous case_01_75]
>
> At the moment the one we actively sell is **the gully sensor**. Whilst we have the gully data, we need to start **looking more widely at other datasets**. We've got our in-house team looking at all these different kinds of sensors now. [Anonymous case_02_26]
>
> We tend to osculate with temperature, we collect PHDC (Passive and Hybrid Downdraught Colling) within our reservoirs. We will start to measure CO2, airflow, a substrate moisture, so the soil replacement moisture that. We about to start with eventually mass of cropping in real time. But currently, that's just a user, collected variable at the end. [LettusGrow_108]

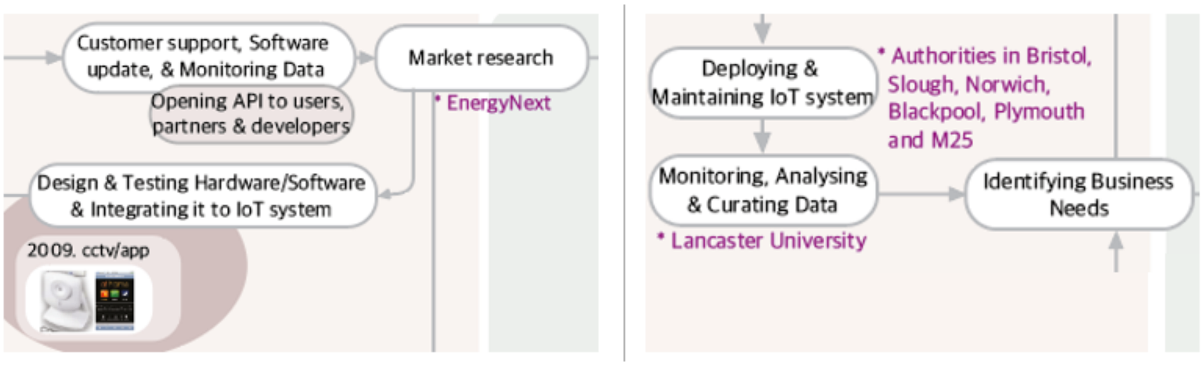


Figure 48 The fifth phase of IoT process of AlertMe (Left) and the anonymous case (Right)

In terms of customer support, AlertMe and the anonymous case had systematised customer support as the IoT system had considerable technical issues that needed to be overcome and solved. The anonymous company regularly runs software that reports technical faults to the team to repair them. AlertMe had three stages of the customer support cycle: As the first line of support, the issues were solved by answering questions within hours; or when the problems were still not solved, they were passed to the second line support, which required detailed engagement, diagnosis and so on; and the problems that were still not solved, passed onto the third line, which was the R&D phase in which the engineers had to discover a technical issue and get it repaied. Once the technical fault was repaired, the software was offered to customers.

> If something happened after releasing the service, we have **a software that any bugs are reported** and they live on that system until they are resolved. And that made our products very stable. We managed that on something we watch very closely. We **run the system regularly** all the time. If it comes to really quick. We have tester and 2 delivery people who are managing our customers all time and dealing with any queries. And we have a process and computer systems for any compliance and people can register any issues online or by phone or by email. [Anonymous case_01_66]
>
> There were **the longer feedback cycles** from that kind of stuff. So, some of it, you'll have like **first, second- and third-line support**. So, the first time, you will be literally having pretty much a script, they'll just, be deep trying to deal with the problem to try this and try this triage whatever. And that solves most of the problems. But the problems that they can't solve has to go the second line and then they require detailed engagement, diagnosis, lots of stuff. And then the problems that they can't solve go to third line which is often R&D where engineers will have to go and really dig in and find out what the hell's going on in this situation where the thing just isn't working. [AlertMe_96]

Figure 49 SPHERE IoT deployment in a participant's house (Left), ClimateEdge IoT deployment in Kenya (Right)

Before data was analysed, the anonymous case reviewed the accuracy of data and removed superfluous data [Anonymous case_02_72]. For the system maintenance, they had a GDPR manager within the company who managed data governance, and a subcontractor that managed the hardware aspect of infrastructure [Anonymous case_01_79]. Whilst supporting customers with technical issues to ensure meeting the users' demand, the companies collect user feedback and conduct further research for system improvement or novel value creation. SilentHerdsman discovered cattle's health monitoring service from market feedback. The customer support team in AlertMe conducted a series of surveys and ethnographic research studies through which they gained a deeper understanding of the issues of using IoT products and services. ClimateEdge and LettusGrow have further developed ideas collected from the data or findings from the market in the R&D phase and regularly reviewed to see what new projects could be initiated. Specifically, LettusGrow and ClimateEdge looked into how to improve the system to optimise it for growing various crops in different sized farms. In order to scale up the number of deployments, the team returned to the farms and speaking to farmers as they lack understanding of growing different types of crops in various sizes of the farms. In addition, they attempted to apply AI to their IoT systems, working with data science companies and Universities [LettusGrow_107; ClimateEdge_DR_46].

> From the market sales, it is identified the heat algorithm is not enough, you need rumination algorithm and eating algorithm as well. I have found out this **from the market feedback**. [SilentHerdsman_69]
>
> We need to **get enough out there** that we are happy with the design, we've learned huge amount from that process. Weather station as an example. you've learned in terms of the installation, or the deployment, a strategy for that, assembly, then user feedback and then **that's gone into the next version** and then you just go back into the process. And then you spin it out, and then the next version again. [ClimateEdge_90]

So, every 2 months, **to see what new projects we can start** where we are at with other ones **based on the data**, **or basis on what you find out here**, basis on what you find out **from a farmer**, something that happens in defining on requirements from this. Actually, that might be a different product here, as like slightly different apart from similar architecture, check in the farm and see if we could do it. **So, we were quite keen to collect**, just like them growing continuously, **data within production process** and that's broadening engineering team as well. **Everyone brought and chuck ideas in R&D phase.** [LettusGrow_105]

5.2.2 Subsequent Cycles of IoT NPD Process

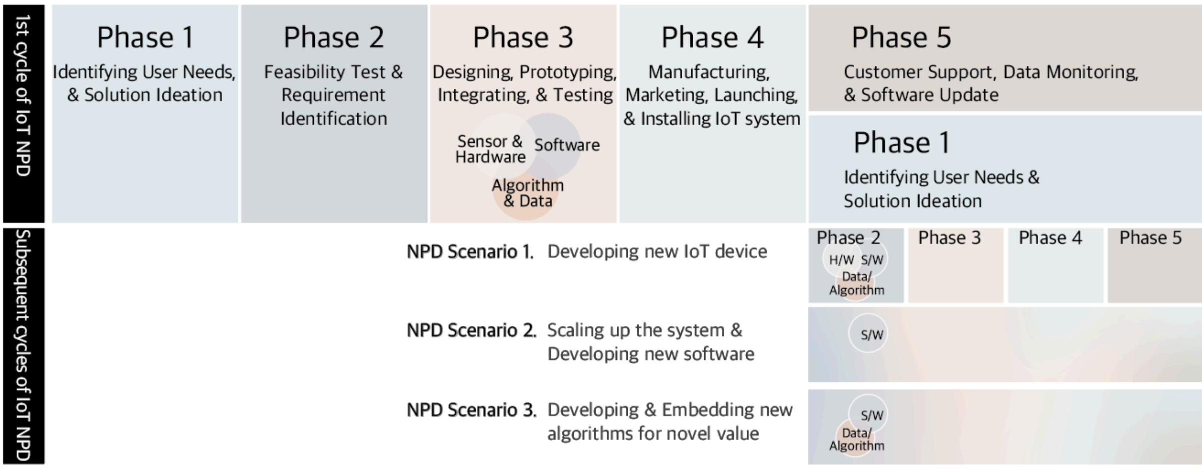


Figure 50 Three different scenarios of the subsequent cycles of IoT NPD

In the subsequent process, the companies expanded the deliverable service areas in three different ways (Figure 50). In the first NPD scenario, a company develops new IoT devices and connects it to the existing IoT system, for example AlertMe and the anonymous case. The subsequent NPD process in this scenario is similar to the first cycle of IoT NPD process which involves the hardware, software and sometimes algorithm development. In the second scenario, a company develops new algorithms with existing data and embeds it in the existing IoT system, like SilentHerdsman. Although it does not involve hardware development, it may be complicated, involving data science process input. In the third NPD scenario, a company improves existing or develops new S/W features, like AlertMe, ClimateEdge and LettusGrow. In this scenario, a company focuses on increasing deployment of and occasionally accompanying minor updates of the current system. Regardless of subsequent NPD scenarios, the deployment of IoT systems means a considerable commitment to system maintenance and data collection which is a continuation of phase 5 and scaling up. Qualitative and quantitative data collected over the customer support were used as the resources for value creation. The subsequent cycle of the NPD process was not identified in SPHERE case as the system was not commercialised.

I would **not want to commercialise**, because just to manage supply chain for **10 years to guarantee spares and availability for customers**, would be really big problem. That must be the truth from the companies in IoT space. So, the bigger the eco-system has to be, the more of problems that is. [SPHERE_82]

Some extent it's the same. I'm not sure about the stages really but there are the same things again and again **from the point of launching** I would say. It might be that you start to work on version 2 ideation or so. [AlertMe_60]

After launching the products and services, it is ongoing support and conversation, not tones of formal feedback of that point. [LettusGrow_33]

AlertMe commenced developing technology for energy and extended the IoT system for security through adding new IoT devices (Figure 51). Its subsequent NPD process encompasses two NPD scenarios, new IoT device development and new software features development. In terms of the third NPD scenario, AlertMe launched the new feature of carbon footprint through iGoogle gadget and Yahoo Widget in 2010 and developed the heating control features with WattBox in 2012. It helped to create competitive and unique IoT eco-system and increased customers' accessibilities to their IoT system. [AlertMe_DR_02; AlertMe_DR_03]. In order to get more services integrated into their IoT system, they also offered API to 3rd parties' developers through which they could enlarge the value constellation and decentralise the innovation activities of the IoT system [AlertMe_DR_01].

Figure 51 AlertMe's energy service integrated in Google PowerMeter (Left), AlertMe's Carbon Footprint measuring feature launched on an iGoogle gadget and a Yahoo Widget (Right)

The first NPD scenario type was observed through several development cycles, including Smartplug in 2008, energy hub and CCTV in 2009, new home display in 2010, smart energy, gas/smoke detector in 2011. As some technologies are a highly specialised and regulated area, AlertMe partnered with several specialised companies. In the manufacturing and marketing phases, British Gas directly involved placing orders and managing manufacturers and committed to re-branding the energy and heating IoT systems. Partnerships with Deutsche Telekom, Lowe's and Essent gave ground for AlertMe to expand their business abroad and potentially helped channel partners to extend their value propositions.

And ultimately, we were able to actually **step out of that loop**. So, big channel partners, like British Gas, would actually place orders on our manufacturers. So, **we wouldn't have to take any of the cash flow** ourselves. So, we **became more of an IP company** which I think is probably better. We should have done that earlier. We were delivering intellectual property, but we weren't actually responsible for our factory. [AlertMe_127]

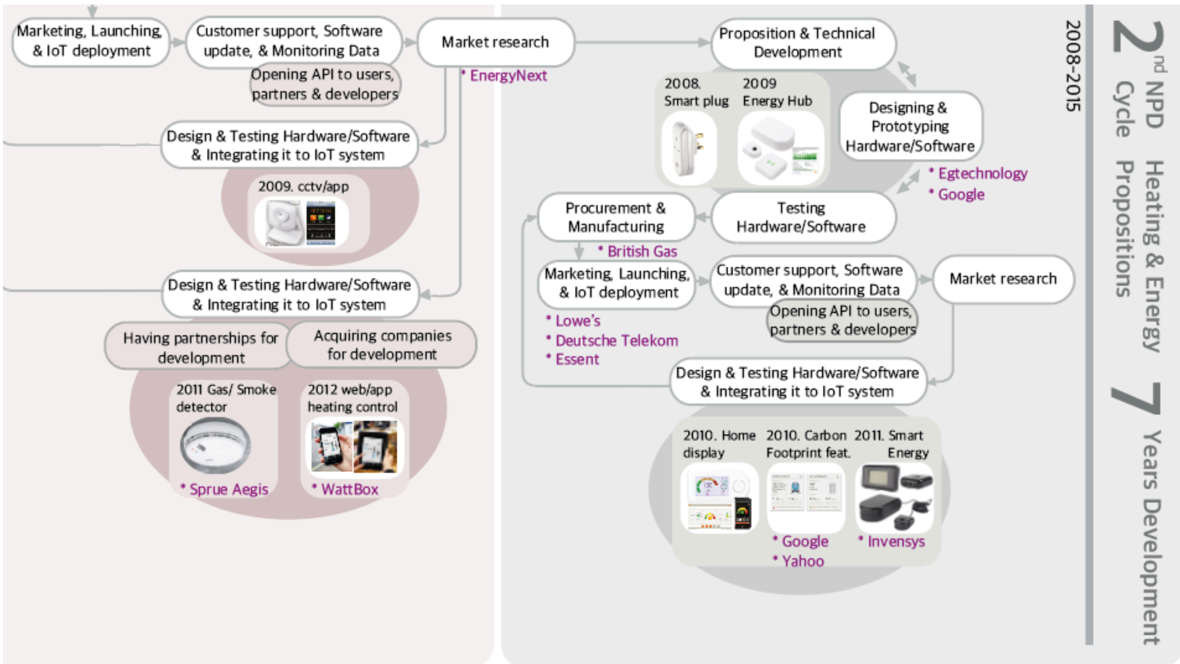


Figure 52 The subsequent NPD cycle of AlertMe

The anonymous case's subsequent process was the third NPD scenario with smaller and shorter loops until they decided to develop a new gully solution for railways which the first type of NPD scenario was observed. On the other hand, SilentHerdsman went through the second NPD scenario. Once SilentHerdsman identified health monitoring service as a deliverable service, they explored how the veterinary doctors and farmers judge when the animal is unwell through observation. As such the team accessed the farm environment to record the muscle movements of the animals and developed and refined the algorithm for a further 12-month period.

The process is ongoing process because for example the kit that we first pop out was from the 1st iteration of this. The kit we put out on trial. We still have our own trial even though we've got a newer kit. And we've learned things from that all the time that identifying new business needs [Anonymous case_02_08]

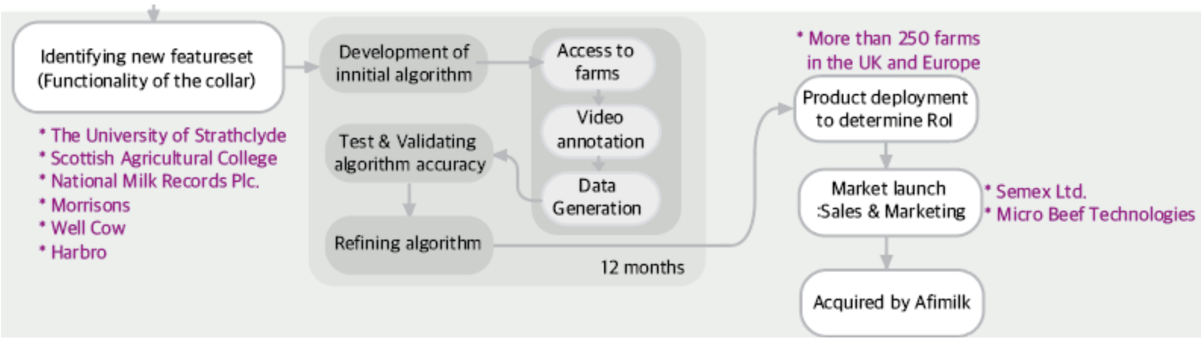


Figure 53 The subsequent NPD cycle of SilentHerdsman

5.3 The five commonalities of IoT NPD Process

From the six case studies, the five commonalities of IoT NPD process and practice are identified as follows:

1. Generalisable phases of IoT NPD process;
2. Developmental considerations
3. Continuous and Emergent Process [Perpetual beta];
4. From Slow, Complex, and Expensive Process to Fast-flowing Process;
5. Collapsing the Temporal Division between Development and Usage phases.

These are described more in detail with relevant data below.

5.3.1 Generalisable Phases of IoT NPD Process

The interviewees from the cases, including SPHERE, ClimateEdge, and SilentHerdsman explicitly describe that the IoT NPD process is comparable to traditional NPD process. Two interviewees describe their NPD processes are ‘similar’ or ‘not unique’ to the traditional NPD process. The co-founder of SilentHerdsman states that the stages of IoT NPD could be generalisable by developing ‘a methodology that fits all’. He stresses that the matter of each phase is more about the details of how; how thoroughly the phase is proceeded.

> I suppose that a generic NPD process is similar to SPHERE process. [SPHERE_100]
>
> I don't think it's in particularly unique in terms of what we do. So, I'd say it probably starts off with problem identification. [ClimateEdge_15]
>
> In business transformation to develop IoT system, there would be a methodology that fits all. There are the same things about business transformation. Understanding businesses is not a problem, but what

> are the challenges, how do you solve them and try to understand if there's a solution to that could be a problem. [SilentHerdsman_23]

Whilst all interviewees illustrate and describe their NPD process and practices, the two interviewees describe their practice of IoT development have never been structured enough. They are the IoT start-ups with five years of development which is the shortest period compared to other four cases. The co-founder of LettusGrow explains that it is because the small team could work with agility, which is more efficient, whereas ClimateEdge sounds more like highlighting on their will of being flexible within the NPD process. In the case of AlertMe, the NPD process become more structured when a number of IoT system is commercialised and deployed [AlertMe_117].

> I don't think we've ever followed it structurally enough. Again, small team, adding in this level of structure seems unnecessary at times. [LettusGrow_13]

> I wouldn't say that is, like a strict process how we go through. … I think really it's the art of possible and do what you can. Like I said, you can just like walk into the farm and do the survey but that takes time, so how many people do you talk to and so on. But there's no format I think. [ClimateEdge_16]

5.3.2 Developmental Considerations

The architecture of the internet of things is complex, equipped with sensors, actuators, and processors. Accordingly, the integration of software, hardware and algorithm development is observed as one of the significant elements of IoT development, which generates a number of challenges within the IoT NPD process. Moreover, the different pace and approaches of software, hardware and data are observed from four case studies (i.e., LettusGrow, ClimateEdge, and SilentHerdsman). Ideas can be generated and validated promptly in software development that is more effective and efficient. In contrast, the nature of hardware development and an embedded IoT hardware system, which requires a deep and thoughtful planning, makes development activities slow and complicated. Consequently, it is observed that IoT development requires applying different approaches between software and hardware development. The interviewee of ClimateEdge clearly illustrates this aspect in the diagram (Figure 37 in Section 4.7 ClimageEdge | Tropical Farming IoT). The co-founder of LettusGrow pointed out that the sequence of development stages for hardware and software is similar, but software development is composed of shorter sprints.

> Okay, every stage is divided into two, which I think is how we have been trying to develop it. You have got the software as a service and the hardware. Obviously, it is a lot easier for software, but there is the hardware. … So, it is a very different process, and the time taking for developing is very different. [ClimateEdge_23]

> We've got software system which operates as a different process to this, well, similar process actually, but just shorter sprints. So, one problem we've had previously is too many things to control on the

> hardware side, for the software to be able to do it more efficiently. There's always the risk around integrating the system. The speed of development between the hardware and the software is very different. Hardware is very slow, and software is very quick. We design parts of the hardware system that adds additional complexity to control logic side of software which then slows everything down and reduce performance. [LettusGrow_68]

Not only the different pace of software and hardware development but also the different pace of algorithm development and proof of RoI is observed to affect NPD process if the data collection takes considerable time. SilentHerdsman and the anonymous case account for this. The SilentHerdsman IoT system was developed to increase cattle's fertility and monitor their health (Section 4.5). For the team to evaluate the profitability of an investment, 12 months was required because it is a cow's pregnancy period. Although it was much quicker to calculate the feature set and develop the algorithm, data collection for testing the algorithm took a year, where the team struggled with. In the anonymous case, although the system is deployed, developing and validating a level of AI is time consuming but critical to creating meaningful value in IoT.

> One pregnancy takes a year. To incur Return-On-Investment, it needs to get pregnant. So, the return-on-investment validation was struggled but the actual feature set calculation and algorithm is quicker. [SilentHerdsman_62]

> So, that was the next issue how would you then set up a level of AI because we didn't have enough time when we were doing it as a project. But you rather need, and this is already being done in other sectors. [Anonymous case_01_48]

The agility of development practice is emphasised in IoT NPD in most cases, even though the hardware and software development speeds were different. The interviewees of AlertMe, the anonymous case and ClimateEdge describe that releasing products quickly to the market is one of the critical issues in order to get market feedback. Moreover, LettusGrow had three design sprints in the R&D phase, a two-week design sprint and two six-week design sprints (Figure 36 in section 4.6 LettusGrow | Vertical Farming IoT), which is the earliest phase within the IoT process.

> Essentially, you know, until this point of design, prototype and test, you haven't really had enough stuff out in the world to worry about and your main challenges being just making stuff and shoving it out into the field. [AlertMe_78]

> …So, part of the risk is how do you balance the getting something to market quickly and trialing it against the fact that it's full of bugs and falls over. [Anonymous case_01_62]

> Understood the agile work for loads so basically start off the concept, get out there as soon as possible get the feedback on the basically UI framework for a get out there and test it. [ClimateEdge_65]

> The fundamental R&D stages are to identify the technical spec of 'How technology works'. Within R&D process, we tend to do Sprints, so 2 weeks exploring then we have a gate review to see how that's all gone, potentially go back round, but normally go into sort of a 6 weeks Development Sprint (Exploring

> features and individual areas of interest) again see how it goes and potentially get back round. And then kind of this is more exploration. [LettusGrow_37]

While the agile approach is considered significant between the cases, the stage-gate approach is still valid and applied to the process. For example, LettUsGrow's NPD process was a mix of dynamic flexibility and rigour with regular design reviews over the whole process. In the anonymous case, the stage-gate approach over the NPD process was inevitable regarding making agreements on decisions between the different stakeholders [Anonymous case_02_50]. They worked with a diverse variety of actors in their autonomous gully management system whose business interests were varied. Consequently, in the design phase, build and prototype, they went through a long gate-review process with extensive discussions.

> So, we kind of loosely follow the stages but regular design reviews where you finished the piece of work you get feedback on it. It is probably the most valuable bit at the moment. [LettusGrow_14]

5.3.3 Continuous and Emergent Process | Perpetual Beta

One of the most critical aspects of the IoT NPD process, which differentiate its traditional counterpart, is that it is continuous and emergent [AlertMe_35; ClimateEdge_90]. The companies add novel value proposition to the existing IoT system through the subsequent NPD process, which meant that the design of the IoT system may never be completed. The project leader of SPHERE summarises how the process could be considered emergent. For example, hardware and software design may never be finalised by adding new services, devices, or analytics to existing IoT systems based on identified market needs; or improving existing software or user interface of the service.

> Obviously, you can have some new service. Now you have a new customer, and then you are trying to see something you can do. Or can you meet their requirement with what you have already, or do you need to have some new thing in which case for example, you need to have a software layer, analytics, or visualisation on top of what I have to give you a new customer. Or maybe what you need to have is a completely new device, so I need to find new sensor, new acceptability, new integration, new everything. [SPHERE_95]

AlertMe, the anonymous case and SilentHerdsman have added novel value propositions on top of their existing IoT systems. One of the significant factors that enable IoT NPD process continuous is that the system could be regarded as a platform through which the services are added. In SilentHerdsman, while the feature of fertility monitoring was being provided to the farmers, monitoring health solution, identified from the data and market feedback, was added to the existing system. In the case of AlertMe, while the team launched their security and safety products and services in 2007 through the first cycle of NPD, they extended their offerings to the heating and energy features by launching a diverse variety of products and services in subsequent NPD processes.

> First service we provided was fertility (pregnancy), and from data collection and market feedback, we added the feature of monitoring health to the system. No new sensor added but with the same system. [SilentHerdsman_70]

> So, the reason we went to Energy Next was by surveying our customers. So, when we had a couple of hundred B2C customers, we spent a lot of time going out and talking to them, running surveys, understanding what they cared about… The overwhelming response was that people wanted the energy because they wanted the smart bug in the heating control. So, that was what made us get into energy and that's what ultimately led to it. [AlertMe_98]

Also, as the system deployment means the long-term relationship with and commitment to the customers, the companies collected data on the customers, which keeps their value propositions evolving in order to enhance the user experience. These data feedback loops in the design processes lead to emergent NPD process and the design of an IoT system that could never be finalized. The interviewee of AlertMe describes that they had to review the usability of their system every twelve months as they scale-up. It is because having the broader range of customers means that the level of technology adoptability becomes low.

> You can capture the data at the end of the process after five years, you can feed into the next design. [SPHERE_33]

> And the journey to making the customer product simpler, was a continuous one, you know, every 12 months with it. We made it much simpler. That's probably about as simple as it can be. And then we discover that it needed to get even simpler. And I think that's part of what happens as you grow up in scale. Because in the early days, your customer is an early adopter. And they are tolerant of things not working very well. But then actually a lot of products fail to make that transition. Because mass market customers are much less tolerant of things working. They might be even less sort of intelligent. [AlertMe_104]

In addition, a dramatically accelerating pace in digital technology development affects the continuous design process. Due to the fast speed of digital technology advancement, the manufacturers with its improved performance, continuously launched novel chips, sensors, processors and others equipment. The components used to develop IoT system became outdated quickly or even no longer available which often required replacing the component [SPHERE_28]. However, IoT system is comprised of a number of components that must work seamlessly between the constituent elements and with a layer of software. One replacement of a component may result in the whole system being redesigned or the whole software being updated because of new security vulnerabilities that could be discovered.

> And also, the other thing is like new security, vulnerabilities, so even if you are happy with your hardware, suddenly you find something threat to the system. And then, you have to change your processor or change your software or something. [SPHERE_74]

5.3.4 From Slow and Complex to a Fast and Simple Process

As discussed earlier, the IoT NPD process is characterised by continuous loops of iterative design. Until the first batch of IoT system is deployed, IoT NPD is characterised by a complex, slow, and consequently expensive process. The development approach for hardware is complex as it requires clear separations and significant review gates between the discrete stages. Similar to hardware development, algorithms development is a lengthy and costly process as data collection is continual and time-consuming. On the contrary, software development is faster than hardware and algorithm developments. Integrating and testing the three different parts make the process slow and complicated. On the other hand, once the system is deployed, the successive cycle of NPD becomes less complex unless no new hardware or algorithm development is involved but software update, customer support, and algorithm accuracy improvement. At the point of scaling up, if the IoT system is extended by developing new devices or algorithms, the process becomes complex which is illustrated through in figure 54.

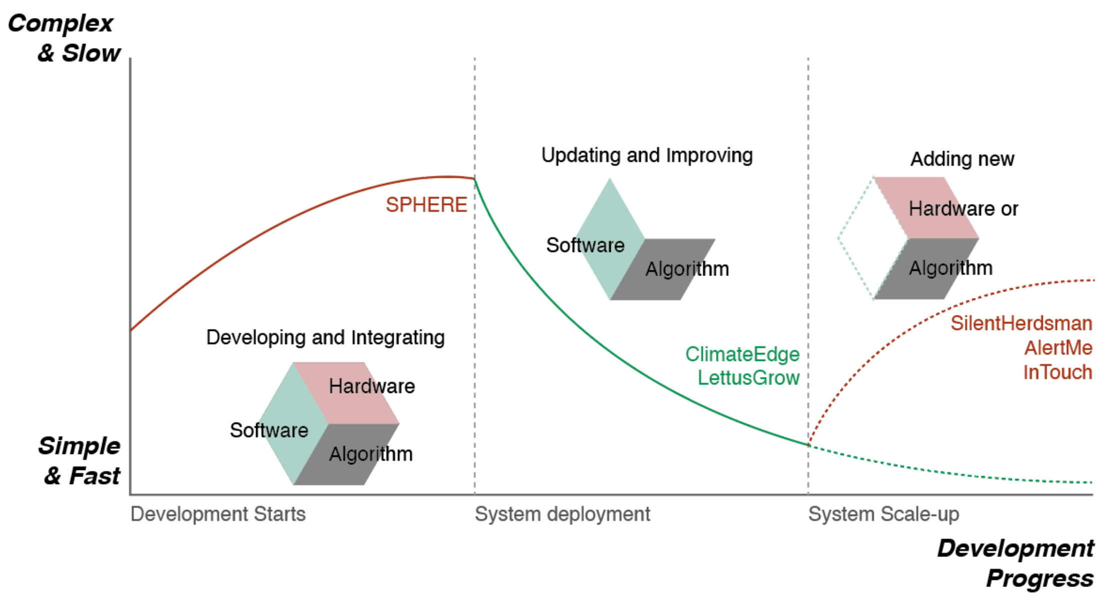


Figure 54 Complexity and Speed of IoT NPD process

Each case can be explained through Figure 54. For example, SPHERE has never deployed system through market launch, so their development progress stopped in the first phase. At the point when the interviews were conducted, ClimateEdge and LettusGrow continued to implement their IoT systems, and seek new ways of developing the algorithm. After launching the IoT system, the organisations' development activities become faster and simpler by updating and improving existing system, mainly the software. The project manager of the anonymous case distinguished the subsequent NPD process to the first NPD process. It is because the subsequent NPD process is characterised by less defined, smaller and shorter loops without major modification of the IoT system.

> I suppose the loop becomes a bit less defined, I think, for a period of time. Because of some of these, we have put the kit out, and then it was a small change that we wanted them to make, and so, it was, you know, kind of request 'Can you do this', so there were some smaller shorter loops where they were still involved. [Anonymous case_02_12]
>
> After launching the products and services, it is ongoing support and conversation, not tones of formal feedback of that point. [LettusGrow_33]
>
> When we want to introduce the software element of control invariably, something pops up, some unexpected interaction or emergent behaviour occurs. You find out pretty quick, and **you have to a small, quickly begin to design it out**. [LettusGrow_66]

AlertMe, SilentHerdsman, and the anonymous case are those that entered another development cycle as their IoT systems were integrated to others and involved new device or algorithm development. In this section, the complexity of NPD process was increased as a major development activity involved with the aim of scaling up the entire system. The complexity of development progress in the first phase is thoroughly represented by the cases. The co-founder of ClimateEdge explains how time-consuming the process of building an IoT system from the beginning was. SPHERE and SilentHerdsman cases have developed AI algorithm before system deployment which makes the NPD process even more complicated. Once the IoT NPD process involves an entirely new hardware design or data science process, it becomes similar to the first cycle of the NPD process with more extensive review gates and defined phases.

> Sometimes you have to accept that the actual feature you want to get is super complex, made up of loads of parts; how do you get there from something that is just one part, and you in your head have a vision, you assemble this one with this. At some point, that would have to come together, but it is not a sort of straightforward… So, it is a very slow process for how you go from something basic to super powerful. [ClimateEdge_71]
>
> This took five years to go from here. So, for sure, this is a five-year process. However, what is more important is that you can capture the data at the end of the process after five years. You can feed into the next design. [SPHERE_22]
>
> After the 1st loop, the loops become smaller and shorter. Until I would probably say until the last 12 months, we have decided to do a bigger review. So, some rather than little tweaks to things, we have completely redesigned them to go back to the bigger loop…[Anonymous case_02_13]
>
> We identified monitoring health from the muscle movement of the animal. They recorded it, and the vet came in and asked the treading data we used to determine the efficacy. That is going to be accessible to all of the environment to prove the validity of the algorithm. So, you did the first one then refined it.

> This was the same process as fertility. But again, 12 months development with the farmers' involvement. [SilentHerdsman_75]

5.3.5 Collapsing the Temporal Division between Development & Usage Phases

Real-time data on customers' experiences, enables the temporal division between development and consumption of offerings to coincide simultaneously. Over the 1st cycle of the delivering stage, while farmers were using the fertility monitoring service, the new offering, was being discovered and developed simultaneously. Unlike developing hardware or software products, developing digitized artifacts increases risks and complexity of development activities due to their multifaceted architectural and abstraction layers. Hence, the multitude of stakeholders and the two different production (hardware and software) processes should be carefully curated in terms of creating value for IoT.

> Because we have an ongoing product that we support, we might get existing customers to phone up and say, you know "We are facing this issue. Can you make a change, or can you do different things?" So, that tends to be how we identify the next steps. [Anonymous case_02_77]

5.4 Value Creation Strategies

Based on the thorough cross-case analysis, five critical attributes of IoT value creation are identified as follows:

1. The reconciliation of technology push and market pull strategies;
2. Value Creation through Delivering Service and Scaling Up;
3. The critical focus on the concept of value co-creation;
4. Users' contributions to value creation
5. Data as a Resource for Value Creation

In this section, the five different aspects of IoT businesses value creation are analysed and described from the case studies.

5.4.1 The Reconciliation of Technology Push and Market Pull Strategies

IoT system development is led by both technology push and market pull strategies. The interviewee of AlertMe describes emphasises that market pull is significant in identifying '*what solutions should be developed'* and technology push is critical in identifying '*how the solutions should be delivered'*.

SilentHerdsman, ClimateEdge and LettusGrow develope their IoT system relying on market pull and technology push strategies, respectively. SilentHerdsman and ClimateEdge started to identify the market segment and business needs first which have become the driver for subtle but significant business decisions.

> We were thinking about technology push, what was technology making possible but also market pull, what were the problems in people's live that can be solved. [AlertMe_05]

> When we started in 2002-2003, we had to determine the market. We did this through a lot of consultations with the businesses involved, technology developer, and technology providers. [SilentHerdsman_29]

> Market segment identification must be the driver for all of your subtle business decisions. There is big money to bring value to all of the people involved in the business and the customers that use the system. If there's no market you are going to fall very quickly, you won't sell anything. So, that must drive any of the solution. [SilentHerdsman_36]

> As individual people and in terms of the main activity, it's been like what are your problems as a company or as a farmer then we've tried to develop the solution that feedback for solution, and then that's what's fed into all of these phases. [ClimateEdge_29]

LettusGrow, on the other side of the spectrum, developed its IoT system with their hydroponic technologies targeting the high growth potential B2C market. After they failed to launch their first IoT system, they went through a thorough identification of the market segment where their unique technology would offer impact. With a technology push strategy, they identified that they would significantly impact the saving energy and water in the B2B marketplace.

> LettUsGrow's original focus was a consumer product that would allow people to easily grow their own food in their kitchens at home with the aid of new aeroponic technology. This focus changed when through Design Foundations, LettUsGrow worked with Crux Product Design to research new markets. LettUsGrow discovered their unique technology could have a significant impact on saving energy and water by pivoting to a B2B model. From this, LettUsGrow could establish Europe's first aeroponic vertical farm in Bristol. [LettusGrow_DR_07]

5.4.2 Value Creation through Delivering Service and Scaling Up

From the case studies, the interviewees perceive that the actual value of IoT is realised through delivering services once the system is deployed. The case companies are in charge of manufacturing sensor-embedded devices while developing the system; then, the focus of business activities slowly moves to delivering highly personalised services. Service delivery activities could be classified into three categories: releasing updated software, replacing hardware components, and delivering insights based on data. Collecting diagnostic data on the device enables organisations to become service providers as which they have to change the battery or other specific equipment. The technical faults on the software side force the companies to continue delivering enhanced customer support. On the data side, companies may provide detailed insights to the customers. These service delivery activities over the fifth phase of NPD process enables them to retain a long-term relationship with the customers and generate recurring revenue.

> …What we see from IoT is that because you know more, you can make better decisions, and make money out of those decisions because of the right factors. I think it's about understanding the knowledge rather than just shipping something often. [LettusGrow_09]
>
> Once you're in the launch with Scale phase, you now have a lot of stuff out there so becomes really important whether it works. And you are constantly about scaling, scaling, scaling. [AlertMe_120]
>
> We have about 70 or 80 stations out there that will be doubling in the next few months. But we're going through this stage at the moment, the scaling stage. There's no point to finish scale and to match and to build go back in the system, going to apply there our scale. [ClimateEdge_93]

Another critical advantage of value creation in IoT development is the ability to scale up as per requirement. The value propositions could be delivered with a combination of multiple products and applications through an integrated holistic platform. Specifically, larger value is created when more devices are interconnected. The interviewees well recognise having more devices and services connected is critical in their business planning activities. AlertMe developed a single platform on which all different products with sensors, inputs, outputs and capabilities can be connected and to run on. This made the users to feel the IoT system is architected as one system that all works together. At the point of when the interview was conducted, LettusGrow and ClimateEdge aimed to establish a platform which delivers multiple products and services [ClimateEdge_DR_74]. IoT companies could build their own unique eco-system within which each device as a node in the network. It strongly does increase satisfaction of the IoT system.

> If you want to make really simple IoT thing, one device, but then again one device isn't an eco-system, and you can't get value very much from just one device. Because if it is one device then, probably Phillips already did that. [SPHERE_81]
>
> …We do not apply the algorithms yet, but we are working with some data science companies to start all network. We integrate a lot of sensors in our product for research purposes, but they are not capital affective at scale. So, we are doing some research at the moment to work out what we can, what we should include and what we can drop and etc. [LettusGrow_107]

5.4.3 The Critical Focus on the Concepts of Value Co-Creation

Co-creation has been ideally suited to complex NPD projects. Unsurprisingly, it is indicated as a core tool for IoT development across all the cases. All of the interviewees explicitly or implicitly describe that they have implemented co-creation as an approach to innovation. Companies openly shared and combined diverse knowledge and specialities between partners, customers, and subcontractors. By doing so, they believe that they can accelerate innovation and create more value for their business. There are four critical motivations identified as to why they adopt a co-creation approach to their IoT ongoing development. The first reason is to ensure the right value propositions developed and delivered to customers. Secondly, co-creation is inevitable if the application domains of IoT system is outside of the technology domain and if domain experts need to get involved in data interpretation. The third motivation is the lack of internal capabilities to develop IoT systems by a single company that arises from the complex layers of IoT architecture. The last motivation is to have more devices connected to create larger value. In other words, to develop their unique IoT system, partnering with, acquiring other companies or connecting to other IoT devices is necessary. Apart from four motivations of value co-creation approach, it is identified that users and universities as co-creation partners have a specific role in IoT value creation.

First, considering various reasons described by the interviewees, co-creation is embraced for IoT companies as a crucial breakthrough innovation. It enables them to have fresh perspectives on the IoT design and value proposition. Working with value chain actors encourages inflow and outflow of knowledge and thus ensures that the appropriate value is developed and provided to customers. At the early stage of the NPD process, cases including SilentHerdsman, the anonymous case and ClimateEdge have involved customers, suppliers, and other stakeholders within the complex ecosystem.

> In often that there are a lot of conversations with the clients and with the customers because you are coming from a separate point of viewing and understanding, and you sometimes tell that it does not make sense between figuring out things that related. [ClimateEdge_48]
>
> We worked with the farmers, supply chain, herdsmen, scientists, the market tiers. The supply chain includes all the suppliers related to the milk to the supermarket. From one farm to the supermarket, there is a supply chain. You provide the processor, and it makes sure the highest quality of milk then provides it to the end-user, the supermarket. So, there are logistics involved. There are also milk recorders who want the farms to make sure the milk is of good quality on the farm. There is an artificial inseminator who provide the semen for the farm. There is a feed guy who feeds for the animals, so all of this are part of the supply chain. [SilentHerdsman_32]
>
> …We work with the university, councils, highways, England Network Rail, and the major PLCs. And we work as a group, and we have all got the same issue we are trying to solve. And then we are trying to commercialise it, make it into a product to move the industry forward. [Anonymous case_01_20]

Secondly, value co-creation is significant to the IoT companies, particularly when the IoT domains are specialised, and data is collected outside of the technology domain. Through SPHERE, SilentHerdsman, and AlertMe cases, the emphasis on the concept of value co-creation is demonstrated and considered prevalent in IoT development. Two reasons are identified why the companies need to work with the domain experts (often customers). Firstly, co-creation is required to transform traditional practice into the algorithm of IoT solutions. For example, in SilentHerdsman case, when farmers were asked how they detect when ovulation occurs, they said ‘they just know’. This is because the traditional practice becomes the experts' daily routine, which is unnecessary to doubt their approach or logic. However, for the engineers to comprehend the farmer’s knowledge and reflect upon it to the right choice of sensors and algorithms, co-creation with domain experts is compulsory. Secondly, IoT companies need to work with specialists when interpreting data into meaningful insights once data is collected. In particular, health or crop related data in SPHERE or LettusGrow cases may be only interpreted accurately by healthcare practitioners or biologists.

> We asked farmers that how did they know that there was ovulating, and they said they just know. We had to identify what does it mean by 'just know'. And they answered that when it gets a little bit more agitated, they know there is ovulation. So, we interpreted that the activity is a good measurement so as energy spent. You only know that if you talked to the farmers. I do not know what it means by when cows get frisky before speaking to the farmers. Then we realised that it means they are ready to be inseminated, which is absolutely crucial in their business. [SilentHerdsman_46]

> IoT engineering company or organisation are not experts in health, so you are probably never going to look at your data and say, wow this really shows us the effect of pollen, asthma because you are not a medical specialist. So, you have to go and talk to somebody else externally. Say another area of IoT, they might not be such a problem, but generally, we need healthcare practitioners to steer health research. [SPHERE_90]

> Within the support stage, we collect all the data, we aggregate in the cloud, and then internally we analyse the data and then we often provide it back to the customer as insights and growing support, so this is where our internal farmers and biologists add the value. and that’s how we provide data back to the customer. [LettusGrow_103]

Thirdly, companies proactively collaborate with a diverse variety of supply chain actors. Mainly because the companies are not capable of creating the different layers of IoT architecture internally. Consequently, co-creating value with external partners is considered critical. With different competences, each partner or subcontractor contributes toward IoT system development differently through the whole NPD process. LettusGrow worked with an electronics consultant who was the expert in electronic engineering and involved in the phase of design and testing of the system. Also, they had to work with a local track company and the engineering company who helped build the system at the phase of system deployment. AlertMe and SilentHerdsman had distribution partners who were the experts in marketing and sales [SilentHerdsman_65; AlertMe_106].

> We have an R&D farm in house. We work with consultants and experienced growers, and we do pilots with them… We have a partnership with local track companies who build our chambers at the white wood boxes and put in the air conditioning systems to maintain the internal environment. And the engineering company at this stage, if we are not just selling a product, if we are also providing full installation, they will come in at this point and set up their stuff in parallel. And then we have the only

> real partner at the moment, in terms of deployment of the product and development product. I mean, we work with an electronics consultant that comes in a lot of these gate reviews to provide additional input and just expertise. Make sure we're on the right track…[LettusGrow_17]

AlertMe demonstrated the proactive co-creation activities when they wanted to have new features that is specialised areas such as gas and smoke detector and heating service (Figure 55) [AlertMe_102; AlertMe_121; AlertMe_123]. With the help of Invensys, AlertMe developed energy devices including heating. In 2010 British Gas, one of AlertMe's partners encouraged them to add smoke and gas detectors to their safety and security features. However, the smoke and gas detectors are highly specialised area, which will take AlertMe years to develop and add the feature to their existing IoT products and services. Thus, AlertMe decided to form a partnership with Sprue Aegis, an alarm manufacturer. Amongst a number of start-ups, the IoT system of Wattbox, the web and app heating control, was integrated into AlertMe's IoT system with the aim of improving their existing services.

Figure 55 Smart Energy devices helped by Invensys (Left), Gas and Smoke detector developed with Sprue Aegis (Centre), Web/App heating control of Wattbox (Right)

In order to get more devices and services integrated into their unique IoT system, AlertMe and the anonymous case opened their API or data with the intention of distributed value creation. AlertMe offered API and proactively involved 3rd parties' developers to connect IoT system to their devices through which they could enlarge their value constellation and decentralise the innovation activities of the IoT system. The anonymous case encouraged small business to make services in relation to their gully management system.

> Finally, the AlertMe API (that's used for the iPhone interface above) is now being offered to 3rd parties. AM are looking for developers to get in touch with the company if they wish to interface to their device. [AlertMe_DR_01]

> It's a transport infrastructure hub and now that hub is been developed and moved on and it is part of, now it is the part of PETRAS Hub, running from the University and the idea of that was to get as much data in at the time as we could. And see if we could then encourage small businesses to make apps out of it. [Anonymous case_01_84]

Universities as one of the actors from the outside traditional supply chains who played a critical role in IoT development. Including SPHERE and SilentHerdsman development cases which are led by university or university spin-off company [4.2.1 SPHERE Project Overview; 4.5.1 SilentHerdsman Project Overview]. In addition, universities contribute to the stage of algorithm development and data processing in the anonymous case, LettusGrow and ClimateEdge cases. As most of the IoT companies are SMEs or start-ups, they lack the necessary ability and resources of developing algorithms and processing data. In the context of SMEs or start-ups leading emerging technology development, they commonly lack the skills in various areas but specifically in data science processes. Universities contributions toward IoT development is significant to enable the companies to widen the potential of value creation. For example, through the partnership with Cranfield University, ClimateEdge is able to add data-led soil management service to their existing system, and LettusGrow is about to improve their current services by analysing data with the support of data scientists from the University of Bath [ClimateEdge_37; LettusGrow_DR_09].

> We have different stakeholders, so what we do with the data is that we employ, again working with the University, supporting us. Because we were only an SME. We employ a data analyst, so it is part of the computing department at Lancaster University. But he worked for us. Then we were using machine learning to manipulate that data so that we can forecast and make value out of it. [Anonymous case_01_76]

5.4.4 User-Driven Development

It is emphasised that the IoT NPD process has to be a user-driven development through cross-case analysis. Users have been involved in various NPD activities as partners, from identifying users' needs, testing hardware prototypes, and helping to collect data to refine algorithms and value propositions. For example, AlertMe engaged with their customers to understand if their hypothesis on values and system solutions would work. In SilentHerdsman and ClimateEdge cases, the teams had to listen to the users to identify the correct problems and develop appropriate solutions. Also, building a good relationship with users from the beginning of the project was critical in IoT development. Firstly, the team could secure the deployment the IoT system for data collection and algorithm refinement in the real environment. Second, novel business opportunities may be generated for existing or new customers, which could lead to the development of new products or services.

> I think it was very customer centric iterative process. We invested a lot of time and money in engaging with our customers to understand how our proposition and technology is working in their house, again, again, and again. [AlertMe_24]

> Our weather station is designed and iterated based on extensive user testing, leading to a number of innovation. [ClimateEdge_DR_47]

> We were lucky with friends and networks from veterinary Universities, Edinburgh University and Glasgow University. They have animals, they have research farms which we utilized for the process. [SilentHerdsman_60]

> So, we worked very closely with our customers. Innovation is driven by need and identifying problems and how can we use technical solutions to be able to do that. So, we hold innovation workshops, we speak to our customers on the regular basis, we are trying to understand where our government is going, and then we look at with University what's happening technically in 5 and 10 years down the line and then we try and work out as a group we formulate solutions to move that solution forward. [Anonymous case_01_52]

Users are at the core of value creation as they contribute to data collection. Apart from using IoT system and being benefited from the system, they generate data on product usages, and the environment where data is generated. This user-generated data is stored, analysed and reported to play a critical role in the decision making of business planning activities. In AlertMe case, customers enthusiastically participated in value creation through discussing issues, suggesting ideas, and sharing software codes. The AlertMe user forum is where users come to seek support and discuss system issues (Figure 56). The User Forum is used as a place to get interactive feedback from other AlertMe users and developers through which the system is improved. In November 2011, a user shared the tips to make better use of AlertMe’s Smart plug which are downloadable as open source. These active users co-created value by refining and sharing the open source thus the system being improved.

> I think the value of IoT platform is more around the data and the knowledge you can get how the physical products are working. And wider than just how it’s working, how it could fit in with everything else that goes on and whatever chain system it works. [LettusGrow_23]

> So, you can capture customer’s needs once you store their data. So, you can start to get some insights from the data to see new things. [SPHERE_89]

> …It can measure how your customers are using it, understand stuff about their lives, and understand how happy they are, even in various ways. And I think where you are starting to scratch the surface. if you’re a conventional product manufacturer, IoT lets you actually measure your customer satisfaction live. [AlertMe_36]

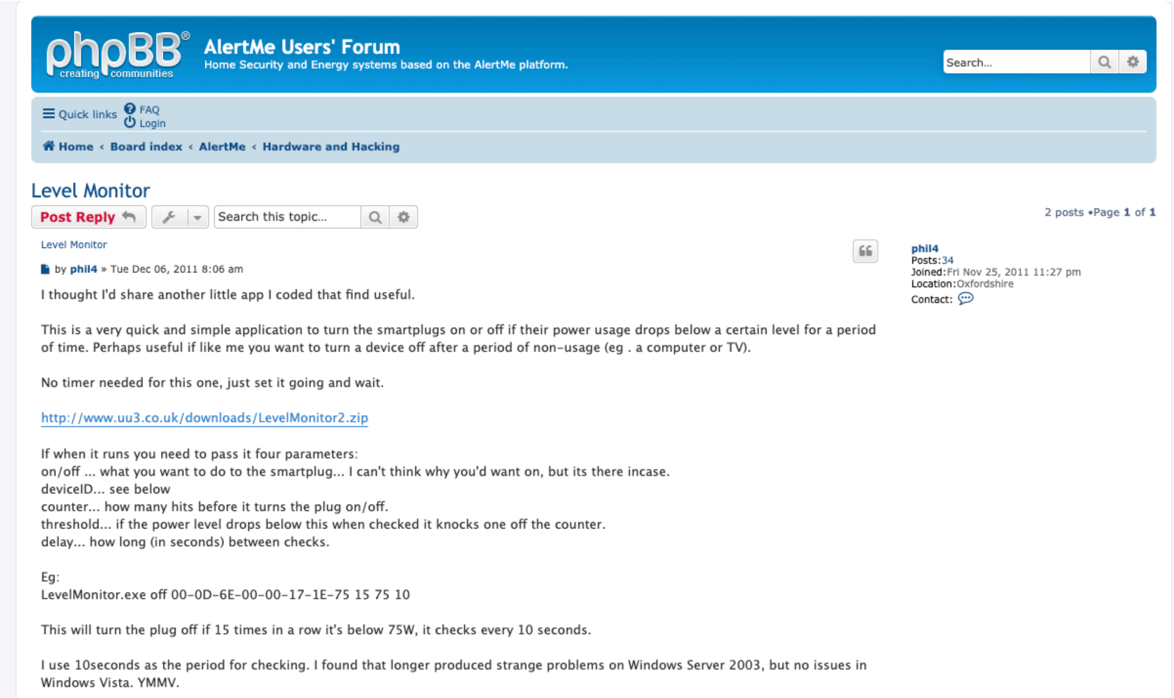


Figure 56 The Screenshots of AlertMe's User Forum

Moreover, users' proactive and iterative involvement in value creation was required as the solution domains were often specialised (Figure 57). This was observed in the cases where users were often considered as domain experts, such as the gully emptiers in the anonymous case, and the farmers in SilentHerdsman, LettUsGrow and ClimateEdge [SilentHerdsman_40; LettusGrow_35]. In SPHERE, although medical specialists were customers not the end users, their opinions were as significant as patients since they were involved in patient care with the access to personal data. These specialised areas are something completely different to the interviewees' expertise which is mainly from an engineering background.

> So, I supposed generally health is a very specialist domain. And so, we are very unlikely to be set looking at our own data and coming up with kind of our own hypothesis. So, generally it would mean going back to the customers to talk to them or something or maybe we have a conversation with one customer and then you realise actually it would be useful for other customers as well, so maybe you can go back round this way, but definitely this would usually involve a medical specialist. Not just looking at the data and see what pattern we see. [SPHERE_91]

Figure 57 SilentHerdsman's co-creation workshop with the farmers to build mobile app and web

5.4.5 Data as a Resource for Value Creation

Data would bring enormous potential of value but requires time, effort, and the right strategy on data management. Through the cross-case analysis, it was identified that the organisations recognise data as a resource for value creation [Anonymous case_01_12; SilentHerdsman_71; AlertMe_92; Anonymous case_02_79]. The interviewees from the anonymous case and SilentHerdsman put a significant emphasis on data when describing IoT. The SilentHerdsman interviewee describes a success factor of creating value through data is that data should be a part of the right context and environment with aligned business purpose. There are six ways of using data as a resource for value creation; Feeding insights back to the customers; Identifying novel value propositions; Fine-Tuning its algorithms and service; Integrating different dataset; Selling data to supply chain actors as a big data broker; and Improving efficiency of business process. Some of the attributes of data-driven value creation are interconnected to other attributes of value creation. For example, 'feeding insights back to the customers which impacts 'Value Creation through Delivering Service than Manufacturing'.

Feeding Insights Back to The Customers

Once an IoT device is deployed, product usage data about when and how these are used is tracked. Big data is ready to be analysed, enabling organisations to send customers the right message at the right time to help them to make the right decisions. The messages may include information on the environment, user behaviours or product usage. LettusGrow provides customers insights on farming as growing support [LettusGrow_103]. The interviewee describes that they value understanding and sharing knowledge rather than selling their vertical farming system. AlertMe observed the Net Promoter Score of British Gas uplifted to 50% by sending insights on energy usages to individual customers [AlertMe_32]. These continuous feedback loops and communications make companies retain existing customers and long-term customer relationship by helping customers decision making.

> So, for example, you know what temperatures people keep their houses at in the UK. You could do quite nice piece of PR (Public relations) on that. You can use that data and then feedback to individual customers and say ‘Did you know your house is 2 degrees warmer than the average for your neighbourhood’. And by turning it down 2 degrees you can save yourself 130£ a year. That requires you to be able to use the aggregate data. [AlertMe_114]

> So, if you go into the financial markets people are getting instant information about what is happening on stock market. And really that's what you want in the transporter in the area we were looking at is timely information, reliable information, and the information in format. [Anonymous case_01_59]

Identifying Novel Value Propositions

Although the flood of big data is available for companies, only two out of six cases explicitly describe how they used digital data combined with customers’ feedback to redefine subsequent value propositions [SilentHerdsman_70; LettusGrow_105]. However, it is slightly unclear if digital data critically contributed to redefining new business opportunities or only confirmed the following values identified by customers’ feedback. Although the project leader of SPHERE highlighted that data is used for the next design, it does not count as the case because the project did not go through the next cycle of the NPD process and value creation [SPHERE_22]. Other cases used conventional methods only. The anonymous case and ClimateEdge collected direct feedback from customers, talked to potential customers at conventions, or discussed with partners. AlertMe used a customer survey to identify the following value propositions.

> …Sometimes we've gone to an exhibition, and we've shown what we currently have, and someone says ‘That’s great, could it also do this because we’re really interested in temperature?’ or ‘Can you also do air quality? because we’ve got issues with that as well’. So, a lot of it comes from conventions and exhibitions. Sometimes our existing customers phone us up and say, ‘you know that how you can monitor this, can you also monitor that’. Also, we're always looking ahead with Lancaster University ‘What's the next thing we could do’. Some of it comes from the projects and some of it just comes through discussions with Nigel ‘oh I haven’t thought that but that would be really useful’. Also, some of it, if the funding has come out and we think can we fit anything to that funding. That happens equally. [Anonymous case_02_81]

Fine-Tuning Its Algorithms and Service

The companies started with a small number of IoT deployments, and then they slowly scaled up the number of deployments. The interviewees described how scaling up was critical in their IoT businesses, particularly because the volume of data increased, enabling the system to be more competitive in the marketplace. The more people use the IoT system; the more data is provided. The anonymous case improved their algorithm models with more accuracy as a sequel to the training from larger volumes of data while slowly scaling up from the feasibility study and small-scale pilot projects to deployment in real-life [Anonymous case_01_77]. SilentHerdsman improved prediction models, which enabled customers to make better decisions. Scaling up with big data-enabled businesses to deliver better value through refining the data feedback loops. This process requires a significant commitment from the companies and involves the dynamics of conversations between the experts, customers, and developers. The more data is collected through the feedback loops, the more accurate the intelligent system becomes, enabling companies to constantly refine and improve their core performance, predictions, and personalised service. The IoT system becomes more competitive and established by scaling up over time.

> …We did a phase of the small feasibility study in which we did a small sample about 250 samples and the sample showed that we could identify what the silt level was and potentially ensure that we might be able to show with hotspots. … We got the feasibility then turned into an extended trial and took about 3000 samples in Bristol. [Anonymous case_01_82]

> You take 200 animals, you talk to the herdsmen, you put the collar on, then you monitor with videos of all these animals, and then marked up when you see our collar saying it's on heat… That's how we get the accuracy. The accuracy is about 95%. In 100 cases, 95% of them is to identify correctly. We reached the 90% of accuracy. The heat and rumination are the same thing. When the animals go on heat, rumination times drop. So, the combination made 99% of accuracy. [SilentHerdsman_59]

Integrating Different Data-Sets

Companies are keen to aggregate other forms of data into their datasets to identify novel business needs or improve current services, providing more insights to their customers. It is challenging but the anonymous case company continuously attempted to integrate their data with others, seeking the impact of data integrations and how it could help customers deal with the problem beforehand. By aggregating diverse datasets, analysts can look for trends and identify new business opportunities without transforming the overall infrastructure. A couple of critical challenges of aggregating different data sets, particularly feely available data, are identified through the anonymous case. The challenges of data commercialisation will be thoroughly and closely discussed in the next section, 'Barriers, Challenges and Tensions'. The two cases in agriculture, ClimateEdge and SilentHerdsman, also indicate that insights from integrating different data sets enable them to make effective business decisions [ClimageEdge_DR_72; SilnetHerdsman_25].

> We've identified many business needs as we are part of our product offering. We can collect the data and we can show live data and what's happening if there's a flood. But we also have another element when we use that data to predict what's going to happen in the future. So, we consider numerous different environmental databases to give advanced ones to people, and the contractors could go out. So rather than waiting until it is flooded, they can clean a gully before flooding. We also identified that we needed other types of data as well. Some data is readily available as open-source, and we can get through the councils. And other data that we think will have an impact we have no way of capturing it. So, whilst we have the gully data, we also need to start looking more widely at other datasets. So that led us down to a road of what other sensors could we monitor with the same infrastructure. So, now we

> are looking at a lot of different things. We are looking at water flow; we are looking at air quality, wind and temperature—lots of different things to see what we can do with that in terms of the predictive model. [Anonymous case_02_25]

Two ways that the organisations believe they could create value from data that has yet to be proven are: selling data to supply chain actors as a big data broker; and improving the efficiency of the business process. The organisations understand that the data and insights that their IoT devices generate are often valuable when combined with other datasets. One of the most direct ways to acknowledge this opportunity is to trade the data with others. SilentHerdsman and ClimateEdge, who collect animal and crop data, respectively, describe their goal as a big data broker [SilentHerdsman_DR_12; ClimateEdge_DR_03]. The anonymous case also considers all the new kinds of opportunities that they could create from data [Anonymous case_01_55].

Data was understood as a critical business asset by the interviewees. However, at the point of the interviews, none of the companies succeeded in making a direct income by selling data to supply-chain actors or redrawing business boundaries and unique value constellations. The co-founder of LettusGrow described data as the majority value of the IoT, which is distinctive from the traditional farming business and thus provides innovation [LettusGrow_22]. Farmers may leverage insights provided through the LettusGrow IoT system to improve the ways farms are managed. It would improve the efficiency of the farming process because real-time data would allow farmers to adjust their practices based on demand and help them manage the supply of crops. Moreover, the value is based on the knowledge and insights they share through their IoT system, which would have been limitedly available to experienced smallholder farmers on traditional farms.

5.5 Barriers, Challenges, and Tensions

Over the NPD process, a diverse variety of barriers, challenges and tensions were identified, which could be categorised into twelve distinct areas:

1. Difficulties to Identify User Requirements and Obtain User Feedbacks on IoT
2. Hard to Develop Technical Architecture
3. System Integration Conflicts
4. Continuous Design Activities
5. Costly and Lengthy AI Development
6. Challenges on Supply Chain Management, Commercialisation, and Installation
7. Costly Scaling Up

8. Value Co-creation Barriers
9. Lack of Internal Expertise
10. Business Transformation | Overlooking the Cost of IoT Maintenance
11. Issues of Trust, Security, Privacy, Adoption and Acceptability
12. Data Commercialisation Issues

As referred by LettusGrow and AlertMe interviews [LettusGrow_47; AlertMe_53], IoT development issues may be found primarily around technology and proposition, which are complex because IoT system is a complete novel product, and the industry is still relatively immature. However, the interviewees of the anonymous case, AlertMe and ClimateEdge agreed that to develop value proposition and business model is more challenging than the technical development. Each problem areas could be further divided by different factors. Some of the challenges were general issues that start-ups or high-tech companies encountered, such as a lack of internal capabilities. Some issues are more general issues related to the current complex business nature, such as the global value chain. However, distinctive issues related to IoT are also discovered.

> The technical risk, you can build anything, if you have enough time and money. But the market risk is really unknown. Because the market risk depends on all the sentiment of the people. The only way to find out is to actually try selling something. [AlertMe_55]
>
> The technology to provide data-driven farming is not the problem, which is a great position to be in. The challenge is in creating business models that allow these technologies to be up taken in the market. [ClimateEdge_DR_38]
>
> The technical problems are probably easiest part of the internet of things because it's just databases and there's lots of people giving solutions where the problem lies… [Anonymous case_01_33]

5.5.1 Difficulties to Identify User Requirements and Obtain Feedbacks on IoT

Identifying customers' requirements is challenging in IoT development. Users generally struggle to articulate and define their needs, which are often impossible, contradictory or poorly defined. One of the factors is that they were unfamiliar with IoT systems and did not know the opportunities and benefits it could give them [SPHERE_68]. Another factor regarding the Ill-defined customers' requirement is attributed to a small number of user samples, poor user feedback, or poor data quality [LettusGrow_29; AlertMe_25]. It happened to be a small number of user samples due to time constraints because the conventional way of identifying users' needs is most likely to be qualitative methods. Consequently, the companies were not able to speak to a sufficient number of customer samples which resulted in biased decision-making and thus not reflecting the entire target market. In the SPHERE case, having random answers from a small group of users would have affected acceptability issues critically related to the system commercialisation.

> They've hired us and said what their problem is. Typically, they struggle to say why they want it. So, it's like that process you quickly parametrise it anyway, parametrise it very different way. [ClimateEdge_45]
>
> Acceptability side, one of the problems we saw is basically this is quite qualitative. So you have quite small sample sizes. So, the issue here is I can almost get any random answer and that is the problem if you have a small sample size. So, what we did for this is we actually have people living in a house for two weeks. So if you think about that even if we could do this every single week of the year, we can maybe get 25 people to give their opinions. For some of this subject, 25 people is not going to give you consensus, so the data is going to be very sparse. And that makes it very difficult to make decisions based on that. [SPHERE_66]

One of the most significant difficulties was to obtain enough insight into how the users interact with the system before the system is developed. The project leader of SPHERE explained that having user feedback was impossible unless the system was fully developed [SPHERE_68]. In the feasibility testing stages, their value constellation was incomplete and consequently, the user feedback ought to be limited. Alternatively, the co-founder of ClimateEdge described that it was difficult to obtain sufficient insights into how the users interact with the system and feedback on UI and UX of the product and service. Because the users were not able to use the system. This is related to the fact that IoT is an entirely new technology with the convergence of digital and the physical worlds and there is nothing existing to model them on. ClimateEdge was critically challenged by this issue of how the system would work in terms of notifying the farmers [ClimateEdge_78]. In the scenario, an SMS had to be distributed to 2000 farmers and make it feel real. However, at the phase of developing Mock-up and MVP, they were not ready to have the interaction work real, nor it did not work to explain to the farmers the scenarios and make people understand what a solution looks like and how it works.

> I'd say probably the most difficult thing at that level is it's very hard to get feedback on **something that doesn't exist from users**. It's so much easier to have something from them and then let them use it and then you see what they make mistakes in, like what they do that isn't what you intend. So, the biggest difficulty again is how we get feedback **before we have things we haven't developed yet**. Because otherwise someone use your service and they are like 'Ah, it's really difficult because every time I did this and that' Do you know what I mean. So, unless you can use the system, you can't have the feedback that we need. So, that like UX side can be quite tricky to get feedback in early stage. [ClimateEdge_77]

5.5.2 Hard to Develop Technical Architecture

In IoT design, building the architecture right in the early R&D stage is critical for value creation because the IoT architecture is hard to change once it is developed and released to the market. The

AlertMe interviewee stated the significance of building the right architecture because IoT is not one off selling but something that has to be maintained and improved for the longer-term [AlertMe_26]. The project manager of the anonymous case supported this by describing designing IoT system is the most significant activity in their NPD process. Three different factors challenging companies to develop IoT architecture right are identified: Complexity of IoT architecture; Novelty of IoT system; and time and cost constraints.

> I think getting that design right first time is the most significant activity in NPD process, because I think we've been through a really long process of where we haven't had that right. And it hits us hard. And so, I think making sure that you get it right at the start and have the right people asking the right questions and right challenges, I would say, that delivers in the long run the best the most value. [Anonymous case_02_14]

Firstly, LettusGrow and ClimateEdge described IoT as a complete novel product which challenges to build the right IoT architecture. They encountered the challenges specifically in the concept design and prototyping stages respectively. As IoT is a high growth industry, there is no existing sample that they could have referred to. Having the right architecture encompass a number of technical questions, including reasonable cost of materials and production, efficient operating models, and a fast launch of the system.

> Prototyping the devices involved a lot of trial and error because there isn't really anything existing to model them on. Weather stations are usually expensive and typically focus on collecting data for weather forecasts. [ClimateEdge_DR_55]

> There're tones of risk in terms of technical capability at the point of concept design. Because a lot of what we're doing is very novel. 'Are we designing the correct thing in terms of product' 'can we make it as cheaply as we need to make it' and 'can we make it operate as efficient as we need to'. We try to mitigate the risks before we put all of them in, we know that it should be feasible. It's just about making it cheap and quickly enough. So, there is the main risks across this stage. [LettusGrow_57]

The complexity of IoT system is another primary factor stated by the co-founder of AlertMe. IoT architecture consists of numerous moving individual parts which does not allow IoT development straight forward. If one part goes wrong, it will have a negative impact on the overall user experience. The complexity of IoT system is also closely related to the challenges of system integration and continuous design activities.

> …But I mean definitely a massive part of our risk was around technology. There are lots of moving parts in an IoT solution, and that's where a lot of risk comes from. There's no one piece of rocket science you have to get right, there's hundreds of things you have to do really well. And if you get any one of them wrong, the user experience will be bad. So, that's the biggest challenge actually sort of complexity. [AlertMe_72]

Finally, the pressure of time and cost constraints, one of the main issues generally found in start-ups, challenged the companies. While ensuring to build right IoT architecture, a delicate balance between concerns is also required; spending enough time on trialling and minimising the technical faults and releasing the system as quickly as possible; minimising the cost of prototyping and having enough prototypes to validate its market fit [Anonymous case_01_62; LettusGrow_28]. The co-founder of LettusGrow described that the lengthy and costly IoT development became more critical at the point where the companies must show their prototype to potential investors. There are many uncertainties and questions about the prototype's performance, which could directly affect further development activities and securing funding.

> Our biggest challenges are probably the same as most other start-ups; making sure that what **we commit to building is correct**, that we grow efficiently but also **as quickly as possible** and making sure **we don't run out of money.** This is **a delicate balance to achieve**, and it is often difficult to make sure you are **spending enough time on validating product market fit versus fundraising**. Both are incredibly important, but when you only have a certain amount of hours in the day and a small team, you have to make decisions on what is most important at that moment in time. [ClimateEdge_DR_27]

> **Tones and tones of risks around that communication with investors**. We had to prove the technology without anywhere near enough time or space for money to do it. We had to show investors **a prototype that was not representative final product to show enough the principles**. And then we had to get it to the point of selling it to get them to close the round. So, we had to sell the product that we have no idea if it was ready in order to get investors to invest. [LettusGrow_70]

5.5.3 System Integration Conflicts

The interviewees stated that the system integration is where the biggest technical risks come in [LettusGrow_67; SilentHerdsman_48]. When merging hardware, software and data algorithms, unexpected technical issues occurred which the companies did not know how long it could take to resolve. Theoretically, companies expect the system to work well together with the software elements of control, but when most of the parts coming together and having to work together, unexpected interaction or emergent behaviour occurred. The interviewee of ClimateEdge highlighted that this integration issue was affected by the complexity of IoT system, comprised lots of different parts. To reduce the integration issues, the project leader of SPHERE suggested making things real as early as possible [SPHERE_61]. That could prevent waste of financial resources and reduce the risks of IoT system not working after a lengthy period of development.

> That's always a risk **when you trying to integrate it.** You don't know until you start what issues you are going to deal with. So, integration can literally be a day, or it could be a year. So, it's **the biggest risk factor** we have. [Anonymous case_01_63]

> Sometimes you have to accept that the actual feature you want to get to is **super complex, made up loads of parts,** how do you get there from something that is just one part, and you in your head have a vision, you assemble this one with this one with this. At some point **that would have to come together but it's not a sort of straight forward…** [ClinateEdge_75]

The system integration issues identified from the anonymous case is slightly different to other cases. The anonymous case runs software solutions, as a separate system that was hard to be integrated to the newly developed IoT platform. The main reason for this was that the company technically relied on Lancaster University for the platform and software development. Although the University and the company supported certain elements of the solution, they failed to manage to integrate existing system into the new IoT system. It resulted in poor user experience as their existing customers are forced to use two different systems.

> We continue to have internal integration issues and I think it comes back to the structure of the projects. So, because we have different partners involved and on the projects Lancaster, for example, does a lot of the technical development for the software. And then that becomes a slight barrier to integrate in between the two. So, Lancaster supports certain elements of the system and we support certain elements of the system. But we don't manage to tie those up entirely right and those could become ongoing issues. We can function with it like that but it's not ideal, especially when the funding runs out. [Anonymous case_02_63]

> We have to always **integrate in with legacy systems with our clients** so whatever we are using becomes a tool. And they don't want many separate tools, they want our tool to be part of the integrated solution. So, when we tried to integrate with third party's solutions, we have challenges. [Anonymous case_01_61]

5.5.4 Continuous Design Activities

Continuous design activities are one of the critical attributes of the IoT NPD process. However, it caused the companies continual pressure and the increase of costs and uncertainty of development activities. As well as perpetual beta, the security vulnerability issues also made IoT design activities continuous. As indicated in the SPHERE project leader's interview, the detection of a security vulnerability in a chip may require the change to the software, which may also require the hardware's change. Also, one of the current market trends, fast pace of technological advancement contributes to constant change of IoT system design. The interviewees of AlertMe and SPHERE described that companies seek to improve the performance of their system by replacing the latest generation, but also, they may be forced to replace the components as it is no longer produced [SPHERE_73].

> So, the other problems we had is that it is very **hard to freeze the design** because you want to say OK now we finish our design, nothing is going to be changed. But then someone says 'Actually it is discovered this security vulnerability in this chip and now we have to change the software.' So even if

> you have frozen your design, you have so many dependencies on other people. We can't deploy in the system. [SPHERE_29]
>
> I think the big risk is really complexity. I think it's just as almost moving parts, **a lot of the technologies are constantly changing**, and so just actually delivering a finished product that works out of all those moving parts is really challenging. So, there's a sort of organisational problem around that. [AlertMe_51]

5.5.5 Costly and Lengthy AI Development

It was commonly identified between the cases that the cost and time associated with machine learning application development was a tremendous challenge. The interviewees of SilentHerdsman and SPHERE argued that data labelling took three years and five years respectively. The anonymous case also confirmed that data collection, and data validation for machine learning development process was enormously labour intensive and time-consuming. For example, the company had to go through manual data collection and validation process to validate if the data collected from the sensor is accurate. To develop a single AI, SilentHerdsman had three or four operatives to annotate data in five of each farm for three years [SilentHerdsman_53]. In order to ensure the accurate predictions of IoT systems, the NPD process becomes energy-intensive, involving considerable human effort for data labelling, a significant factor in all AI systems. Enhancing the accuracy of AI systems is an undeniable challenge to the businesses but also critical issues relevant to trustworthiness and adoption of IoT system.

> But it is difficult and especially when we put kit out there for trial because **validating that data becomes really difficult,** so we have sensors in different places over the country. And the only way if the sensor is telling us that gully is full, is **sending somebody across the country to actually go and check it** which is quite difficult. But it's something that we are going to have to do. At the moment we have a local testbed, and we try to do regular physical validation of that. But we don't currently do that out in the field. [Anonymous case_02_68]

SPHERE pointed out that this energy intensive process seems even more significant issues for IoT start-ups who want to embed machine learning technology into the IoT system. As data collection and validation is the most laborious part, the start-ups could rely on someone else's labelled data, which might reduce the risk of time and cost management. In this case, however, the IoT start-ups may lose their competency in the market, as it is less likely to be an innovative IoT system. Another risk related to this is the uncertainty of the system performance until the IoT system is finished integration. At an early stage of the NPD process, a company would not know how long it would take to develop an AI and the performance of it because they do not have data to build an AI model. In the SPHERE case, they eventually were able to obtain some data to classify and refine the algorithm after 5 years of development [Anonymous case_01_48].

> If you have **IoT start-ups**, they should **not be reliant on machine learning** which acquires lots of labelled data that you don't have. So that can be **a big problem of developing new businesses in this space**. You could only do business that **somebody else's done before**, so I can make an image only because Google already gave me framework for testing, training and evaluation. But if I want to do something that Google hasn't done, now I am in big trouble, but I can't do what Google has already done, because **Google is better than me**. Because they have over data, so I want to do something new which means now **I have to spend 5 years to collect data.** So that is maybe a little bit unusual about IoT as a proposition. Start-ups, how you are **going to explain to your investors**, if they might not work. [SPHERE_39]

5.5.6 Challenges on Supply Chain Management, Commercialisation and Installation

While manufacturing and managing the supply chain of IoT systems, several challenges were identified across IoT development cases. The challenges that require good management skills include cash flow, lower quality product than expected, increase of the manufacturing and material prices, delays, finding labours and suppliers [ClimateEdge_82; AlertMe_86; LettusGrow_89; Anonymous case_01_70]. The co-founder of AlertMe stated the immature IoT industry as one of the factors increasing the threats to quality control. Therefore, it often results in a low volume of IoT components manufactured.

AlertMe was challenged in managing supply chain and quality control because this component shortage issue and fast pace of technology advancement required them to redesign the whole IoT hardware and software system. It is interrelated to the NPD process attribute, continuous design activities. Another factor highlighted in the SPHERE case is outsourcing production to China, which increases a quality control problem as the factories are physically far away. Also, having a more complex value constellation results in a more considerable vulnerability in quality control over the supply chain and manufacturing management. If one component is no longer available, the whole system could have to be started again with subsequent design changes.

> You can have component shortages and that's often a problem. Obviously, if you look at components supply chain in IoT, most IoT components are still relatively low volume compared, for example, to the smartphones. So, you actually end up wanting to try to buy the same sorts of components that are used in smartphones, because they'll be cheap, and they'll go with me for a while. Because it was so often ended up specifying higher performance components… [AlertMe_85]
>
> Here in the UK, it has very little electronic industry, almost anything is going to be manufactured overseas, so **a lot of our devices are manufactured out of China** that is fine. But of course, if you have **a quality control problem,** like they are really far away. If the manufacturer is disappeared, doesn't answer the phone. If chip model is changed, or battery is going to be out of the production, or there are stock problem. **Then again, the bigger your eco-system is, the more vulnerable you are.** [SPHERE_79]

SilentHerdsman and AlertMe stated that commercialising IoT system was critical to companies in terms of cash flow problems [AlertMe_110; SilentHerdsman_66]. Despite the companies', best efforts, if they failed to afford to pay off the cost for manufacturing, it will be a significant threat to the business. An inadequate cash flow system may occur other problems. To commercialise the system, the companies must identify the right price point for the system. However, there are not many similar solutions available in the marketplace. In this regard, competitor analysis was limited, and companies were challenged to define the appropriate price positioning of their products. AlertMe resolved this through commercial trials which enables them to test their price positioning point [AlertMe_80].

> **There were no such things like IoT** systems that time, so we **had to determine the cost of components etc**. But that is fore sighting in which you have to identify the market need. [SilentHerdsman_14]
>
> The main risks are around '**how we can do cost effectively in commercialisation size**, so will people buy it, between we hopefully have addressed with the feedback, but we haven't got anything really to show them. 'Does it make commercial sense in terms of CAPEX (CAPital EXpenditure) and OPEX (OPErating EXpenditure) costs for the customer.' [LettusGrow_56]
>
> So, it's hard for us to provide any advice unless we have found out the data. Our problem is that **there's no product solution that allows us to think about defining affordable price**. The client doesn't really matter. [ClimateEdge_73]

There are different challenges that the company may face depending on the installation strategy. Two different approaches, hiring specialists for installation or developing a self-installable IoT system, are clearly explained by the interviewees of SPHERE and AlertMe. If specialists install the system, the company ought to consider the cost of training the specialists, HR demand management and business models [SPHERE_84]. On the other hand, if it is a self-installable IoT system like the AlertMe IoT device, the company must ensure that installation and instruction are as straightforward as possible. Although AlertMe invested much effort in it, they identified that very few users follow the instructions, and they do things in entirely unexpected ways. Consequently, it resulted in AlertMe's NPD process and the IoT system is highly customer centric.

> The product was self-installed which is a good thing in theory. But that was such a journey. I mean, we kept thinking and invested a lot of effort in making the product easy to install. The box would arrive, you'd open it, and it would have instructions right on the outside of the box, say step one, do this. Then step two, as you open the boxes, instructions were written on the boxes. We invested a lot of effort in that, and we discovered that **nobody follows the instructions**. They do things it completely **random ways**. If you told them sign it before you put the batteries in, they put the batteries in first. They would just do anything they could possibly do. So, eventually we realised, well, we can't. We just had to make it work no matter what and become really customer centric. [AlertMe_91]

5.5.7 Costly Scaling Up

Scaling up by either of increasing numbers of deployment, diversifying the application areas of IoT system, or integrating the IoT system to others is considered expensive. The interviewee of the anonymous case stated that when the IoT architecture was not correctly built, the company had to develop the system from the beginning, making it manufacturable and considering it globally scalable. The co-founder of LettUsGrow agreed that there were risks in scaling up due to the lack of understanding of how system requirements changes depending on the farm size. Scaling up through integrating their systems to others could be another critical challenge. For example, while the anonymous case was scaling up, customers required the team to update software and make the integration of their system and the anonymous case's system seamless.

> Scaling up is always risky and that's where rapid prototyping and developing something properly. That's where you get contention. You have to quite often start again and build from scratch. So, the risk is resource and money. It's very expensive to be developing new solutions in high tech. And the way the funding works is very 'stop and start'. [Anonymous case_01_86]
>
> There's a lack of understanding of how these requirements scale, and how we solve problems at scale. So, 50 meter squared, growing area farm is very different to a 5,000 square meter growing area farm. So, there are risks around understanding the needs of those people in different sizes. That's why we go and speak to people with bigger farms to try them out. [LettUsGrow_110]
>
> So, a lot of the contractors already have existing asset systems that they want us to make their system to communicate with ours. So, **they want us to update their main system** that has been an ongoing technical risk for the company. [Anonymous case_02_60]

5.5.8 Value Co-Creation Barriers

Value co-creation is a critical attribute in IoT development. However, diverse challenges over the NPD process were identified from the anonymous case, SPHERE, ClimateEdge and AlertMe: reaching an agreement between organisations with different interest; operational challenges of each partner working remotely; inherent risks of competition and intellectual property; completing partnership due to strategy difference; and the difficulties of applying the agile approach when working with subcontractors. The product manager of the anonymous case pointed out that co-creation with stakeholders was challenging at the requirements identification phase as each firm had a different opinions and interests. For example, the duration of the product lifetime guarantee was an extensive discussion. The anonymous case wanted the period of their product warrantee a minimum of a 10-year life, but it ended up a 5-year life as the design partners did not wish to commit to that.

> Yeah, there was a lot of people there and it was a really **painful process** to go through. Because everyone had a different opinion so we were trying to be quite specific about what the sensor should look like, what should it monitor, how often it should monitor it, and **getting agreement on that is pretty tough**. And then there was the thing like we want it locked everything in it, so we wanted minimum of 10-year life on this bit of kit and then the design partners kind of pushing back so you know they don't want to commit to that. So, we ended up going for a 5-year life on it. So, it was just tough in that **everything was a big discussion**, **everything was a compromise**, and go through all that kind of stuff and things got missed that we found after. [Anonymous case_02_50]

Given the complex and multi-faceted nature of IoT technology, it is unlikely that a single company may have all the expertise internally. Related to this, the interviewee of SPHERE highlighted that IoT co-creation was physically distributed as different parts of the system were contributed from different actors. When the partner made a system change or update, it resulted in the clashes of the system.

> The systems **spread around the different stakeholders**. Everything needs to be procured, tested, assembled, configured, software installed, and even you have to talk together which is actually really hard to do that within one organisation. Because if someone in University of Reading said 'your sensor does not talk to my sensor' on the phone and changed software, it would mean that the thing working before is now not working. That is the system integration thing. [SPHERE_31]

The complicated value constellation of the IoT system raised concerns of knowledge protection from collaborations with outsiders as it often encompasses coopetition. In the anonymous case, while working with infrastructure providers and their design partners, inherent risks of competition and intellectual property are observed within the value constellation. However, they overcome this issue by signing contracts from the beginning. AlertMe was also challenged in terms of protecting intellectual property while providing the users working prototypes of the new IoT system [AlertMe_42]. AlertMe surveyed a working prototype to ensure they have developed the right value proposition. In this case, they have comprehensive user feedback, but there were concerns about knowledge protection and giving people a working prototype to use.

> There are risks and benefits and we have to do way up depending on who that partner is, whether the risks outweigh the benefits, or the benefits outweigh the risks. We currently find ourselves **working a lot with other infrastructure providers,** so people who already have communications networks out there and we're trying to form strategic partnerships with them so that **rather than competing with each other** that we are working alongside each other that inherently comes with **risks associated with the competitiveness** and they could switch markets and all that kind of stuff. So, we try to make sure that we're covered with NDAs (Non-Disclosure Agreements) and contracts that kind of things. [Anonymous case_02_24]

Although a company can have a good relationship with a partner, benefiting each other, the co-creation activity could fail if they do not share and agree on the strategic direction of the business. For example, AlertMe partnered with Invensys, an engineering and information technology company that helped develop the prototype and build relationships with British gas. However, their value co-creation activity did not bring to fruition as their strategic directions were different.

> Invensys is actually engaged with us who had a brand called 'Drayton'. They helped us to embed Zigbee into some of the devices. And in a way, it was quite a warm relationship, AlertMe had a good relationship technically with Invensys. The challenge of our relationship was, even though they could basically be developing the product for you, the whole company was not centred around innovation, they didn't see any big reason to innovate really. Every quarter, they made a bit more stuff made a bit more profit. There wasn't an ethos of innovation. So, that relationship, they helped us to build our early prototypes and that helped us with the British Gas relationship. But we never really went to market together. Because at some level, at the top of the company, that CEO just didn't really understand, and I suspect that's been a massive problem for them. [AlertMe_103]

The interviewee of ClimateEdge concerned the difficulties of applying the agile approach when working with their subcontractors. The company followed the agile approach under which the team tried and failed fast through iteration instead follows the strict plans through linear stages. However, when working with contractors, the company had to set the deadline, quality expectations, and cost in the contract which would have not been easy to specify. Thus, the subcontractor management and the agile approach were considered compatible.

> For contractors, it's probably the most difficult to manage. **A contractor works best if you know exactly what you want to achieve which is in contrast to our agile workflow**. Also, you **don't necessarily know what you want to achieve,** you only want to get something out there. So, sometimes it would be hard to bring someone in and get something very specific done. But then through the process, you might learn something, or you might have a conversation that allows you want to change something which obviously doesn't quite be on the contracts. So, I'd say it's probably the biggest issue, obviously it seems more expensive to have a team, but you know it's basic by the fact that you can also cut that person and ask what you need to. [ClimateEdge_39]

5.5.9 Lack of Internal Expertise

Across the cases, the lack of internal knowledge and capabilities in IoT development challenged the companies. In the anonymous case study, their original expertise lies on software development and service provider. Thus, the company was a lack of hardware and algorithms development capabilities. Over the decade, they transformed their core skills from software to IoT and product development which was not an easy journey. It required more thoughtful management and cautious approaches otherwise; it resulted in financial damage to the business.

> There has definitely been a shift within the company to **build up our own internal capabilities** that we didn't have. We're still a little bit at risk because we're trying to **manage people that we don't have**. For example, I don't have the expertise in creating a hardware product. It's very difficult to manage a team of people as you can't challenge them. This is the same difficulties that we had when we had **an external**

> **design partner**. We are getting better at that but obviously that **comes as a cost**, so we have to pay for the right people to be up to support that. [Anonymous case_02_21]

A funding played a significant role in complementing internal capabilities but the one-off system did not help the companies. The interviewees of LettusGrow and the anonymous case described the shortage of funding as a critical challenge in labour supply but from slightly different perspectives. In the IoT development of LettusGrow, the different speed for and timeline of adding the technical capabilities is particularly difficult to manage. Thus, they had to ensure to secure investment. In the anonymous case, the primary funding resources came from UKRI, which was most likely to be short-term funding. Similar to LettusGrow, they needed internal capability supplies as they progressed with IoT development. However, because the funding worked one-off, it was challenging to manage the demand and supply of labour for the longer-term. The location of the company also affects a labour shortage, such as the anonymous case. They have been located in a small town in the northwest England, the regional constraints prevented hiring quality expertise. However, the company had a development partnership with a university that helped retain the IoT development capability, specifically in data science [Anonymous case_02_38].

> We are limited by funding and staff at the moment, so hiring more people and raising more money. But there's just **a timeline with which we could progress along with different speeds for adding the technical capability** we need**.** So, there's always financial risk of not being able to encourage investment round, which is quite severe. But nothing you can really do about it; we just get on with it so. We don't want to lose too much. [LettusGrow_109]

> So, the other issue with resource is because **the funding works in 'stop go'** so if you get funding for a short period of time, one minute you haven't got enough staff, next month you've got staff in that area. Well, that's the difficulty which is to be able to resource up and resource down in a wrap it and not lose the momentum of what we're trying to develop. We're having constraints if we are having quality people. Particularly where we are in, Morecambe, **there is not lots of people are available**, they are just not here. [Anonymous case_01_37]

The shortage of financial resource resulted in the lack of all kinds of expertise but having internal designers or external designers was not prioritised. In SPHERE, AlertMe, and SilentHerdsman cases, the products were designed by engineers at the early phase of development. On contrast, ClimateEdge was the one, which had hired a product designer from the early phase of IoT development. The anonymous case had an external design subcontractor and LettusGrow supplemented design capabilities through government program, InnovateUK design foundation [LettusGrow_36].

> At that time, we were three and we didn't hire designers because of the budget so we did it by ourselves. [SilentHerdsman_50]

Hypothetically for example, our design company they would be good at doing that, they would be too much expensive for us to use. So, we just designed it by ourselves. That can easily happen with the real company as well. They don't use professional designers. [SPHERE_72]

We didn't really have designer. Later on, we brought up contractors or employees who would help us with getting UX experience. But that's not really a full-time job in a company. [AlertMe_22]

5.5.10 Overlooking the Cost of IoT Maintenance

Although each case has different situations, the several critical issues were identified with regard to creating value through delivering service than manufacturing. The issues include the long-term commitment of hardware maintenance, a software update for technical faults and security patch, ensuring data availability, and the cost of data storage. The interviewee of AlertMe explained that businesses overlook the downside of the IoT business [AlertMe_34]. Providing customer's service based on data collected through the system means recurring revenue, but it also means high cost and long-term commitment. More significantly referred by LettusGrow and the anonymous case, they did not know if their device would last 20 years, and they could maintain it and price the maintenance cost. Their IoT system was still a prototype as they never ran the IoT system for a guaranteed period of time.

The concerns on data storage and availability were critically indicated through the anonymous case. The interviewee stated that data availability affected customers' adoption of and organisations' long-term commitment to the IoT system. The anonymous case has been highly dependent on government funding for IoT development and applied for several short-term funding to move the IoT project forward. In this regard, maintaining the IoT system for 20 years required the company to secure funding on a regular basis. The managing director of the anonymous case suggested a possible solution to this, which was that the central government should reflect the long-term nature of IoT business on the government funding programmes [Anonymous case_01_42].

We'd expect the farm to last about 20 years and our kit to be operational for a good portion of that eventually all of it. But it is still prototype stage, so **we don't think they'll last for 20 years**. There's always a risk given that we haven't run up of the kit for 20 years that **we don't know how it is going to react.** Main risk being around is **that how we price our maintenance contract**. Because that's a complete unknown. We collect data on our kit internally and learn about how often it breaks and how expensive that is in terms of labour and materials. But we don't really know about how often it breaks and how expensive that is in terms of labour and materials for now. [LettusGrow_101]

So, one of the issues that needs to be thought through is **who is going to host and pay for this**. But part of the problem you have with that is if you say 'we're going to do this, we are going to have access to these systems and so on'. Who's going to maintain that you're not going to do this on the short term. It is a long-term commitment and if the infrastructure isn't guaranteed to be in place for 20 years. And I'm saying 20 years because some of the information has to be stored for 20 years. So, people want to know

> that this information is going to be readily available on a long period of time and that is another inhibitor for taking it off and who's going to fund that. [Anonymous case_01_41]

5.5.11 Issues of Cybersecurity, Adoption and Acceptability

The issues of adoption, acceptability, trust, privacy, and security are critical priorities in IoT development. The five companies indicated that they had multiple issues which were often interrelated to each other. Security was quite critical for value creation. The interviewee of SPHERE explained that these issues become more critical if a company has a larger value constellation because it means there are more data bridges that data leakages could have possibly happened. The co-founder of AlertMe explained that there was tension between the security and usability of IoT system. In essence, it could be described that if an IoT system is designed to have high security, it would be possibly designed to not user-friendly. The co-founder of SilentHerdsman also raised security concerns, particularly when relying on an AI system. It is because there is no impenetrable system and if the autonomous system is hacked, it could risk the entire IoT value constellation. Exceptionally, LettusGrow was the only one that they did not have data security issues [LettusGrow_102].

> …Imagine you have the data bridge, have three companies, making an ecosystem and some data gets out and who gets the blames for that, who gets sued. This is not quite simple answer but that is interesting. [SPHERE_32]
>
> Particularly, there's often **a tension between security and usability**. You can make s**omething secure by making it very hard to use.** But that's not a good solution, particularly for consumer product. So, we had to find things which were very easy. For example, if you take a new sensor and add it to AlertMe system in your house, you have to somehow **exchange some kind of tokens** to do so that the sensor can securely get onto the network and nobody else can. There's lots of ways solving out the problem, but most of them are quite annoying for the user. [AlertMe_46]
>
> Also, data security, hacking is a significant issue. What if I **start relying on autonomous system** based on data. I could destroy your business over night through hacking the data security. So, even if I convinced that I've got a very heavily protected shell where my data is useful and operationally efficient. I think they got to be **very careful about what they do with data**. But they are forced to do it because there is the evolution to this. Individual systems are all IoT base such as milking robots. [SilentHerdsman_61]

The project leader of SPHERE stated that the security issue might be closely related to the system acceptability and privacy issue. When data is about personal information, there are critical questions could be raised, for example, '*would the customers be willing to share their private health data in real-time'*, 'what level of private data would people be willing to share and think acceptable'. They were the difficult questions for SPHERE to identify as each user's privacy standard is varied. AlertMe recognised the data security is critical, and it is hard to be added to the IoT system once its architecture is developed. Thus, they were cautious about data management and put a significant amount of effort, cost, and expertise from day one.

For example, after designing the IoT system securely, they hired penetration testers to hack the system and audit the code. To ensure privacy, they accessed customers' data, only the vision of the customer and the data was kept encrypted at the CCTV so that only customers have the key to decrypt their own data. They had not shared customers' data with other stakeholders in the majority of circumstances. For example, British Gas, one of the value creation actors of the AlertMe IoT system, had never accessed to AlertMe's data unless they had to. The CIO of British Gas understood the criticality of data issues and barely allowed their system to interact with AlertMe's system [AlertMe_50].

> If you start to think to make complicated IoT products, like healthcare or something **providing complex service**. Then is it acceptable for you to **give your data to company to monetize**, so you get lower energy bills? That is quite difficult question to explore with them out of the public. And again, it may take quite long time to do that. So, this kind of feasibility, before you do, it can be quite hard. [SPHERE_67]

> Actually, partly because our initial application was around home security and partly because we had some **good engineers who understood how important** that was, we took **security extremely seriously** from day one. So, security is one of those things you can't build in afterwards, you have to design it in from day one. And it requires a significant amount of effort, cost, and expertise to get it right which is why a lot of people just ignore it. [AlertMe_29]

A software update is referred to as a possible solution to preventing the security issue by the interviewees of AlertMe and SPHERE [SPHERE_76]. However, they both indicated the difficulties of updating software for IoT as it is often a constrained device. For example, a smartphone user often always carries it and receives an update notification, making it easy to update. However, IoT devices hardly have user interfaces like smartphones or do not have to be carried unless they are wearable. Moreover, AlertMe does not know when it is not being used.

> So, you've also got to be quite reactive to react quickly when you discover there's a problem. And obviously, part of that is better to upgrade all your software which is very hard to do in IoT… With IoT devices, you often don't have user interface like smartphone, it can be hard to tell whether the products being used, and therefore it's OK to upgrade now. Anyway, so there are various reasons why that's a much harder for IoT. [AlertMe_48]

In terms of building trust and increasing adoption, the anonymous case, AlertMe, and SilentHerdsman experienced similar issues. The anonymous case had serious adoption and trust issues when the IoT system was deployed in highway gullies. Their end-users, gully cleaning professionals, did not trust the IoT system and considered it monitored to neglect their duty. They destroyed the system, filled in the wrong information, which in turn, lowered the level of data accuracy. As identified from the anonymous case, data availability, accuracy, and reliability are critical for trusting and adopting the system. In AlertMe Case [AlertMe_115], providing accurate data on energy usage was critical for their business because their customers adopting energy IoT device were most likely considerate of saving on energy bills.

They were also concerned if the energy measures were not consistent with the measurement from other systems. AlertMe had one minor issue that would lower customers' trust in data by providing conflicting information on different devices to the customers. The interviewee of SilentHerdsman pointed out that commercialising the IoT system in the agriculture industry was particularly difficult [SilentHerdsman_63]. It is because farming practices had become entrenched, and the farmers resisted adopting new practices and subsequent changes. In order to solve this issue, the company had to prove the return on investment of system to the farmers. The project leader of SPHERE highlighted that the commercialisation could be critical issue in IoT development with AI because if no one installed the system, there is no way to label data and improve their products and systems.

> Because farmers are entrenched practices. They have to be convinced the value of what they are buying. They did their own ways for over 100 years. You need to demonstrate Return on Investment and convince them. [SilentHerdsman_67]
>
> It is very hard to evaluate until you have enough labelled data to improve your product or system, but how you get the labelled data that nobody has the system installed because nobody wanted it, because it doesn't do anything. So that is really nasty problem. [SPHERE_102]

Regarding the adoption of IoT system, ClimateEdge had the accessibility issue of IoT system. The target market of ClimateEdge is the farming industry in tropical regions, such as East Africa and Central America, in which technological development is slow. Smartphones and computers are uncommon for farmers to have access to. Thus, ClimateEdge had to develop different methods of providing information to the farmers, such as SMS and voicemail which was readily available. In the same vein, the anonymous case raised critical questions related to sharing information, such as the type of devices, the format of data, and whether it be interactive information or notification [Anonymous case_01_69]. Accordingly, a front-end service had to be designed easy to interact with while providing customised data in right amount and types.

> **Accessibility** is a key priority for the team, as each region and individual farmer will have different needs and requirements. We're working on **different methods of feeding back information** to the farmers. We have developed **web software**, but we know that not all farmers will have access to **computers or smartphones**, so we're also making use of **SMS and voicemail**. [ClimateEdge_DR_56]
>
> So, that the big huddles we identified, you need to get over, was having a front end which would allow you to give people easy access so you could for example go on to the internet and order I want to have

> the weather data, I want it at this level, and I want to have this amount of data. So, that was number one, you **need a front end that is easy for people to interact with**. [Anonymous case_01_60]

5.5.12 Data Commercialisation Issues

Data is all around and ever growing. The case companies utilised or aimed to utilise data as a powerful commodity to create value [Section 5.4.6]. As referred to the interviewees of the anonymous case and SilentHerdsman, the primary considerations in data commercialisation can be summarised as data sharing, and curating. Data sharing with the partners was also critical in value creation [Anonymous case_02_80]. The project manager of the anonymous case explained a critical mistake they made which they gave the highway contractor access to the raw data with some anomalies before cleaning it. In the end, they only shared processed data that they could explain to their customers.

> One of the main things that we learn in this first round is **the importance of being able to show the data**. And we went through a few painful experiences where initially **we just provided the raw data to a highway contractor**. And we shouldn't have done that because we haven't done any cleansing of the data or any of that kind of stuff. And they started asking questions that we at that point didn't have the answers to. [Anonymous case_02_78]

In terms of data curation, extracting value from big data was considered impractical because there was no context and meaning, a lack of data standard, and awareness of data value [Anonymous case_01_32]. The founder of SilentHerdsman described the farming industry as where different types of digital data were available. From that perspective, there were possibilities of integrating data and creating value out of it but having no data standards challenged to build ecosystem. The managing director of the anonymous case stated that each stakeholder had different interests and security issues which was burdensome for them to resolve [Anonymous case_01_44]. They also faced the commercialisation challenges when dealing with freely available data. It was because people lacked the awareness of data value. People did not appreciate the economic value of curating data and making it something useful.

> So, IoT to me is dangerous definition. Business talk about **value of data**. But extracting value from that data is like no way, there is **no context of that data**, there is **no relationships**, there is **no validation of what the data means**. It's an absolute nightmare. They don't understand the value or how to get the value from the data. [SilentHerdsman_19]

> The farm is easy in terms of collecting meaningful data. They use satellite images, images from a drone, GPS. In the farm, **there is a whole bunch of things of infrastructures which provide you data**. It's their integration. The problem is that **data isn't integrated easily**. The data is totally desperate, because there is **no standardisation of formats of data** So, here is commercial barriers in IoT which are **horrendously more difficult** than any software and hardware development. If we get Afimilk (neck-mounted collar) to talk to Lely (milking robot) **to integrate data**, you have no idea **what value they will bring in**. They could

> probably tell you the exact illness even before and you can stop there and use of drugs significantly. But **there's no formal data standards**, and hardware standards. I mean, IoT which people are working towards is all about driving them across. [SilentHerdsman_21]

> So, internet of things is amazing that it creates new marketplace. But the part of the problem that we have is **people expect not to pay for information now**. So, if you're going to create an infrastructure where people can go and get information why would I want to pay for it. And that's an inhibitor we have to get over. So, if we want to make it and if we've got information, we can't charge for it because it's government information, how we are going to make that information available. [Anonymous case_01_40]

5.6 Chapter Summary

This chapter presented the findings and analysis of the study to examine IoT NPD process and practice, value creation activities, and challenges of IoT development and value creation.

Section 5.2 provided the IoT NPD process and practice while combining and comparing each project development activity and phase. The five generalised stages of the IoT NPD process are identified as follows: phase 1. Identifying user needs and solution ideation; phase 2. Feasibility test and requirement identification; phase 3. Designing, prototyping, integrating and testing of hardware, software and algorithms and data; phase 4. Manufacturing, marketing, launching and installing IoT system; and phase 5. Customer support, data monitoring, and software update. The generalised phases of IoT NPD seem similar to the traditional NPD process, but each phase has distinctive activities for and concerns over value creation. The critical distinctions are identified over the subsequent cycle of the IoT NPD process, which can be diversified into three different scenarios: first, developing new IoT devices; second, scaling up the system and developing new software; and last, developing and embedding new algorithms for novel value. There are no one right trajectories for the companies to follow since launching the initial IoT system; thus, each case company demonstrates diverse ways of value creation through different subsequent NPD processes.

Section 5.3 and 5.4 described the five attributes of the IoT NPD process and the five attributes of IoT value creation strategies, respectively. Firstly, the IoT NPD phases are generalisable even if the process and practice are less structured and emphasise agility and flexibility. Second, numerous developmental considerations arose from the different pace and approaches of hardware, software and algorithms development. Third, the IoT NPD process is continuous and emergent as the services can be added to the IoT platform. Fourth, due to the complexity of the IoT system, the NPD becomes complex and slow or fast and straightforward depending on the subsequent NPD process. Finally, the temporal division between development and usage phases was collapsed. In value creation strategies, value is created through delivering service and scaling up, with a critical focus on the concept of value co-creation. Users' contributions to value creation are critical in IoT development, but the reconciliation of technology push and market pull strategies is identified. As data is considered a Resource for value creation, companies exploit data in various ways, including: to feed insights back to the customers; identify novel value propositions and improve IoT systems; integrate different datasets for discovering new services; sell data to other actors; and improve business process efficiency.

Section 5.5 summarised various challenges in value creations over the NPD process. The reasons of the challenges are multifold and interrelated to each other, including complications in perceiving the real value that IoT may bring, the non-maturity of the IoT industry, and the novel concept of IoT. The complex and multi-faceted nature of IoT technology enhance development risks, for example, difficulties to develop technical architecture including costly lengthy machine learning technology, integrate system, identify user requirements, manage supply chain, commercialisation and installation, and lack internal expertise. The prerequisite for IoT value creation causes obstacles, such as value co-creation, business transformation to service, scaling up the IoT system, continuous design activities, and value creation through big data. Specifically, a numerous issues are identified around data, including trustworthiness, security, and privacy of data and IoT system which may affect adoption, acceptability, commercialisation of IoT system.

CHAPTER 06

Discussing and Validating Research Findings

6. Discussing and Validating Research Findings

6.1 Introduction

In the previous chapter, the findings of the cross-case analysis were presented and critically discussed. The analysis was conducted surrounding IoT NPD process and practices, value creation activities, barriers, and tensions. Chapter 6 aims to compare and synthesise the literature and thematic findings, adopting the approach of contrasting research findings to current literatures. The comparison of empirical findings with the comprehensive literature is understood as a critical aspect of theory building as it can improve “internal validity, generalizability, and theoretical level of theory building from case study research” (Eisenhardt, 1989, p. 545). Adopting this approach, this chapter will address the following two research questions:

- RQ3: How does design contribute towards IoT value creation?
- RQ4: What is the conceptual model of IoT NPD practice and process?

Each subsection in this chapter discusses their interrelated aspects and positions the findings in relation to current literature. RQ 4 is answered through section 6.2. Firstly, section 6.2.1 discusses the stages of IoT NPD practice and processes, comparing and synthesising the generalised stages of existing NPD models through the extant literature. Then the section 6.2.2 discusses the attributes of the IoT NPD process reflected on a conceptual model of IoT NPD in section 6.2.3. Further discussion on value creation strategies for the IoT system provides a comprehensive understanding of IoT NPD practice and process. RQ3 is answered through section 6.3. The empirical findings on the role of design in IoT development are synthesised and compared with existing literature. Experts in academia and industry review the research findings to validate the conceptual model, which are discussed in section 6.4. The chapter concludes with a summary of the discussion in section 6.5.

6.2 The Design of a Conceptual Model

6.2.1 The Five Phases of IoT NPD Process

The five phases of IoT NPD process identified from empirical data are not that discernibly different to contemporary NPD processes (Figure 58). The initial phase is ‘Identifying user needs and solution ideation', in which the organisation undertakes market and user research as well as strategic planning depending on the concepts of IoT business and technical solutions. Throughout this phase, building a strong relationship with their customers is vital, as real-life trials through which a company can test integrated systems and refine algorithms. This stage features the business and technical aspects of activities for hardware and software development. The way to collect data during this stage is more likely to be through traditional NPD activities, including surveys, focus groups, interviews and observation. Although Yu and Yang (2016) propose a model through which they describe the application of the data science process for the market analysis phase, the model cannot be considered complete at this stage as big data is yet to be freely available to validate the integrity of the model. Consequently, data and algorithm related activities are due to be performed apart from understanding the main business aims.

Activities	Conventional NPD	IoT NPD Phases	Activities H/W	S/W	Data & Algorithms
market research and analysis	Discovering Users and Business needs	Identifying User Needs and Solution Ideation	- Value proposition & technical discussion, - Identify market segment, - Parameterise problems, - Solution ideation	- Explore software platform concept	- Understanding business aim
System and software requirements, business model, concepts of software, product, & service	Defining concepts of & strategies for business & technical solutions				
System and business analysis, screening & evaluating the solution ideas	Testing Feasibility of business & technical solution	Feasibility Test and Requirement Identification	- Explore feature sets, - Validate product viability, - Develop demonstrator, - Test feasibility, - Identify value proposition & Technical specification	- Explore features, - Develop demonstrator, - Test feasibility, - Identify requirement	- Explore & identify data type - Manual data collection, - Explore the data process, - Build trust, - Test acceptability
Developing prototyping, and testing, coding and debugging, casting	Designing, Prototyping, and Testing solutions	Designing, Prototyping, Integrating and Testing	- Develop sensors & individual components, - Design and build prototypes from low-to high-fidelity, - Test the hardware functionality - Determine RoI	- System design, coding, & debugging, - Testing system security, - System integration, - Real-life trials for data collection	- Access to the customers, - IoT system deployment & Data collection - Data profiling & wrangling - Develop initial algorithms, - Test & validate algorithms accuracy, - Refining algorithms
Process development, Resetting organisation, and Modifying product design	Manufacturing, Marketing & Releasing solutions	Manufacturing Marketing, Launching and Installing IoT system	- Production tooling, - Production, Marketing, commercialization, - System deployment	- Release software	
Maintaining and after-sales service	Evaluating and Planning the next phase	Customer Support, Data Monitoring, Software update, Identifying User needs & Solution Ideation	- Send insights to users, - Collect user feedbacks, - Improve value proposition & Technical discussion, - Parameterise problems, - Solution ideation	- Customer support regarding technical faults, - Software update, - System management, - Explore software platform concept	- Data profiling & wrangling - Data analysis, - Build data product, - Improve accuracy of algorithms, - Explore different data sets

Figure 58 Comparison between conventional NPD phases and IoT NPD phases

Once the concept and system requirements are identified through the first phase, the organisation undertakes a feasibility test for potential business and technical solutions. Over the second phase 'feasibility testing and requirement identification', the hardware and software elements of development activities are performed which include: exploring feature sets, validating product viability, developing demonstrator, testing feasibility, and identifying appropriate value propositions and technical specifications. At this point, the organisation is unlikely to have its own hardware components and sensors to demonstrate if it properly works. Consequently, the organisation tests the concept with commercial sensors to assess its viability in practical operation. The data and algorithm development process begins with exploring and identifying what types of data should be collected. While figuring out how the IoT system could best work, they would manually collect data and examine the whole data process as to how it should be effectively managed. Moreover, testing users' acceptability of and building users' trust in the IoT system is of paramount importance within this phase.

The third phase of 'Designing, Prototyping, Integrating and Testing' incorporates many design and development activities regarding development of hardware, software and algorithms, and their full integration. During this phase, the organisation designs and develops individual hardware components, builds prototypes from low to high-fidelity, determines RoI (Return on Investment metrics), and designs and tests the initial software system. Developing a well-defined technical architecture is critical as an IoT system is not a singular product or easy to change once developed and released but it must be maintained and improved over the longer-term, while scaling up the application domain or integrating with other systems. Mashal et al. (2015) argued that IoT cannot be globally deployed without effectively building the main architecture. Unless the architecture is developed appropriately in the first place, considering the possibility of being universally acceptable and usable for a diverse global population in various contexts, the company may have to re-design the whole system from the beginning. Once the hardware and software are seamlessly integrated, the firm accesses the customers user-data, which is critical as this is the first time verifying if the integrated system works in daily operation.

Kahle et al. (2020) indicate seamless integration of heterogeneous technologies is somewhat difficult for SMEs due to their limited resources. For instance, an IoT system may encompass AI elements; the uncertainty of system performance possibly gets worse; system integration between the heterogeneous technologies generates even greater pressure; testing and refining algorithms through real-life trials require vast amounts of real-time data to ensure accurate predictions to the users. This whole process, building annotated data sets, and building and testing the algorithm is labour intensive, time-consuming (Deutsch, 2015; Kandel et al., 2012), and costly, adding more complexity to the IoT design process. Alternatively, if a company decides to use annotated data sets, its design process would be more refined, but it might be difficult to differentiate its business offerings to that of their competitors. Porter and Heppelmann (2014) compared the advantages and disadvantages of both closed and open system approaches. Through a closed system, a company may create a competitive IoT system, but the design of the system could be slow and less responsive.

Alternatively, open system enables a faster development as multiple actors contribute to its overall effectiveness and value in operation.

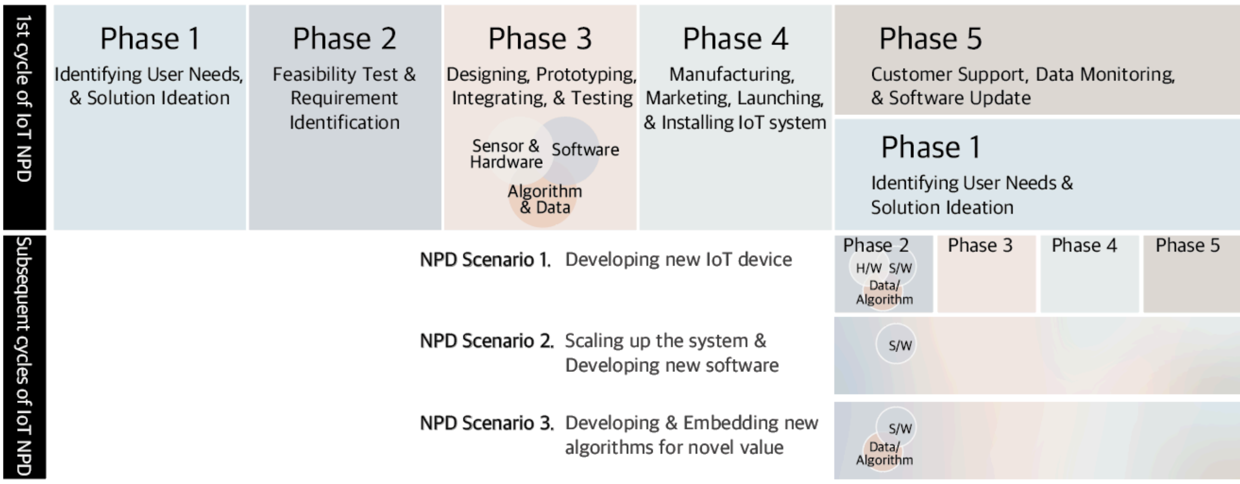


Figure 59 Five phases of IoT NPD and three different scenarios of the subsequent cycles of IoT NPD [see section 5.2.2 Subsequent cycles of IoT NPD process in Chapter 5]

The fourth phase of the IoT NPD process is 'manufacturing, marketing, launching and installing the IoT system.' As software development is more agile and faster than hardware development, this phase is mainly concerned with hardware development activities. The organisation performs production tooling for manufacturing through which they review if the product is suitable for large scale and costly production. Once the IoT system is marketed, commercialised and deployed, real-time data starts to be collected which means the organisation enters the final phase of the IoT process of 'customer support, data monitoring, and software update.' During this phase, strong management skills on supply chain, quality control, and cash flow are required. Also, identifying the right price-position point for the system is challenging as there are not many comparable solutions available on the market.

System deployment means long-term relationships with and commitment to the customers, as the companies collect customer data. Thus, fifth phase overlaps with first phase where companies keep identifying user needs to enhance their value propositions and augment user experiences. In the frame of traditional NPD, these activities called Fuzzy-Front End (FFE) (P. G. Smith & Reinertsen, 1992) as the characteristics of the initial stage (Dewulf, 2013). However, regards IoT development processes this terminology is obsolete as the whole IoT NPD process remains interrelated, unstructured and uncertain (Khurana & Rosenthal, 1997) throughout its entire duration of development. In the subsequent development process, the companies expanded the deliverable service areas through three different NPD scenarios which will be further explained in the next section.

6.2.2 The Five Attributes of IoT NPD Process

Although the five phases of the IoT NPD process appear to be similar to the conventional NPD processes, after a deeper investigation into the activities of IoT development, five attributes of IoT NPD process are identified as follows:

1. Consisting of three distinctive NPD scenarios, a hardware centred, a software centred, and a data/algorithms centred IoT NPD
2. The continuous and emergent process
3. Involving three different types of subject matter, hardware, software, and data/algorithms development
4. Distinctive characteristics of each subject matter impact development speed and approaches
5. The temporal division between development and usage being condensed

The five attributes distinctive to existing NPD, SDLC, NSD, and PSS are reflected in the creation of the conceptual IoT NPD process (Figure 60).

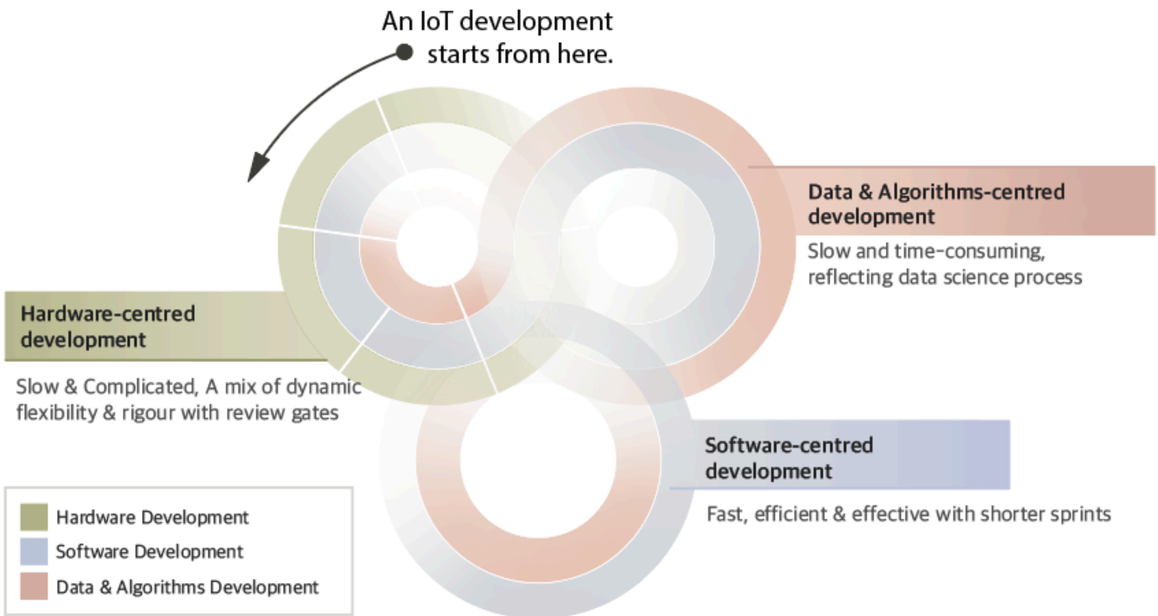


Figure 60 A conceptual model of IoT NPD process [Simple version]

Firstly, the IoT NPD process consists of three distinctive NPD scenarios, illustrated as three cycles. Each represents the subsequent IoT NPD processes with a critical focus on development and related value creation activities. These three distinctive loops can be supported by and explained within the IoT paradigm as a result of the convergence of different visions: 1) A hardware-centred, 2) a software-centred, and 3) a data/algorithms-centred development perspective. Accordingly, each loop has a distinctive emphasis on developmental activities. The first NPD on the top left involves developing and integrating hardware, software, data and algorithms. The IoT NPD on the bottom is software-centred development, and the IoT NPD on top right is a data and algorithms centred development.

Second, the IoT NPD model highlights the continuous and emergent process thanks to real-time data that helps identify new value propositions and the software elements that enable perpetual beta development. For example, Zittrain (2008) points out that digital artefacts are intentionally designed to be incomplete and perpetually in development. Similarly, Alaimo et al. (2020) argues that value creation with big data enables NPD as a never-ending process, thus extending far beyond making and delivering 'final' products and services. The IoT NPD process starts from the top left loop and continues to the top right and/or to the bottom of IoT NPD processes. The subsequent cycles can run simultaneously or sequentially depending on a firm's value creation strategies. The fifth phase of the IoT NPD process, where companies support their customers, monitor the real-time data and update software, re-enforces this value enhancement attribute to the end-user. The development cycle may return to the first IoT NPD process if a newly identified value proposition requires new device development.

Third, a conceptual IoT NPD process involves three different types of subject matter which are illustrated as different colour legends. The green layer involves hardware, the blue layer is software, and the pink layer relates to data and algorithm development. Unlike other NPD, SDLC, and NSD processes, developing different types of subject matter simultaneously occurs tensions and challenges. It includes, for example, the different speeds and approaches of physical products and software development (Svahn et al., 2009) and the integration of all the different components of the IoT system. As Kahle et al. (2020) point out that IoT system integration is the most difficult but critical in respect to value creation, firms should synchronize the contrasting "clock speeds" of hardware and software development (M. Porter & Heppelmann, 2014).

Fourth, hardware, software, data, and algorithms development activities have distinctive characteristics in terms of the development speed and approaches. The first IoT NPD process is a combination of dynamic flexibility and rigour with regular design reviews as it involves hardware, software and data practice. In contrast, the bottom centred IoT NPD process is more agile with vague distinctions between the phases as it is software centred development set of activities. The top right IoT NPD process where data and algorithm centred development is characterised as a lengthy and continuous process. Also, the model integrates all three development activities, ensuring that the first IoT NPD is more complicated than the two others. Once the system is launched, the process may become a fast-flowing process that is predominantly software centred. While the NPD approach of each loop varies depending on the focus of value creation activities and subject matter, the agility of development practices is encouraged. This is in aligned to existing scholarly work on NPD. For instance, Scholars emphasise the agile approach in NPD process to cope with the increased pace of change in the digital innovation realm (Yoo et al., 2010) and the increasing globalisation (Bohemia & Harman, 2008).

The last attribute of the IoT NPD process is that the temporal division between development and usage is condensed once the IoT system is launched onto the marketplace which is explained through the 8-shape design process and data role (Janne & Bogers, 2019) [see the section 2.3.3.2 Design and Development Processes for IoT in Chapter 2].

6.2.3 The Mobius Strip Model of IoT NPD Process

The novel approach is named the Mobius strip model of IoT NPD as it implies three infinite loops of value creation and NPD activities (Figure 61) occurring in real-time. This IoT NPD model is distinctive to other PLM, PSS models, data-driven design process, and digital twin design frameworks. Firstly, although some of the PLM and PSS models (Wiesner et al., 2015; Maussanget al., 2009; Aurich et al., 2006; Marques et al., 2013) are the hybrid of tangible and intangible products development, intangible products do not necessarily mean software development. Thus, they cannot explain IoT NPD process. Moreover, existing Data-driven design process models (Feng et al. 2020; Janne and Bogers, 2019; Tao et al, 2018) do not encompass the entire process and stages of the new product development activities but focus on design process. Particularly, IoT development involving the algorithms development, such as the Anonymous case and Silentherdsman case, cannot be explained through these models. It is because the existing models do not include algorithms development which is critical in IoT development and value creation. The Mobius strip model of IoT NPD process is novel as it encompasses the different approaches of digital, physical and algorithms development unlike the other process models (Jacob and Cooper, 2018; Yu and Yang, 2016). The attributes of the model will be further explained below.

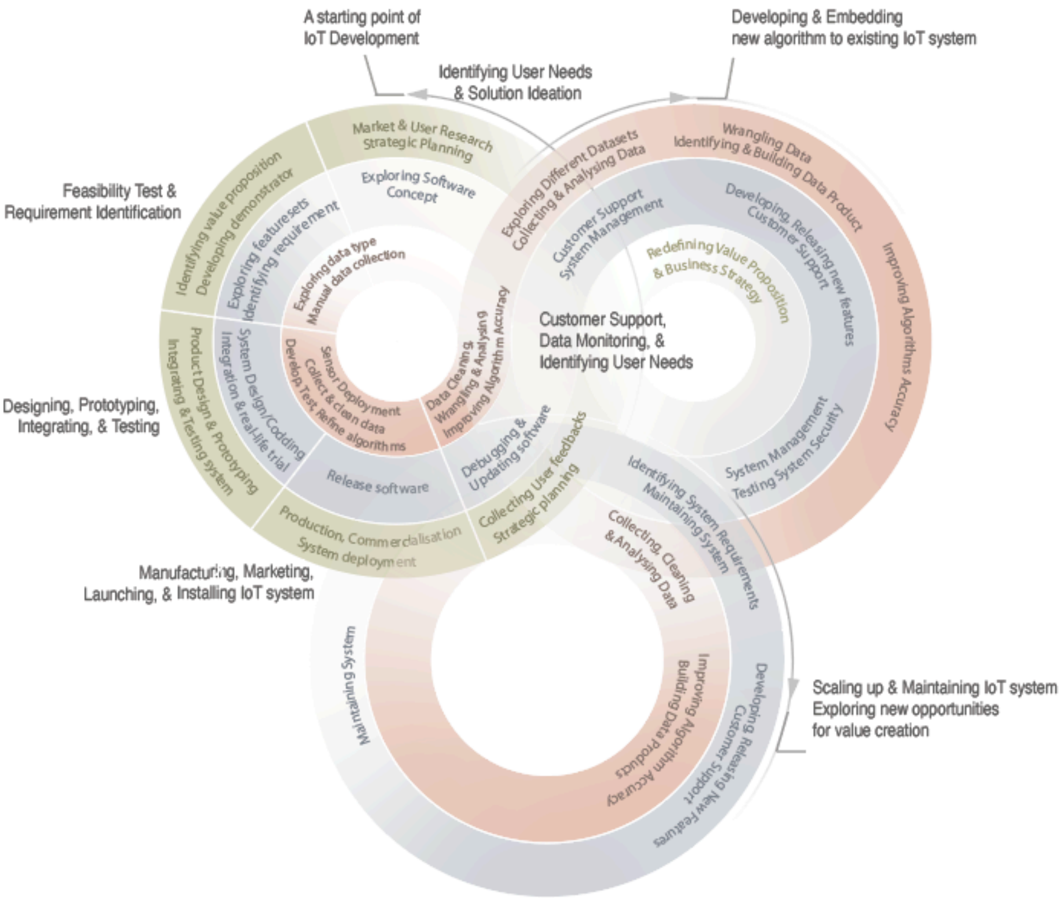


Figure 61 The conceptual IoT NPD process, the Mobius strip model of IoT NPD

The first cycle of the IoT NPD process involves all three developments, including hardware that requires robust approval, deep and thoughtful planning influenced by linear NPD process (Booz et al., 1982; Cooper, 1990; Walsh et al., 1992). Thus, it makes development activities and integration of all three slow and overly complicated. However, once the IoT device is launched and implemented, the development activities become more agile, composed of shorter sprint cycles due to the primary focus on software development. The bottom centred development activities are more flexible, efficient, and effective without major modification to the IoT system, but mainly updating and improving existing system. The third NPD element on the top-right hand is novel in NPD literature. It demonstrates that organisations create new value propositions via adding new services through the introduction of new algorithms. This process heavily involves data and algorithm development so that the NPD process is slow and time-consuming, reflecting the challenges of the data science process which are discussed in established literatures (Baumer, 2015; Kandel et al., 2012).

IoT NPD begins from the top left cycle that consists of the five distinctive phases. This IoT NPD is influenced by the traditional hardware development approach, which requires clear demarcation and review gates between the stages (R. G. Cooper, 1990). Alongside hardware development, integration of different layers of IoT system is characterised by complex, slow, and consequently expensive processes. Although the first cycle encompasses the development activities for algorithms and data, algorithm development is not necessarily for machine learning. It depends on how serious an organisation takes the analytical activities, such as descriptive, predictive, and prescriptive analytics (Delen & Demirkan, 2013; Hartmann et al., 2016). The smartness level of the IoT system that SilentHerdsman, the anonymous case, and SPHERE developed and embedded into the system was predictive, thus making the first IoT NPD cycle a lengthy process. However, the analytic activities of LettusGrow and ClimateEdge are descriptive, which makes the first NPD cycle relatively short in nature. The fifth phase of the IoT process on the top left cycle, 'customer support, data monitoring, and software update', overlaps with the first phase of the process.

Over the bottom centred cycle of IoT NPD, a software-centred development, companies aim to scale up by increasing numbers of deployment or diversifying the IoT application areas while improving their existing system with a focus on satisfying their customers. Including SilentHerdsman, all companies continuously released software updates through this cycle of activity. New features often are developed through having partnerships with or acquiring rival companies. For example, when AlertMe redefined the customer value proposition of tracking carbon footprints, they developed new software features with web service providers, Google and Yahoo. They also acquired Wattbox to develop heating control software. LettusGrow, the anonymous case and ClimateEdge have scaled up a range of IoT system applications for different purposes and application contexts. In this process, they are often required to modify the software to adjust to each application. As software development is faster than standard hardware and algorithm developments, this successive cycle of NPD becomes less complex but more efficient and effective. Regarding data and algorithm development, the company develops and delivers valuable information to their customers through PR messaging, via notifications or alerts.

Over this continuous cycle, there might be small changes of hardware due to the shortage of the components from the non-maturity of the IoT industries and a dramatically accelerating speed of digital technology development. Ferrara et al. (2021) argues the component replacements are necessary as outdated hardware components could threaten the security of devices The manufacturers continuously launch novel chips, sensors, processors, and other components with improved performance, resulting in the hardware components used for IoT systems being either outdated or no longer available in the marketplace. Component replacements may cause system vulnerability and a significant design change requiring the whole system to be redesigned. Consequently, businesses' continual pressure on and uncertainty of continuous design activities increase development time and costs which is identified as one of the biggest NPD risks (Gil & Tether, 2011).

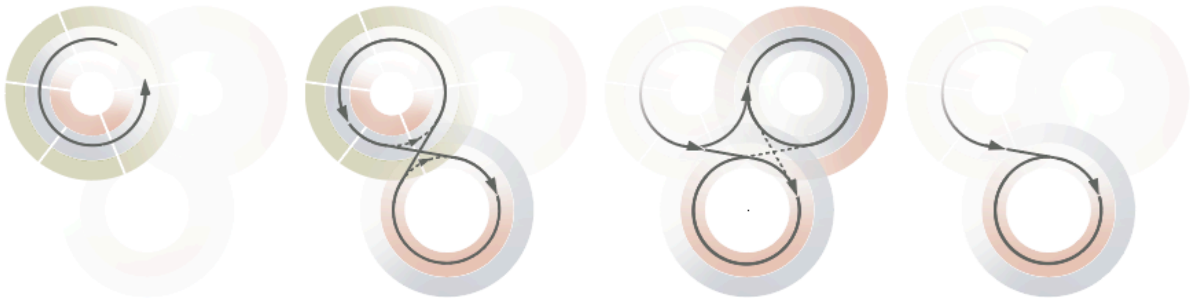


Figure 62 Different subsequent IoT NPD cycles and value creation

While deploying the IoT systems, supporting the existing customers, and maintaining up-to-date software, novel users and business needs can be found at anytime that may trigger the other left NPD loops or the right NPD loops (Figure 62). Once a company decides to develop a new value proposition involving adding a new device to the system, the IoT NPD process reverts back to the top left-hand cycle. The anonymous case and AlertMe are examples that developed and added new devices to the IoT system, but slightly differently, they created value over this cycle. Regarding the anonymous case, they re-designed hardware while applying their gully management solution for highways to broader contexts, like the railway network. On the other hand, AlertMe had partnerships with Sprue Aegis for developing the smoke detector and Invensys for smart energy devices. It often would not be much different from its first IoT NPD journey, which requires the separation between the development phases and strict review gates. However, if a company adds the new hardware features by partnering or acquiring companies, the hardware development may be less intricate, but the system integration may be equally challenging.

Whether developing a new device or merging other's devices to the existing IoT system, the companies experience slow and complicated processes again. This point is where one of the actual values of the IoT is thoroughly realised, having more things connected and communicated with each other in a seamless manner. Many scholars have argued that the IoT as interconnected objects which is one of the most critical features of IoT (ECIS, 2008; Gubbi et al., 2013; Patel & Patel, 2016). Thanks to *communicability* (Yoo et al., 2010), one of the material properties of digitalised artefacts, a mixture of physical and digital components can be connected which makes the IoT system a *digital technology platform*. Communication between the interconnected devices and platforms would make the system more complex, requiring integrating one's IoT system to their legacy system or the other partners system. Without seamless integration and communication between the platforms, it results in a poor user experience.

A novel IoT service and value can be also created through the upper right cycle of data and algorithms-centred development. The majority of IoT NPD activities can be related to data science practice and machine learning algorithm development. This cycle is identified as a data and algorithms centred IoT NPD and value creation involving the interpretation and exploitation of complementary datasets. Only SilentHerdsman, out of six, create value through embedding new algorithms with the existing raw data. In the SilentHerdsman case example, while providing fertility monitoring with heating algorithms, they developed a health monitoring service by embedding eating and ruminating algorithms with the existing dataset. *Digital convergence*, one of the dimensions of digital innovation (Yoo et al., 2010), can support this value creation approach. The IoT architecture layer is loosely coupled, enabling the combination and re-combination of each layer for different material properties and to develop different services.

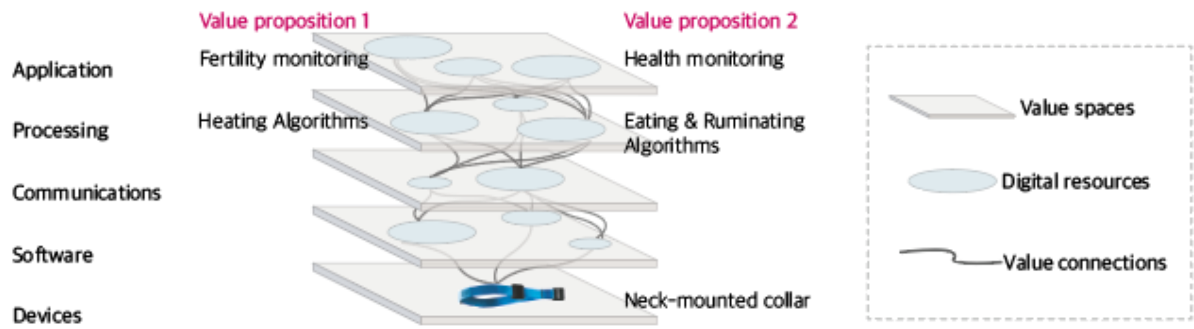


Figure 63 The value spaces of SilentHerdsman, modified from Henfridsson et al.'s the value space framework (2018)

Figure 63 illustrates this attribute of IoT value creation through the value spaces of SilentHerdsman, where multiple and possible values can be created. *Digital materiality* (Yoo et al., 2012) of the neck-mounted collar was initially a fertility monitoring device, then, later on, health monitoring was added. *Design flexibility* explains this further as it refers to subsidiary functionality of digitised artefacts that can be modified, or entirely new functionality can be introduced over the product lifecycle because of digital components, such as sensors, collected data, and embedded software (Henfridsson et al., 2014). In the same manner, Arthur (2009) also perceives that the infinite recombination of digital artefacts has become a new source of innovation. Due to the *reprogrammability and homogenisation of data*, digitised artefacts development has the aspects of *generativity* (Yoo et al., 2010) which empowers the continual reinterpretations, expansions and refinements of products and services. The *generativity* is observed to be prevalent throughout all three IoT NPD loops in the other cases. AlertMe released new features of tracking carbon footprint over the bottom cycle and embedded more devices over the left cycle. The anonymous case released a second value proposition through a hardware centred IoT NPD loop.

6.2.4 IoT Value Creation

Data-Dominant Logic as The Next Wave of Innovation

From the research, Data Dominant Logic (Kugler, 2020) is considered as the next wave of innovation and the economic foundation. It is because even though the value of IoT is created through 'value in use' (Vargo & Lusch, 2008) and 'value co-creation' (Vargo & Lusch, 2004a), one of the fundamental enablers of all this is data. In the same vein, Rymaszewska et al. (2017) explain that IoT expands the company's value creation scope beyond traditional manufacturing thanks to turning data into value. For example, in all cases, exploration of different data sets and data management have continued, developing data-informed products, or enabling improving algorithms. Raw data collected from sensors is interpreted and produced as a data product, such as periodic user reports and real-time alerts. It is also utilised to improve value propositions, combined with data collected through conventional means like customer feedback or user research. Having long term relationship with the customers is considered as significant business activities enabled by the internet. However, critical issues related to data-driven value creation are often overlooked, including the long-term commitment of hardware maintenance, a continuous software update for technical faults and security patches, ensuring data availability and accuracy, and the cost of data storage.

This data-based value creation and NPD can be even more widely understood as a continuous process of meaning and knowledge construction (Zuboff, 1988), featuring the various ways of data commercialisation (D. Machan, 2009) through recombination, re-contextualisation or re-interpretation of the different datasets (Alaimo et al., 2020). According to Fayyad et al. (1996), a firm's offering from data mining can be categorised into two: 1) raw data as a set of facts without an attached meaning and 2) information/knowledge after having the data interpreted and visualised. These two offerings were mapped along with the data science process and how they are utilised for data-driven value creation (Figure 64). Raw data is used to improve the IoT by refining algorithms, and information and knowledge are applied to support customers by providing insights and identifying new business and user needs. However, creating value through integrating different datasets is challenging and remains to be resolved [see section 5.4.5. Data as a Resource for Value Creation in Chapter 5]. Although companies utilise big data for innovating new products and services, which scholars agree with (CEBR, 2012; Hagen et al., 2013; McKinsey, 2011; Petter & Peppard, 2012; Porter & Heppelmann, 2014; Schroeck et al., 2012), the companies are likely to rely on the traditional methods when identifying users and business needs.

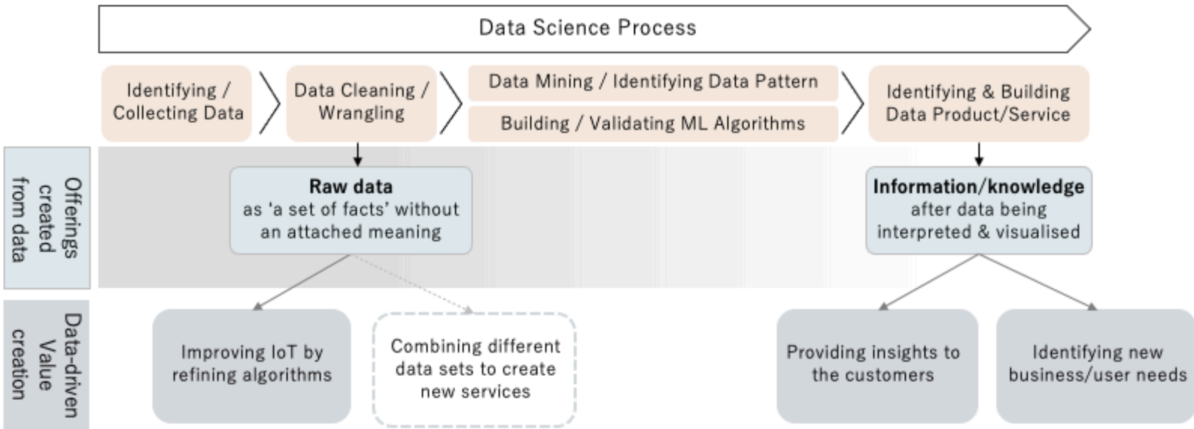


Figure 64 Data-driven value creation alongside data science process

As it is well recognised that value of information increases when combined with other information (Kubler et al., 2015), companies are keen to extract value through aggregating the different datasets [Section 5.4.5]. However, in reality, no company has proven value creation through aggregating the different datasets. It is because they encountered several issues around no data standards, context, meaning, and awareness of data value [Section 5.5.12]. In essence, the homogenisation of data, a discrete representation of data in bits of 0 and 1 which are collected from all different types and sources, empowers any digital data efficiently combined with others and creates a diverse variety of services and dissolves product and industry boundaries (Yoo et al., 2010). However, in practice, it hinders value creation by removing the context and meaning of digital data. In literature, scholars propose several factors hinder data-enabled value creation: inconsistency across data sources, and/or inaccuracy for certain records (Baumer, 2015; Cassina et al., 2008; Kandel et al., 2012; Kubler et al., 2015); data policies, organisational change and talent, access to data, and industry structure (Wamba et al., 2015).

It is because the third-party businesses would not want to share their private data. Particularly, when data is freely available, sharing it with other parties often requires additional labour costs. The users are not aware of the value of data thus are not willing to pay for the service created through curating freely available data. Also, each stakeholder has different interests and security issues. Scholars raised similar concerns regarding data owners' ideas on how to utilise data different to the IoT stakeholders (Aivalioti et al., 2018), ensuring data quality and trust between the ecosystem actors

(Breivold & Rizvanovic, 2018) and the complex IoT value chains for various ecosystems exploiting big data (Oh et al., 2020).

The Critical Focus on The Concept of Value Co-Creation

Mazhelis et al. (2012) identify an "Ecosystem of Connected Things" as a unique type of business ecosystem comprised of companies who compete and cooperate by utilising a group of shared resources. Research demonstrates that a primary shift in value creation logic is required from a value chain to value constellation where value is co-created both vertically and horizontally (Centerholt et al., 2020). In this regard, there is a strong emphasis on value co-creation over the Mobius strip model of IoT NPD. Within the value constellation (Richard Normann & Ramírez, 1994), co-creation is implemented as an approach to innovation for many reasons.

Firstly, a single company hardly has all the competencies: developing physical components, sensors, and data gathering and processing, and developing digital services. Particularly, when the IoT application is outside of the technology domain, such as energy, healthcare provision and animals, the firm needs to include domain experts in data interpretation. Due to the lack of analytic skills, companies struggle to add data and analytics to their offerings as value-added services. As Reynolds and Uygun (2015) demonstrate a strong connection between SMEs and universities in IoT development, universities play a crucial role in supporting the companies to profit from advanced technologies such as machine learning and data analytics [see the section 5.4.3 The Critical Focus on the Concepts of Value Co-creation in Chapter 5]. A horizontal connection of IoT ecosystems through interoperability and interconnectivity of devices and platforms allow new ways of cooperation, accelerating innovation across sectors and regions (Aivalioti et al., 2018; Weber et al., 2018).

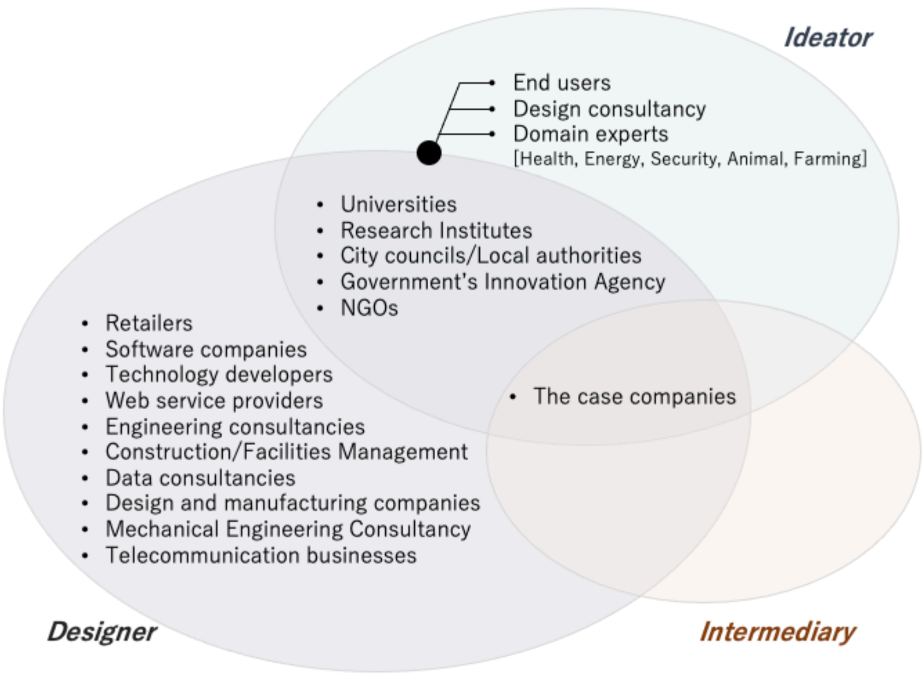


Figure 65 Types and roles of IoT value co-creation stakeholders

Referring to the three categories of the IoT ecosystem role, including ideator, designer, and intermediary (Ikävalko et al., 2018; Lusch & Nambisan, 2015; Smedlund & Toivonen, 2005), various actors in IoT development are mapped (Figure 65). As the case companies coordinate activities and lead IoT development, they are positioned in the intersection of intermediaries, designers, and ideators, responsible for the entire NPD process. Ideators are those who dedicate to ensure developing and delivering the right value propositions to the marketplace. Depending on the project context, end users, design consultancies, and domain experts played roles such as ideators, or ideators and designers. For example, the advanced users in AlertMe case were actively involved in NPD process through the user forum platform [Section 5.4.4]. In this case they improved the overall service as ideators and designers. In literature, it has long been understood that having lead users early in NPD process is critical to drive product development in the desired direction specifically in radical innovations (Chatterji & Fabrizio, 2014; Lettl et al., 2006; von Hippel, 1986). Similalry, design consultancies and domain experts are categorised either as ideators, or ideators and designers in accordance with the context.

Those dedicating to ensuring the development of the right value proposition and developing and delivering the right solutions are mapped at the intersection of ideator and designer. Universities, Research institutes, city councils, local authorities, Government's innovation agencies, and NGOs are included here.

Several institutions are categorised as designers who are involved in developing and delivering IoT systems. The difference between those two 'designer' and 'designer and ideator' is most likely the level of involvement. Designers are highly likely subcontractors of the project and 'designers and ideators' are project partners. The extant literature shows that value co-creation assists firms to identify customers' needs and wants (Lusch & Vargo, 2006; Peyne et al., 2008), which generally happens in the early stages of the NPD process. However, value co-creation for IoT happens throughout the entire NPD process as the conception of the fuzzy front end is not applicable within a continuous IoT NPD process. Involving dynamics of conversations between the domain experts, customers, software developers, data experts, hardware producers, distributors, and other technology suppliers, the majority of ecosystem actors are identified as 'ideators and designers' or 'designers'.

Scholars suggest that embracing value co-creation and constellation perspective becomes a prerequisite in IoT business as it demands particular capabilities, including software developers, data interpretation, hardware producers, distributors, and other technology suppliers (Dedehayir & Steinert, 2016). However, it could raise severe business disadvantages (Ghanbari et al., 2016; Westerlund et al., 2014). In this manner, the critical challenge factors that make the process of value co-creation are identified. Firstly, the highly connected and distributed IoT ecosystem increases complexity and various development challenges, including complications of reaching an agreement between organisations with different business interests and security issues, operational challenges of each partner working remotely. Increasingly distributed IoT development activities, moving toward the periphery of organisations is also originated from several innovation trends, including open innovation (Boudreau, 2010), and open-source software development (Kogut & Metiu, 2001). Also, there may be inherent risks of competition and intellectual property sharing when collaborating with competitors.

Co-opetition [see the section 2.2.2.3. IoT Ecosystem for Value Co-Creation in Chapter 2] is crucial in IoT development alongside co-creation, and scholars emphasise well defined partnership based on trusted relationships to avoid the risk in IoT co-creation (Aivalioti et al., 2018; Centerholt et al., 2020; Kahle et al., 2020). Secondly, companies are challenged in managing the partners and value creation process as they lack the expertise in specific areas. Yoo et al (2008) propose that companies need to develop an ability to overcome differences in governance, communications, knowledge resources and value among the various stakeholders. The regional disparity in prosperity is identified as one of the primary factors that prevent hiring quality expertise in value co-creation and innovation. For example, a company located in somewhere else other than south-east England is challenged in employment and prosperity (Zymek & Jones, 2020). Interoperability is a critical element for maximising the value of IoT system (Aivalioti et al., 2018), but having a more complex vertical and holistic partnership constellations results in a more considerable vulnerability in quality control over the value of the entire co-creation process.

Moreover, apart from value co-creation, value co-destruction can be considered to acknowledge the limitations of value co-creation in IoT development. Value co-destruction is defined as 'an interaction process between service systems that result in a decline in at least one of the system's wellbeing (which given the nature of the service system can be individual or organisational)' (Plé & Cáceres, 2010, p.431). Co-destruction of value may emerge when there is the absence of information, an insufficient level of trust, an inability to serve, an inability to change, the absence of clear expectations, and customer misbehaviour (Järvi et al., 2018). Particularly, in this study, it is observed that value can be co-destructed through the absence of information, the insufficient level of trust, and the inability to serve.

The absence of information is when the provider is unable to provide correct information (Järvi et al., 2018). When integrating IoT systems to others, AlertMe offered different information to their users through different channels. Regarding the insufficient level of trust which customers' unwillingness to provide information (Järvi et al., 2018), the gully cleaning professionals, the end-users of the Anonymous case, provided the wrong information as they did not trust the system. Lastly, the inability to serve represents that the value can be destroyed when the customer does not receive what was promised (Järvi et al., 2018). In this regard, the farmers wanted to receive what was promised through RoI in the SilentHerdsman case.

User-Driven Development

IoT development is revealed as a combination of technology push and market pull strategies [see the section 5.4.1 The Reconciliation of Technology Push and Market Pull Strategies in Chapter 5] and the end users' value co-creation is moved from the temporary and passive peripheral (Agrawal & Rahman, 2015) to the continuous and fundamental pivot. The critical distinction of users' contributions between traditional and IoT value creation is that regardless of the NPD phases, users are inherently and continuously co-creating value through sharing data with businesses. It is afforded with the conception of value-in-use in which users gain the experience through the consumption of IoT systems. The longer they use IoT systems and thus sharing their data with companies, the more customised experience and value they co-create.

Within the value constellation, end-users are involved in the NPD process with various roles. Referring to the roles of customers (Agrawal & Rahman, 2015), three specific roles are identified across the case studies, including co-designers to design the system integrating their knowledge, co-ideators to generate ideas, and co-testers to test the IoT system. As co-designers, end-users share their knowledge in a context specific domain. As co-ideators, end-users are often invited to workshops, competitions, and conversations to offer their creativity. They also contribute to value creation as co-testers, being involved in testing new offerings that are then used to further enhance and upgrade subsequent features.

As the users' contributions towards value creation is critically increased, there are numerous challenges to be managed. Users, as co-designers, generally struggle to articulate their requirements, often impossible, contradictory or are poorly defined in scope [see the section 5.5.1 Difficulties to identify Users' Requirement and Obtain Feedback on IoT system in Chapter 5]. A small number of users samples leads to the user data being of limited quality, which does not represent the entire target market. It results in biased decision-making outcomes, critically affecting acceptability issues and system commercialisation. Creating value for IoT as co-ideators is not easy as they are unfamiliar with and have a limited understanding of IoT. As an entirely new technology with the convergence of the digital and the physical worlds, IoT creates values and services that can be ultimately unique depending on the various combinations of software, sensors, and machine learning algorithms that are embedded.

Continuous IoT development may restrict users' involvement in co-creation as co-testers. In the feasibility testing stages, in which the companies have not had the whole value constellation and connected other devices and services yet, the user feedback is highly likely limited. Companies strive to obtain sufficient insight into how the users interact with the system, which is impossible unless the system is fully developed. If the interaction does not work efficiently enough, it is challenging to explain to users the service scenarios and make them understand how the solution could work [see the section 5.5.1 Difficulties to identify Users' Requirement and Obtain Feedback on IoT system in Chapter 5]. Another concern is how to protect intellectual property when conducting user-test before launching the IoT system to the marketplace.

Delivering Service and Scaling Up

While providing invaluable information and additional add-on services that are continuously improved and adapted to customer needs, organisations gradually transform the business model into a service provider, generating recurring profit. The companies could increase customer loyalty

(Saarijärvi et al., 2013), build close relationships with the existing customers (Rymaszewska et al., 2017), and expand the target customer base. It is one of the significant differences in value creation between the traditional and digital economies. In the traditional economy, a firm embeds value in the operand resource (goods), a primary unit of exchange (T. N. Beckman, 1957). As several scholars defined IoT as an extension of the internet (Bradley et al., 2013; Gershenfeld et al., 2004; IEEE, 2014), products have continuous connections to the internet and are better considered as services.

Cybersecurity Issues in IoT Value Creation

Throughout the IoT NPD and value creation process, there are numerous concerns to maximise the satisfaction of services for users, such as trust, security, privacy, adoption and acceptability around data and IoT systems. These issues have been addressed extensively as the barriers of IoT value creation in many studies for over a decade (Mashal et al., 2015). Firstly, there is a tension between security and usability which requires a significant amount of effort, cost, and expertise from day one of NPD. Regarding data privacy, companies should consider users' willingness to share their private data and the level of privacy as each user's privacy standard is varied. A frequent security patch release ensures system security, but it is challenging to have the users update the IoT device as it is often a constrained one. Trustworthiness of the system, data accuracy, availability and reliability affect the adoption and commercialisation of the overall system. If the target customers of the IoT system are entrenched practitioners, market penetration may be more challenging as it requires the users to adopt new practices and subsequent behavioural changes. The system must be designed to be accessible and user friendly for delivering the right amount and types of real-time data and front-end service offerings to customers.

6.3 The Role of Design

Although the theme of design has gained substantial attention in the industry and academic arenas as a source of innovation, only limited design interventions are observed in IoT development. Because the featured case companies, most of whom are SMEs except SPHERE project, have financial constraints, one of the well-recognised development risks for the start-ups. Consequently, they prioritise hiring quality engineers to build the IoT architecture effectively instead of hiring designers—whether internally or externally—to build desirable IoT systems. It then becomes a barrier to answering the research question on the role of design (RQ 3) (section 3.3.5 Main study design and setting in Chapter 3).

Despite this challenging situation, designers in IoT development contribute mainly to styling and partially to process (Figure 66). Styling is considered as explicit design activities that are mainly focused on the third phase of NPD; designing, prototyping, and testing the product. In contrast, the role of design as process is understood more as implicit design activities. Thus, the first and second phases are often conducted by non-designers. Non-designers are well aware of these implicit design activities at the process and strategic level and try to apply design thinking approaches to IoT businesses. For instance, they understand some of the main practices of design thinking such as understanding users at an early stage (Brown, 2008; Michlewski, 2008; Dell'Era et al., 2018), interdisciplinary collaboration (Brown, 2008; Dunne & Martin, 2006; Luchs et al., 2016), and failing often and soon Boland & Collopy, 2004; Brown, 2008; Drews, 2009).

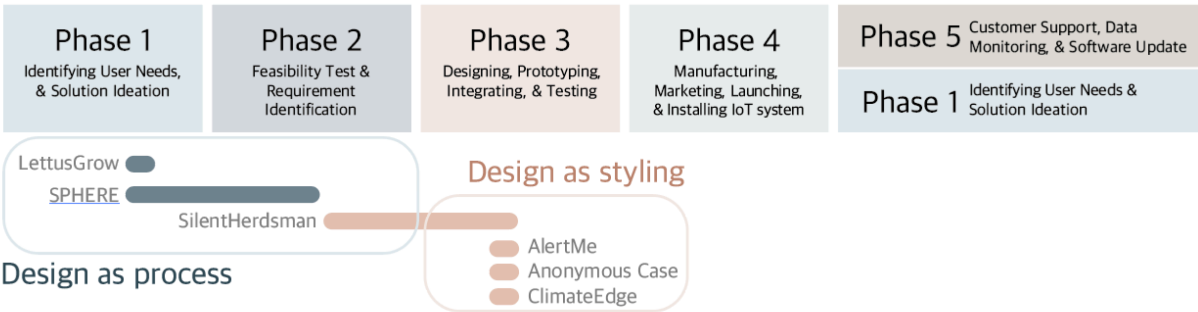


Figure 66 Design intervention in IoT NPD process

AlertMe had a couple of design subcontractors who improved the product and package designs more user-centred way. Although the ClimateEdge is the only case having an industrial designer internally at the point of data collection, design is limited to form-giving. With initial competency in software development, the anonymous case employed an external partner for product design and manufacturing. The other half utilises design as a process for and approach towards identifying user needs and solution ideation. SPHERE is another case with internal design capability, a design researcher involved in IoT development at the early stages of NPD. A mix of qualitative research methods were utilised to identify users' needs and test feasibility and acceptability, including ethnographic studies, interviews, and workshops. In the SilentHerdsman case, a software development consultancy was involved in the early phases to improve the system's usability through the low fidelity paper prototypes and test the service and UI of the IoT system. LettusGrow worked with a design consultancy to refine the value proposition through a government funded program. The design experts were encouraged to utilise the co-design approach and reconfigured the NPD process rigorously.

Compared to the increasing efforts in recent literature on novel design approaches to the critical challenges in IoT development, including more-than human-centred design (Coulton & Lindley, 2019), data-enabled design (King et al., 2017; Speed & Oberlander, 2016), and design for ethical and trust issues (Bhattacharya et al., 2017), the design application in IoT development remains in its traditional practice and application. The design capability is not utilised to its full extent, with a relatively more significant focus on hardware or software domains but on data and algorithms development. However, as product and service development and value creation become more data-driven (Kubler et al., 2015; Tao et al., 2018; Feng et al., 2020), design must be prepared to become better equipped to support data-driven innovation. In order to identify design implication for data-driven innovation, figure 64 (Data-driven value creation alongside data science process) is adapted and remapped depending on the design intervention and innovation level (Figure 67).

The left column is where incremental innovation opportunities can be created, commonly observed in the study. The companies provide insights to the customers or create customised products and services (Hagen et al., 2013; Schroeck et al., 2012; Petter and Peppart, 2012; Porter and Heppleman, 2014), and refine the algorithms and improve the accuracy of the predictions which is more related to data-science practice (Porter and Heppelman, 2014). Moreover, companies can utilise data to identify new business/user needs (Hartmann et al., 2016; Chin et al., 2017; Porter and Heppelman, 2014) or combine different datasets (Kubbler et al., 2015). These two areas on the right column of radical innovation are identified as the most challenging for the companies in this PhD study.

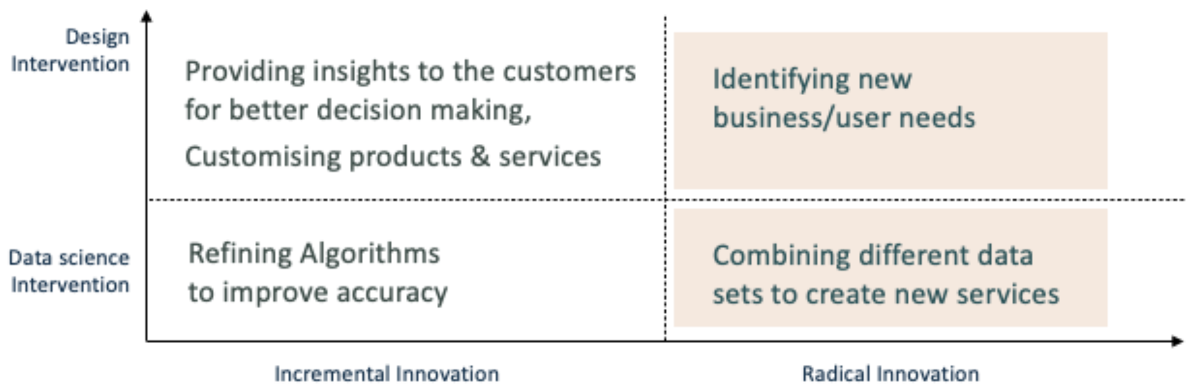


Figure 67 Data-driven innovation and design intervention

The author would recommend that design as a discipline should focus on two areas in radical innovation which are to identify new business/user needs and combine different data sets to create new services. Design methodologies and approaches should be adapted throughout the data-science process with a considerable emphasis on the adaptations of qualitative design tools in a way to support making sense out of the vast dataset. Also, although not many explicit design roles in different design disciplines are not observed through the case studies, the strategic design approaches seem to be mandatory in combining different datasets and interpreting insights into the IoT solutions across all the different touchpoints coherently. To do so, the author argues that in IoT development, the designers must hone their skills of 'making sense of things' alongside having technical knowledge, fostering moral recognition.

6.4 Validating the Mobius Strip Model of IoT NPD Process

Although it was challenging to recruit the right expert for validating the IoT NPD process due to the complexity of the IoT development and value creation, eight experts in academia and industry have participated in validating the Mobius Strip Model of IoT NPD. Each reviewer gave valuable and constructive comments from different perspectives. Most of the reviewers generally agreed with the Mobius Strip model of the IoT NPD process, whilst some experts suggested their complementary perspective on the finding. In particular, the reviewers described how the Mobius strip model is suitable for explaining the complex NPD process of the IoT and capturing some peculiarities of the IoT NPD process. For example, the conceptual model consists of iterative hardware, software, and data/algorithm processes and reflects the different clock speed and approaches that is critical in IoT development.

Regarding the author's concerns over the generalisability of the model, there were varied responses. In particular, an academic respondent from an engineering school advised that the model is detailed and appropriate, whereas another reviewer from a business school advised that the model is very generic. The other reviewer commented that the model is not generalisable as it only reflects the case of companies that do not include information technology providers. The Mobius Strip Model can be further developed with the appropriate degree of a more generic or specific NPD process.

Two reviewers disagreed that the data and algorithms-centred development cycle is slow, as data and algorithms development is categorised as software development. They argued that the development speed of this cycle is different for each case. As the limited number of cases were recognised as one of the limitations of this PhD study, the development speed of data and algorithms centred IoT NPD should be revisited and complemented by investigating more cases in the future.

In terms of missing insight, one reviewer supplemented that the challenges of getting beyond the first cycle of IoT development should be stressed, as it will not be realised without a critical mass of IoT deployments. One of the critical opinions found in the experts' reviews was that the reviewers were curious about how the model could help overcome the challenges and tensions created by the different 'clock speeds' and how the hardware, software, and algorithms developments can be managed synergically. Further constructive research questions were raised, for example, 'if the model can be used for system design where multiple IoT products interact to create a system'. The critical questions will be addressed in the continuation of this PhD study.

6.5 Chapter Summary

In this chapter, the two main findings of the case studies are presented: A conceptual model of IoT NPD process alongside the attributes of NPD processes, and the role of design for value creation were discussed and compared to existing literature. Furthermore, the research findings mainly around the Mobius strip model of IoT NPD have been reviewed by the academic and industry experts. The challenges, and tensions against value proposition creation were raised of which the four factors were identified as: 1) the complexity of IoT architecture, 2) the novelty of IoT systems, 3) the non-maturity of the IoT market, and 4) the general issue of time and cost constraints. The five attributes of IoT NPD process and value creation activities are critically discussed and situated within existing theories, such as value co-creation, SDL (service-dominant logic), value space framework, data-based value creation and several attendant factors. Then they were thoroughly reflected in the model development.

The Mobius Strip Model is developed which is an initial approach to comprehend the complicated IoT development process, value creation activities and numerous challenges associated with it. The model encompassing three cycles of continuous NPD process demonstrate that each cycle has distinctive attributes and critical emphasis on development and value creation activities: hardware, software, and data. To enhance the understanding of the model, how challenges hinder IoT development and value creation is further supplemented. Through the value creation and NPD processes, companies attempt to make sense of things comprehending IoT not only as physical things in appearance, but also in larger network ecologies.

Through the discussion, three different trajectories of value creation are identified: first, hardware and software centred value creation which has a critical focus on the interconnectivity of devices and services; second, diversifying services through machine learning technologies; and lastly, scaling up IoT application domains and refining IoT systems. Service-Dominant Logic can explain IoT value creation as the fundamental theory; emerging theories, such as the value space framework and data as critical resources for value creation, are helpful to comprehend IoT value creation. Over the NPD process, companies struggle with the extra layers of development complexity resulted from integration of IoT hardware-related features into software-based development and data science. If the complexity is managed accordingly, organisations would fully unlock value of IoT by selling physical products, customised services, and harnessing data produced.

Finally, how design intervenes for value creation over the IoT NPD process was discussed in relation to the three-level of design identified based on literature. Although the companies recognise the significance of co-creation and user-centred development and attempted to apply them across NPD practices, project leaders with engineering backgrounds mainly lead developmental activities. In essence, design contributions are limited to industrial design, interaction design, or identifying user needs. Design is not utilised and managed coherently at a system integration level but sporadically in the context of IoT development. Several attributes, including delivering a coherent customer experience through connected devices, enhancing customers satisfaction based on data, and continuous design process, imply that the business may leverage the ability of strategic design.

The experts assessed the validity of the IoT NPD practice and process and provided different opinions on the author's insights regarding the conceptual model. As a result, the attributes of the IoT NPD and the conceptual model were validated. Although most of the experts agreed that the conceptual model captures the attributes of the NPD processes relevant to IoT solutions, there were various comments on the generalisability of the model. Therefore, the necessity to better conceptualise the NPD process with the appropriate degree of genericity or specificity was highlighted. A couple of questions addressed by the experts could be investigated as the continuation of this PhD study.

CHAPTER 07

Conclusions, Limitations, and Future Research Opportunities

7. Conclusions, Limitations, and Future Research Opportunities

7.1 Introduction

Innovation is widely accepted as one of the critical contributors to competitive advantage. As the NPD model visualises the innovation process for firms, scholars claimed that having structured NPD processes and managing NPD is critical in bringing opportunities for organisational prosperity (Margaret. Bruce & Cooper, 2001)(Goffin & Koners, 2011). The importance of NPD created the foundation for this PhD research, which set out to investigate the IoT system development processes and design roles that create value propositions for organisations. Through a comprehensive literature review covering interdisciplinary subjects from economics, business, engineering, information systems, innovation, and design studies, a theoretical foundation of value creation activities, a NPD process and practice and design roles were developed. The primary research involved exploratory case studies on six IoT development projects. The process, characteristics, and challenges of IoT development and value creation activities were identified through the case studies. Also, how design intervenes in the NPD process was explained.

The PhD study supports the structure of the novel IoT NPD model, Mobius Strip model. It helps to comprehend the key attributes and challenges of IoT NPD, and value creation activities. IoT development is an emergent process with complex practice, involving three different types of subject matter. This research confirmed that value of IoT system can be created through a hardware centred, a software centred, and a data and algorithms centred development which was reflected to a conceptual model. Moreover, design is not utilised to its full extent but limited as styling and a process within IoT development. Design as styling is mainly focused on sketching, prototyping, and testing the product or user interface of web and app, and design as a process is utilised to identify user needs and develop solution ideation. The final chapter reflects on the results of this study by summarising how they answered the research questions in section 7.2. It also discusses the contributions of this research to knowledge and practice in section 7.3. Then the chapter addresses the research limitations in section 7.4 and suggests future research directions in section 7.5.

7.2 Research Questions and Answers

This PhD research was undertaken to answer the main research question 'What are the conceptual IoT NPD process and the design roles which aim to create value propositions for organisations?'. To answer the research question, the three research objectives were established. This section briefly summarises where and how the research objectives were achieved.

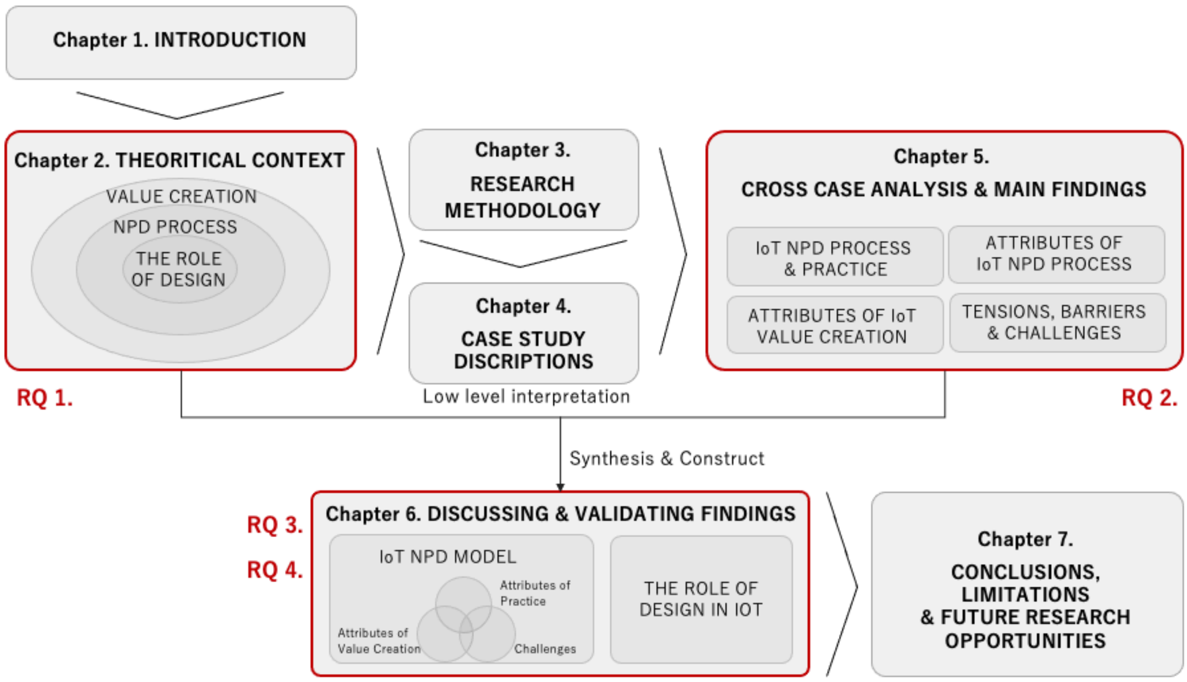


Figure 68 Where the research questions were answered

RQ 1. What are the existing and emerging theories on value creation, NPD process, and design roles in the organisational setting?

Through Chapter 2, existing and emerging theories on value creation, NPD processes, and the role of design in the organisational setting were investigated. First of all, existing theories on value creation discussed by economics, marketing, and management scholars can be explained through Goods-Dominant Logic and Service-Dominant Logic (Vargo & Lusch, 2008). G-D Logic is a worldview characterised by 'value-in exchange', 'a firm-centric approach', 'a linear-view of value creation', 'a customer as a destroyer of value'. On the contrary, S-D Logic is an alternative worldview of G-D Logic through which value is created while being used through a value constellation in which customers are involved as co-creators of value. Recently, several scholars contribute to the emerging theories on IoT value creation, arguing the distinctive perspectives of it. Mejtoft (2011) proposes a conceptual model on value creation considering the concept of the IoT. Rymaszewska et al. (2017) argue as to how IoT expands the scope of companies value creation beyond traditional manufacturing; Henfridsson et al. (2018) propose a framework that explain the digital components as non-human factors can play a significant role as value creation actors. Mazhelis et al. (2012) and Aivalioti et al. (2018) suggest that IoT ecosystem is specific type of it with a mixture of co-creation and coopetition. Whilst supporting the S-D logic where value is created within a value constellation, they argue that the potential value of IoT arises from the interplay and identify the different value co-creation roles into three categories. the new terminology of Data-Dominant Logic is introduced by Kugler (2020) with the necessity of a new type of dominant logic to explain more appropriately the situations for firms that deal with data and data science-driven practices. The concept of Data-Dominant Logic could be a foundation for the empirical knowledge of IoT value creation.

Through a thorough comparison amongst different development processes and NPD models, wide variety types of new product, service, and software development processes are identified within the literature. Over 600 diverse NPD models, this PhD study focused on discussing the existing activity-based NPD models due to the limitations of the chapter. Whether it is NPD, SDLC, NSD, and PSS, existing and emerging models can be categorised into the four NPD approaches:

1. Sequential: Booz, Allen and Hamilton's BAH model (Booz et al., 1982); Walsh's over the wall process (Walsh et al., 1992); Robert Cooper's stage gate model (R. G. Cooper, 1990); Herbert Benington's SDLC model (Herbert Benington, 1956); Royce's Waterfall Process (Royce, 1970); Birrell and Ould's b-model (Birrel and Ould, 1985); V-shape life cycle (Forsberg & Mooz, 1991); Sashimi model (Mcconnel, 1996); Ramaswamy's service design and management model (Ramaswamy, 1996).
2. Concurrent: Parallel processing models (Takeuchi & Nonaka, 1986); Activity-stage models (Crawford, 1997); Concurrent Engineering (Pennell et al., 1989).
3. Spiral: Boehm's spiral life-cycle model (Boehm, 1986); Unger and Eppinger's Spiral model (Unger and Eppinger, 2009); Microsoft Solutions Framework (Microsoft Team, 2003); Johnson's New Service Development Process (2000); Lin and Hsieh's Stage-Activity Framework of a NSD (F.-R. Lin & Hsieh, 2011).
4. Agile: Agile development method (R. C. Martin, 2002); Scrum software development process (Schwaber & Beedle, 2002); Lean Development (Poppendieck & Poppendieck, 2003).

There are also emerging theories and models which could be relevant to IoT development process, for example: technical service design processes (Aurich et al., 2006); product-service development methodology (Marques et al., 2013); PSS design model (Maussang et al., 2009); Systems of hardware and software (Department of Defense, 1988); IoT development process (Jacobs & Cooper, 2018); 8-

shape model (Janne and Bogers, 2019); Cyber physical system development process (Hartsell et al., 2020).

Existing NPD models have been continuously evolving, supported by emergent trends of increasing significance of NPD activities which are closely related to the key attributes of value creation. For example, balancing between the structured review and flexible iterations was a critical attribute. The shift to more iterative, rapid, and lightweight processes with agility became a dominant trend over time. Alongside inter-company interactions, external network interactions were also emphasised to reduce uncertainty. With the blurring boundaries of digital and physical products, the hybrid of hardware, software and service development approaches have emerged, and manufacturing and service activities are becoming progressively interwoven.

Lastly, design's existing and emerging role within an organisational context was discussed. Literature on design contributions to value creation presents three levels of design contributions within the NPD process: Design as Styling, Design as a process, and Design as Strategy (Kretzschmar, 2003; Buchanan, 2001; Perks et al, 2005). In terms of different design levels, different roles of designers are required in value creation. For design as styling, designers' contributions are limited to the marginal part. Regarding design as process, various theories are developed including Co-creation (Sanders & Stappers, 2008), co-design (Sanders & Stappers, 2008), and participatory design approaches (Schuler & Namioka, 1993). There are scholarly works on design as strategy from management and design such as design thinking (Brown, 2008), design-led innovation (Verganti, 2008). Extensive research highlights the need of the strategic level of design to innovate and to address users' needs (Chen & Venkatesh, 2013); to reinvent business models and NPD processes (Gruber et al., 2015); and to offer unique insights to strategy formation and implementation (Best et al., 2010). Furthermore, Perks et al. (2005) elaborate on the actions and associated skills of each designer role undertaken in the phases of the Stage-Gate process.

Lately, several research on design roles and practices related to IoT development are increased as developing the IoT was a significant challenge for designers due to its constant connection to the internet, cybersecurity challenges, and data as a novel material. From HCI and Information systems, scholars see designers may create novel products by decoupling form from function and media from content in IoT development (Yoo, 2010; Gibson, 1977; Norman, 1988; Tilsonet et al., 2010; Jonssonet et al., 2009). Coulton et al. (2018) argue more than human-centred design as an appropriate approach to IoT design that designers consider invisible elements where the system works with minimum human interaction. Scholars from architecture, HCI, and design informatics identify the typologies of Data-centric design (King et al., 2017; Speed and Oberlander, 2016; Churchill and Tan, 2017). Being aware of the cyber security challenges around the IoT, scholars stressed design role as building trustworthy system (Harte et al., 2014; M. C. Lin et al., 2011).

RQ 2. How is an IoT system developed with the aim of creating value propositions for organisations?

Through conducting six qualitative case studies from various sectors, including healthcare, smart home, drain maintenance, dairy, vertical farming, and tropical farming the way of businesses creating value and developing IoT systems is identified (Chapter 5). The five phases of the IoT NPD process were identified which seemed similar to the traditional NPD process, but the subsequent cycles of the IoT NPD process were diversified into three different scenarios: first, developing new IoT devices; second, scaling up the system and developing new software; and third, developing and embedding new algorithms. Also, distinctive attributes of NPD process were identified as follows:

1. Consisting of three distinctive NPD scenarios, a hardware centred, software centred, and data and algorithms centred IoT NPD
2. The continuous and emergent process
3. Involving three different types of subject matter, hardware, software, and data/algorithms development
4. Distinctive characteristics of each subject matter impact development speed and approaches
5. The temporal division between development and usage being condensed

In terms of value creation strategies, the value was created through delivering service and scaling up, with a critical focus on the concept of value co-creation. Users' contributions to value creation were critical in IoT development, but the reconciliation of technology push and market pull strategies was identified. As data was considered a Resource for value creation, companies attempted to exploit data in various ways, including: feeding insights back to the customers; identifying novel value propositions and improving IoT systems; integrating different datasets for discovering new services; selling data to other actors; and improving business process efficiency.

While creating preferable value propositions, several challenges were identified. The challenges were multi-fold and interrelated to each other, including complications in perceiving the real value that IoT may bring, the non-maturity of the IoT industry, and the novel concept of IoT. The complex and multi-faceted nature of IoT technology increased development risks. For example, difficulties in developing technical architecture, including costly and lengthy machine learning technology, integrating systems, identifying user requirements, managing supply chain, commercialisation and installation, and lacking internal expertise. The prerequisites for IoT value creation caused obstacles, such as value co-creation, business transformation to service, scaling up the IoT system, continuous design activities, and value creation through big data. Specifically, numerous issues were identified around data, including trustworthiness, security, and privacy of data and IoT system, which may affect the adoption, acceptability, commercialisation of IoT systems.

RQ 3. How does design contribute to IoT development and value creation?

The findings on the role of design in IoT development was limited as there were few designers involved in the projects at the point of data collection (section 3.3.5 Main study design and setting in Chapter 3). Despite the challenging situation, two design roles were identified, design as styling and design as process. As design contributions were limited to industrial design, interaction design, or identifying user needs, it was not utilised and managed coherently from the strategic design perspective. Whilst the explicit design activities were conducted by designers, non-designers understood and tried to adopt implicit design activities such as design thinking. Moreover, to take advantage of big data as business assets, the author recommends that design emphasise two possible data-driven innovations: identifying new business/user needs and combining different data sets to create new services.

RQ 4. What is the conceptual model of IoT NPD practice and process reflecting value creation strategies and challenges?

Based on the findings from RO 1 and RO 2, associated insights were derived: a conceptual IoT NPD process, so called 'Mobius Strip Model' and design interventions within IoT NPD process (Chapter 6). The Mobius Strip Model implied three infinite loops of value creation and NPD activities each of which were hardware centred, software centred, and data & algorithms centred IoT NPD. The hardware centred NPD cycle was hardware centred development which had stricter review gates compared to other two software centred and data/algorithms centred development cycles. The software centred NPD cycle was software centred development of which activities were flexible, efficient, and effective without major modification to the IoT system. The data and algorithms centred IoT NPD was data and algorithms centred development, which was slow and time-consuming, reflecting the challenges of the data science process. The IoT NPD process involved three different types of subject matter, hardware, software, and data/algorithms development. Service-Dominant Logic is applied as the fundamental theory that can explain IoT value creation, including delivering service and scaling up, value co-creation, and user-driven development. However, emerging theories, such as Data-Dominant Logic, the value space framework, and data as critical resource for value creation, complement to comprehend IoT value creation.

7.3 Contribution to Knowledge

The contribution of this research work is discussed with respect to the state-of-the-art in the area of IoT development for businesses. By developing a conceptual model, the distinctive attributes of IoT design are explored, which will contribute to a body of research into information systems, innovation management, and design. More specifically, this thesis presents the following contributions:

- This research has proposed generalised phases and attributes of the NPD process through a comprehensive literature review on various NPD models from engineering, software engineering, service marketing, design and innovation studies. It provides an integrative understanding of the characteristics of existing NPD processes across disciplines and their relevance to IoT product and service development activities.
- The proposed conceptual model of IoT NPD, 'The Mobius Strip Model, ' contributes to NPD studies by encompassing the data science process within the process and reflecting various factors that affect designing digitised products. While combining interdisciplinary knowledge within the process provides the foundation upon which other knowledge can be constructed, including business models, development risks, innovation, and product management studies.
- Through explorative case study methodology, the nature of IoT development and value creation could be critically interrogated and thus contributed to new knowledge: how data is integrated into the IoT NPD process and utilised for value creation; what development challenges against IoT value creation do companies face; and how various actors involved in the value co-creation process.
- This PhD study also has proposed several design implications. For example, a knowledge gap exists between industrial and academic arenas regarding understanding design as a source of innovation. Whether product design or interaction design, design contributions towards IoT development are limited at the level of form giving or process. Also, considering vulnerable development risks within continuous IoT development, the need to leverage strategic design is claimed.
- The businesses in the IoT industry and design practitioners would benefit from this study. Firstly, businesses that develop IoT products and services and stakeholders involved in IoT value constellation could comprehend the value creation, development process, and various

challenges in IoT development. They will utilise different approaches and strategies appropriate for each phase and cycle of the IoT NPD process. Second, the conventional role of design for value creation is reframed in connected artefacts development. The possible design contributions are identified to overcome development risks, thus increase IoT value.

7.4 The Research Limitations

Acknowledging a study's limitations is critical for two reasons. First, it provides an opportunity to critically consider further research opportunities and areas of improvement. Second, it serves a significant role to critically appraise the overall research process. This PhD research has three limitations, which are listed below.

- The sample size and composition: The total number of cases and interviews undertaken was six and seven, respectively. Although IoT has been the hyped for a while, it was challenging to recruit IoT cases that successfully launched the system and realised value through subsequent NPD cycles due to the immature IoT industry. As a result, the cases were not equally spread between different IoT sectors nor focused on one sector. This sample was relatively small, geographically limited to the UK, and may not be representative of IoT development, value creation and design roles. Also, the epoch of the six IoT development cases are focused on from 2003 to 2020 (at the point of the research). Consequently, the findings may be limited to its temporal boundaries.
- The lack of multi-sided aspects of value creation: Although the IoT development project is the analysis unit for the case studies, which normally would include the multiple perspectives of value creation, the findings here have limitations in investigating the organic interactions among all stakeholders. This is because some of the case studies started and finished before a period where wider value analysis could be obtained. Also, it was realistically impossible to undertake this within the time frame of the PhD study, and therefore the author critically selected the informants who drive the project and make strategic decisions. Thus, the multi-sided aspects of value creation could be considered for future research.
- Lack of available data: Whilst gaining tacit insights about design contributions over NPD processes, there were a couple of challenges in data collection. Firstly, half of the IoT systems were developed in early 2000. For that reason, some interviewees had difficulty recalling all the details of development practices at the moment of data collection. Also, confidentiality

about highly reliable data was another concern as this research is about reliable high-level data such as NPD practices and value creation activities. Some participants were also reluctant to speak about the projects' details and denied sharing data about the external design experts. Alongside limited access to available data and confidentiality, the limited design resources in IoT businesses also challenged data collection in design roles.

- Limited validation of the research findings: The research employed a qualitative case study methodology, which enables critical understanding of IoT NPD process and practices. Although the expert audit review was designed to overcome the limitations and validate the conceptual model, the challenge for the validation still remains as there are a few experts in the IoT NPD process.

Although the limitations concerning the methodology have been identified, the strength of this study should be considered. The strength of this study was that the author had structured an in-depth and broad understanding of various aspects of IoT development. This study has also identified the gap of understanding and utilising design between academia and industry. Consequently, this research offers a foundation for other researchers to build upon additional research dedicated to the IoT NPD and design roles for value creations. The limitations of this research naturally lead to future research opportunities, which is described in the next section.

7.5 Future Research Opportunities

Within the journey of undertaking this PhD research, the need for further research has been recognised. Time and geographic constraints, the interdisciplinary nature of the research subject and the nature of doctoral study affect the possibility of further research, which are listed below:

- Exploration and validating the conceptual process would provide further valuable insight into the concrete IoT model development. Further validation of the conceptual model could be conducted through survey research, which would potentially provide a broad sample that could increase input from a variety of NPD and address this study's geographic and sector bias. It would enable to increase the generalisability and applicability of the model to the broader context.
- This research has identified the limited level of design utilised for value creation within the NPD process. However, as the small sample size restricted the findings, further research on the design practice to resolve the distinctive IoT development challenges can be conducted.

IoT, as the hybrid of tangible and intangible products and services, emerging practices can be mapped according to different design disciplines. Mapping each order of design interventions in IoT development over the Mobius Strip model could be another research agenda.

- Due to the lack of prior research studies on design contributions to IoT value creation specifically related to data process, new knowledge can be constructed through the comparative study on emerging design approaches and tools for data-driven value creation across industry and academia. This would provide an extensive understanding of the state-of-the-art in design knowledge and practices.

This section has discussed an agenda for future research resulting from this research. The above-listed agenda for future research ultimately aims to broaden design management studies and attract new attention to design studies in the digital economy. Three potential areas were identified: survey research to further validate the conceptual IoT NPD process, the investigation into designer's approaches to IoT development risks within the IoT NPD process, and exploration of design tools in data-driven value creation. The following section will provide a chapter summary and concluding remarks to the body of research in this thesis.

REFERENCES

Aagaard, A. (2018). *Digital Business Models – Driving Transforming and Innovation*. Palgrave Macmillan Ltd.

Aagaard, A., Presser, M., & Beliatis, M. (2018). A Tool for Internet of Things Digital Business Model Innovation. In *IEEE Globecom Workshops*.

Agrawal, A. K., & Rahman, Z. (2015). Roles and Resource Contributions of Customers in Value Co-creation. *International Strategic Management Review*, 144–160.

Aivalioti, S., Yves., S., Schmitt, C., López, L., Monforte, D., Olszewski, A., … Patrick, Z. (2018). From Innovative Niches to a Cooperative IoT Ecosystem. In *Global Internet of Things Summit*.

Alaimo, C., Kallinikos, J., & Aaltonen, A. (2020). Data and Value. In S. Nambisan, K. J. Lyytinen, & Y. Yoo (Eds.), *Handbook of Digital Innovation* (1st Ed). Edward Elgar. Retrieved from https://www.researchgate.net/publication/343524358_Data_and_Value

Alam, I. (2006). Removing the fuzziness from the fuzzy front-end of service innovations through customer interactions. *Industrial Marketing Management*, *35*, 468–480.

Alam, I., & Perry, C. (2002). A customer-oriented new-service development process. *Journal of Services Marketing*, *16*(6), 515–534.

Alderson, W. (1957). *Marketing Behavior and Executive Action: A Functionalist Approach to Marketing Theory*. Homewood, IL: Richard D. Irwin.

Allee, V. (2000). RECONFIGURING THE VALUE NETWORK. *The Journal of Business Strategy*, *21*(4), 36–39.

Allen, C. W. (1990). *Simultaneous Engineering Integrating Manufacturing and Design*. (C. W. Allen, Ed.). Dearborn, Michigan: Society of Manufacturing Engineers.

Alonso-Rasgado, T., & Thompson, G. (2006). A rapid design process for total care product creation. *Journal of Engineering Design*, *17*(6), 509–531. https://doi.org/10.1080/09544820600750579

Alspaugh, S., Zokaei, N., Liu, A., Jin, C., & Hearst, M. A. (2018). Futzing and Moseying: Interviews with Professional Data Analysts on Exploration Practices. *IEEE Transaction on Visualisation and Computer Graphics*, *25*(1).

Andreassen, T. W., Kristensson, P., Lervik-Olsen, L., Parasuraman, A., McColl-Kennedy, J. R., Edvardsson, B., & Colurcio, M. (2016). Linking service design to value creation and service research. *Journal of Service Management*, *27*(1), 21–29. https://doi.org/10.1108/JOSM-04-2015-0123

Andrews, B. (1975). *Creative Product Development; A marketing approach to new product innovation and revitalisation*. London: Longman Group Limited.

Arbnor, I., & Bjerke, B. (1997). *Methodology for Creating Business Knowledge*. SAGE Publications.

Arthur, B. (2009). *The nature of technology: What it is and how it evolves*. Simon and Schuster.

Ashton, K. (2009). That "Internet of Things" Thing. *RFID Journal*. Retrieved from http://www.rfidjournal.com/article/print/4986

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*.

Aurich, J. C., Fuchs, C., & Wagenknecht, C. (2006). Life cycle oriented design of technical Product-Service Systems. *Journal of Cleaner Production*, *14*(17), 15.

Awwad, A., & Akroush, M. N. (2016). New product development performance success measures: an exploratory research. *EuroMed Journal of Business*, *11*(1), 2–29. https://doi.org/10.1108/EMJB-12-2014-0043

Babin, B. J., & James, K. W. (2010). A brief retrospective and introspective on value. *European Business Review*, *22*(5), 471–478. https://doi.org/10.1108/09555341011068895

Baker, L. M. (2006). Observation: A Complex Research Method. *Library Trends*, *55*(1), 171–189.

Balaji, S., & Murugaiyan, S. (2012). WATEERFALLVs V-MODEL Vs AGILE: A COMPARATIVE STUDY ON SDLC. *International Journal of Information Technology and Business Management*, *2*(1), 26–29. Retrieved from www.jitbm.com

Baldwin, C. Y., & Clark, K. B. (2000). *Design Rules: The Power of Modularity*. MIT Press.

Barrett, M., Davidson, E., Prabhu, J., & Vargo, S. L. (2015). SERVICE INNOVATION IN THE DIGITAL AGE: KEY CONTRIBUTIONS AND FUTURE DIRECTIONS. *MIS Quarterly*, *39*(1), 135–154.

Bassil, Y. (2012). A Simulation Model for the Waterfall Software Development Life Cycle. *International Journal of Engineering & Technology (IJET)*, *2*(5), 2049–3444. Retrieved from http://iet-journals.org/archive/2012/may_vol_2_no_5/255895133318216.pdf

Baumer, B. (2015). A Data Science Course for Undergraduates: Thinking with Data. *American Statistician*, *69*(4), 334–342.

Beck, K., Grenning, J., Martin, R. C., Beedle, M., Highsmith, J., Mellor, S., … Marick, B. (2001). Manifesto for Agile Software Development. Retrieved from http://agilemanifesto.org/

Beckman, S. L., & Barry, M. (2007). California Management Review Innovation as a Learning Process: Embedding Design Thinking. *California Management Review*, *50*(1).

Beckman, T. N. (1957). The Value Added Concept as a Measurement of Output. *Advanced Management*, *22*(April), 6–9.

Begel, A., & Nagappan, N. (2007). Usage and Perceptions of Agile Software Development in an Industrial Context: An Exploratory Study. In *First International Symposium on Empirical Software Engineering and Measurement* (pp. 255–264). Washington.

Bell, T. E., & Thayer, T. A. (1976). SOFTWARE REQUIREMENTS: ARE THEY REALLY A PROBLEM? In *The 2nd international conference on Software Engineering* (pp. 61–68). California.

Benington, H. (1956). Production of large computer programs. In *ONR Symposium on Advanced Programming Methods for Digital Computers* (pp. 15–27).

Berger, W. (2009). *How design can transform your life, and maybe even the world*. Penguin Press.

Berkhout, G., Hartmann, D., & Trott, P. (2010a). Connecting technological capabilities with market needs using a cyclic innovation model. *R&D Management*, *40*(5), 474–490. https://doi.org/10.1111/j.1467-9310.2010.00618.x

Berkhout, G., Hartmann, D., & Trott, P. (2010b). Connecting technological capabilities with market needs using a cyclic innovation model. *R&D Management*, *40*(5), 474–490. https://doi.org/10.1111/j.1467-9310.2010.00618.x

Bernard, H. R. (2002). *Research methods in anthropology: Qualitative and quantitative approaches* (3rd eds). Walnut Creek, CA: Alta Mira Press.

Bessant, J., & Maher, L. (2009). Developing radical service innovations in healthcare-the role of design methods. *International Journal of Innovation ManagementMa*, *13*(4), 555–568.

Best, K., Kootstra, G., & Murphy, D. (2010). Design Management and Business in Europe: A Closer Look. *Design Management Review*, *21*(2), 26–35.

https://doi.org/10.1111/j.1948-7169.2010.00062.x

Beverland, M. B. (2005). Crafting brand authenticity: The case of luxury wines. *Journal of Management Studies*, *42*(5), 1003–1029. https://doi.org/10.1111/j.1467-6486.2005.00530.x

Bhattacharya, S., Wainwright, D., & Whalley, J. (2017). Internet of Things (IoT) enabled assistive care services: Designing for value and trust. In *Procedia Computer Science* (Vol. 113, pp. 659–664). Elsevier B.V. https://doi.org/10.1016/j.procs.2017.08.333

Birrell, N. D., & Ould, M. A. (1985). *A Practical Handbook for Software Development*. London: Cambridge University Press.

Blaxter, L., Hughes, C., & Tight, M. (2010). *How to Research*. McGraw-Hill.

Blazevic, V., & Lievens, A. (2004). Learning during the new financial service innovation process - Antecedents and performance effects. *Journal of Business Research*, *57*(4), 374–391. https://doi.org/10.1016/S0148-2963(02)00272-2

Boehm, B. W. (1976). Software Engineering. *IEEE Transactions on Computers*, *25*(12), 1226–1241.

Boehm, B. W. (1986). A spiral model of software development and enhancement. *ACM SigSoft Software Engineering Notes*, *11*(4), 22–42. Retrieved from https://ieeexplore-ieee-org.ezproxy.lancs.ac.uk/stamp/stamp.jsp?tp=&arnumber=59

Boehm, B. W. (1995). Spiral model of software development and enhancement. *IEEE Engineering Management Review*, *23*(4), 69–81. https://doi.org/10.1145/12944.12948

Bohemia, E., & Harman, K. (2008). Globalization and Product Design Education: The Global Studio. *Design Management Journal*, *3*(2), 53–68. Retrieved from http://web.b.ebscohost.com.ezproxy.lancs.ac.uk/ehost/pdfviewer/pdfviewer?vid=1&sid=68ba521c-1801-4363-b71f-e9997adf4200%40sessionmgr103

Booz, E., Allen, J., & Hamilton, C. (1982). *NEw Product Management for the 1980s*. New York: Author.

Borja de Mozota, B. (2003). *Design Management: Using Design to Build Brand Value and Corporate Innovation*. New York: Design Management Institute and Allworth Press.

Boudreau, K. (2010). Open platform strategies and innovation: Granting access vs. devolving control. *Management Science*, *56*(10), 1849–1872. https://doi.org/10.1287/mnsc.1100.1215

Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method. *Qualitative*

Research Journal, *9*(2), 27–40. https://doi.org/10.3316/QRJ0902027

Bowen, K. H., Clark, K. B., Holloway, C. A., & Wheelwright, S. C. (1994). Developing Project: The Engine of Renewal. *Harvard Business Review*, 110–120. Retrieved from https://hbr.org/1994/09/development-projects-the-engine-of-renewal

Boyd, D., & Crawford, K. (2012). CRITICAL QUESTIONS FOR BIG DATA. *Information, Communication and Society*, *15*(5), 662–679. https://doi.org/10.1080/1369118X.2012.678878

Bradley, J., Barbier, J., & Handler, D. (2013). Embracing the Internet of Everything To Capture Your Share of $14.4 Trillion. *Cisco*, 1–18. Retrieved from https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoE_Economy.pdf

Braham, J. (1992). The Wizards of Industrial Design. *Machine Design*, *64*(23), 37–41.

Brannen, J. (1992). *Mixed methods: qualitative and quantitative research*. Aldershot, England: Avebury.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, (3), 77–101.

Breivold, H. P., & Rizvanovic, L. (2018). Business Modeling and Design in the Internet-of-things Context. In *International Conference on Cloud Computing* (pp. 524–532).

Brown, S. L., & Eisenhardt, K. M. (1995). Product Development: Past Research, Present Findings, and Future Directions. *The Academy of Management Review*, *20*(2), 343–378.

Brown, T. (2008). Design Thinking. *Harvard Business Review*, *86*(6), 84–92.

Bruce, Margaret., & Cooper, R. (2001). *Creative Product Design: A Practical Guide to Requirements Capture Management*. London, England.: John Wiley & Sons, Ltd. Retrieved from https://www.wiley.com/en-us/Creative+Product+Design%3A+A+Practical+Guide+to+Requirements+Capture+Management-p-9780471987208

Bruce, Margeret, & Bessant, J. (2002). *Design in Business: Strategic Innovation Through Design*. Financial Times/Prentice Hall.

Bryman, A. (2004). *Social research methods* (2nd eds). New York: Oxford University Press.

Bryman, A., & Bell, T. E. (2011). *Business Research Methods* (3rd eds). Oxford University Press.

Brynjolfsson, E., & McAfee, A. (2014). *The Second Machine Age: Work, Progress, and*

Prosperity in a Time of Briliant Technologies. W.W. Norton & Company.

Buchanan, R. (2001). Design Research and the New Learning. *Design Issues*, *17*(4), 3–23.

Buckingham, D. (2009). "Creative" visual methods in media research: Possibilities, problems and proposals. *Media Culture & Society*, *31*(4), 633–652.

Bucolo, S., & Matthews, J. (2010). USING A DESIGN LED DISRUPTIVE INNOVATION APPROACH TO DEVELOP NEW SERVICES: PRACTICING INNOVATION IN TIMES OF DISCONTINUITY. In *The 11th International CINet Conference* (pp. 176–187).

Burkitt, F. (2014). A Strategist's Guide to the Internet of Things. *Strategy+Business Magazine*.

Burmeister, E., & Aitken, L. M. (2012). Sample size: How many is enough? *Australian Critical Care*, *25*(4), 271–274.

Caputo, M., Lamberti, E., Cammarano, A., & Michelino, F. (2016). Exploring the impact of open innovation on firm performances. *Management Decision*, *54*(7), 1788–1812. https://doi.org/10.1108/MD-02-2015-0052

Cassina, J., Taisch, M., Potter, D., & Parlikad, A. K. (2008). Development of PROMISE Architecture and PDKM Semantic Object Model. In *IEEE International Technology Management Conference (ICE)*.

Cavanillas, J. M., Curry, E., & Wahlster, W. (2016). *New Horizons for a Data-Driven Economy: A Roadmap for Usage and Exploitation of Big Data in Europe*. Cham, Switzerland: Springer International Publishing.

Cavaye, A. L. M. (1995). User participation in system development revisited. *Information and Management*, *28*(5), 311–323. https://doi.org/10.1016/0378-7206(94)00053-L

CEBR. (2012). *Data Equity – Unlocking the Value of Big Data*. London, England.

Cecilia, M., Baranauskas, C., & Bonacin, R. (2008). Design: Indicating through Signs. *Design Issues*, *24*(3), 30–45. Retrieved from http://archives.nd.edu/latgramm.htm.

Centerholt, V., Kjidderö, F., Saarikko, T., & Grahn, S. (2020). Value Chains vs. Ecosystems: Current Perspectives Among Swedish SMEs Entering the Interconnected World of IoT. In *SPS2020*.

Chatterji, A. K., & Fabrizio, K. R. (2014). Using users: When does external knowledge enhance corporate product innovation? *Strategic Management Journal*, *35*(10), 1427–1445. https://doi.org/10.1002/smj.2168

Chen, S., & Venkatesh, A. (2013). An investigation of how design-oriented organisations implement design thinking. *Journal of Marketing Management*, *29*(15–16), 1680–1700. https://doi.org/10.1080/0267257X.2013.800898

Chesbrough, W. H. (2004). Open Innovation: Renewing Growth from Industrial R&D. In *10th Annaul Innovation Convergence*. Minneapolis.

Chetty, S. (1996). The Case Study Method for Research in Small-and Medium-Sized Firms. *International Small Business Journal: Researching Entrepreneurship*, *15*(1), 73–85. https://doi.org/10.1177/0266242696151005

Chin, J. K., Hagstroem, M., Libarikian, A., & Rifai, K. (2017, July). Advanced analytics: Nine insights from the C-suite. *Mckinsey Analytics*.

Chiva, R., & Alegre, J. (2007). Linking design management skills and design function organization: An empirical study of Spanish and Italian ceramic tile producers. *Technovation*, *27*(10), 616–627. https://doi.org/10.1016/j.technovation.2007.05.015

Christensen, C. M., & Raynor, M. E. (2003). The innovator's solution: creating and sustaining successful growth. *Research-Technology Management*, *46*, 61–61.

Churchill, E. F. (2012). From Data Divination to Data-Aware Design. *Interactions*, *19*(5), 10–13. https://doi.org/10.1145/2334184.2334188

Cisco. (2017). The Journey to IoT Value: Challenges, Breakthroughs, and Best Practices. *Cisco*.

Clark, K., & Fujimoto, T. (1991). *Product Development Performance: Strategy, Organisation, and Management in the World Auto Industry*. Boston, MA: Harvard Business School Press.

Collis, J., & Hussey, R. (2003). *Business Research*. Palgrave Macmilan.

Cooper, R. G. (1990). Stage-gate systems: A new tool for managing new products. *Business Horizons*, *33*(3), 44–54. https://doi.org/10.1016/0007-6813(90)90040-I

Cooper, R. G. (1994). Third Generation New Product Processes. *Journal of Product Innovation Management*, *11*, 3–14.

Cooper, R. G. (2014). "What's Next After Stage-Gate?" *Research Technology Management*, *57*(1), 20–31. https://doi.org/10.5437/08956308X5606963

Cooper, R. G. (2017). We've Come a Long Way Baby. *Journal of Product Innovation Management*, *34*(3), 387–391. https://doi.org/10.1111/jpim.12372

Cooper, R., & Kleinschmidt, E. J. (1993). Major New Products: What Distinguishes the Winners in the Chemical Industry? *Article in Journal of Product Innovation*

Management, *10*(2), 90–111. https://doi.org/10.1016/0737-6782(93)90002-8

Copeland, A. J., & Agosto, D. E. (2012). Diagrams and Relational Maps: The Use of Graphic Elicitation Techniques with Interviewing for Data Collection, Analysis, and Display. *International Journal of Qualitative Methods*, *11*(5), 513–533.

Corley, K. G., Gioia, D. A., Johnson Graduate School, B., Jones-Cor-ley, J., Trevino, L., Jansen, K., … Balkundi, P. (2004a). Identity Ambiguity and Change in the Wake of a Corporate Spin-off. *Administrative Science Quarterly*, *49*(2), 173–208.

Corley, K. G., Gioia, D. A., Johnson Graduate School, B., Jones-Cor-ley, J., Trevino, L., Jansen, K., … Balkundi, P. (2004b). Identity Ambiguity and Change in the Wake of a Corporate Spin-off. *Administrateive Science Quarterly*, *49*(2), 173–208.

Coulton, P., Lindley, J., & Cooper, R. (2018). *The Little Book of Design Fiction for the Internet of Things*.

Coulton, P., & Lindley, J. G. (2019). More-Than Human Centred Design: Considering Other Things. *Design Journal*, *22*(4), 463–481. https://doi.org/10.1080/14606925.2019.1614320

Crabtree, B. F., & Miller, W. L. (1992). *Doing Qualitative Research*. SAGE Publications.

Crawford, M. (1997). *New Products Management* (5th Editio). McGraw-Hill, Inc.

Creswell, J. W. (1998). *QUALITATIVE INQUIRY& RESEARCH DESIGN: Choosing Among Five Approaches* (2nd eds). Thousand Oaks,: SAGE Publications, Inc.

Creswell, J. W. (2003). *Resarch Design: Qualitative, Quantitative and Mixed-Method Approaches* (3rd eds). SAGE Publications.

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed methods approaches* (3rd edn). SAGE Publications, Inc.

Crilly, N., Blackwell, A. F., & Clarkson, P. J. (2006). Graphic elicitation: using research diagrams as interview stimuli. *Qualitative Research*, *6*(3), 341–366. https://doi.org/10.1177/1468794106065007

Cross, N. (2011). *Design Thinking: Understanding How Designers Think and Work*. Oxford, UK: Berg Publisher.

Crotty, M. (1998). *The Foundations of Social Research: Meaning and Perspective in the Research Process*. SAGE.

Curran, J., & Blackburn, R. A. (2001). *Researching the Small Enterprise*. London, England.: SAGE Publications.

D. Kyriazis, and T. V. (2013). Smart, autonomous and reliable Internet of Things. *Procedia Computer Science*, *21*, 4420448.

D. Machan. (2009). Daas: The new information goldmine. *Wall Street Journal*, pp. 1–3.

D'Ippolito, B., Miozzo, M., & Consoli, D. (2014). Knowledge systematisation, reconfiguration and the organisation of firms and industry: The case of design. *Research Policy*, *43*(8), 1334–1352. https://doi.org/10.1016/j.respol.2014.03.013

De Mozota, B. B. (1998). Structuring Strategic Design Management: Michael Porter's Value Chain. *Design Management Journal*, *9*(2), 26–31.

De Mozota, B. B. (2006). The Four Powers of Design: A Value Model in Design Management. *Design Management Review*, *17*(2), 44–53.

de Saint-Exupery, A. (2009). *Internet of Things Strategic Research Roadmap*. Brussels.

Dedehayir, O., & Steinert, M. (2016). The hype cycle model: A review and future directions. *Technological Forecasting and Social Change*, (108), 28–41.

Deichmann, J., Heineke, K., Reinbacher, T., & Wee, D. (2016). *Creating a successful Internet of things data marketplace*.

Delen, D., & Demirkan, H. (2013). Data, information and analytics as services. *Decision Support Systems*, *55*, 359–363.

Demarrais, K. (2004). Qualitative interview studies: Learning through experience. In K. DeMarrais & S. Lapan (Eds.), *Foundations for Research: Methods of Inquiry in Education and the Social Sciences* (pp. 51–68). Mahwah: Lawrence Erlbaum Associates.

Department of Defense. (1988). *DoD-STD-2167*.

Desantis, L., & Ugarriza, D. N. (2000). *The Concept of Theme as Used in Qualitative Nursing Research*. *Western Journal of Nursing Research* (Vol. 22). Doris Noel Ugarriza.

Desarbo, W. S., Jedidi, K., & Sinha, I. (2001). Customer value analysis in a heterogeneous market. *Strategic Management Journal*, *22*(9), 845–857. https://doi.org/10.1002/SMJ.191

Design council. (2007). *Eleven lessons: Managing Design in Eleven Global Companies (Desk Research Report)*. London, England.

Design Council. (2013). *Design for Public Good*. London, England. Retrieved from http://www.designcouncil.org.uk/resources/report/design-public-good

Deutsch, R. (2015). Leveraging data Across the Building Lifecycle. *Procedia Engineering*, *118*, 260–267. https://doi.org/10.1016/j.proeng.2015.08.425

Dewey, J. (1933). *How We Think. A restatement of the relation of reflective thinking to the educative process* (Revised ed). Boston, MA: D.C. Heath and Co.

Dewulf, K. (2013). Sustainable Product Innovation: The Importance of the Front-End Stage in the Innovation Process. In *Advances in Industrial Design Engineering* (pp. 139–166). https://doi.org/10.5772/52461

Downe-Wamboldt, B. (1992). Content analysis: Method, applications, and issues. *Health Care for Women International*, *13*(3).

Dumas, J. (1999). *A Practical Guide to Usability Testing* (1st eds). University of Chicago.

Dupuit, J. (1844). De la mesure de l'utilité des travaux publics. *Annales Des Ponts et Chaussées*, *2*(2), 332–375. https://doi.org/10.3406/rfeco.1995.978

Durisin, B., Calabretta, G., & Parmeggiani, V. (2010). The Intellectual Structure of Product Innovation Research: A Bibliometric Study of the Journal of Product Innovation Management, 1984-2004. *Journal of Product Innovation Management*, *27*(3), 437–451. https://doi.org/10.1111/j.1540-5885.2010.00726.x

Easterby-Smith, M., Burgoyne, J., & Araujo, L. (1999). *Organisational Learning and the Learning Organisation*. Thousand Oaks, CA: SAGE Publications Ltd.

Easterby-Smith, M., Thorpe, R., & Lowe, A. (2002). *Management Research: An Introduction* (2nd edn). Thousand Oaks, CA: SAGE Publications.

ECIS. (2008). *Internet of Things in 2020: Roadmap for the future*.

Edvardsson, B., Johnson, M. D., Gustafsson, A., & Strandvik, T. (2000). The effects of satisfaction and loyalty on profits and growth: Products versus services. *Total Quality Management*, *11*(7), 917–927. https://doi.org/10.1080/09544120050135461

Eisenhardt, K. M., & Bourgeois, L. J. (1988). POLITICS OF STRATEGIC DECISION MAKING IN HIGH-VELOCITY ENVIRONMENTS: TOWARD A MIDRANGE THEORY. *Academy of Management Journal*, *31*(4), 737–770. https://doi.org/10.2307/256337

Eisenhardt, Kathleen M. (1989). Building Theories from Case Study Research. *The Academy of Management Review*, *14*(4), 532. https://doi.org/10.2307/258557

Eisenhardt, Kathleen M, & Graebner, M. E. (2007). Theory Building from Cases: Opportunities and Challenges. *The Academy of Management Journal*, *50*(1), 25–32.

Eisenman, M. (2013). Understanding Aesthetic Innovation in The Context of Technological

Evolution. *The Academy of Management Review*, *38*(3), 332–351. https://doi.org/10.5465/amr.2011.0262

Ekbia, H. R. (2009). Digital artifacts as quasi-objects: Qualification, mediation, and materiality. *Journal of the American Society for Information Science and Technology*, *60*(12).

Emmanouilidis, C., Pistofidis, P., Bertoncelj, L., Katsouros, V., Fournaris, A., Koulamas, C., & Ruiz-Carcel, C. (2019). Enabling the human in the loop: Linked data and knowledge in industrial cyber-physical systems. *Annual Reviews in Control*, *47*, 249–265.

Evans, B. (1985). Japanese-style management, product design and corporate strategy. *Design Studies*, *6*(1), 25–33. https://doi.org/10.1016/0142-694X(85)90038-9

Evans, D. (2011). *The Internet of Things How the next evolution of the Internet is changing everything*.

Fairlie-Clarke, T., & Muller, M. (2003). An activity model of the product development process. *Journal of Engineering Design*, *14*(3), 247–272.

Fallman, D. (2003). Design-oriented Human-Computer Interaction. In *SIGCHI on Human Factors in Computing Systems*.

Fayyad, U., Piatetsky-Shapiro, G., & Smyth, P. (1996). Knowledge Discovery and Data Mining: Towards a Unifying Framework. In *KDD-96 Proceedings* (pp. 82–88). Retrieved from www.aaai.org

Federal Trade Commission. (2014). *Data Brokers: A Call for Transparency and Accountability*. . Washington, DC, USA: Federal Trade Commission.

Feng, Y., Zhao, Y., Zheng, H., Li, Z., & Tan, J. (2020). Data-driven product design toward intelligent manufacturing: A review. *International Journal of Advanced Robotic Systems*, 1–18. https://doi.org/10.1177/1729881420911257

Ferrara, P., Mandal, A., Cortesi, A., & Spoto, F. (2021). Static analysis for discovering IoT vulnerabilities. *International Journal on Software Tools for Technology Transfer*, *23*, 71–88.

Firestone, W. A. (1987). Meaning in Method: The Rhetoric of Quantitative and Qualitative Research. *Educational Researcher*, *16*(7), 16–21.

Flick, U. (2018). *Designing Qualitative Research* (2nd eds). SAGE Publications Ltd.

Forrester. (2012). *The Big Deal About Big Data For Customer Engagement Business: Leaders Must Lead Big Data Initiatives To Derive Value*.

Forsberg, K., & Mooz, H. (1991). The Relationship of System Engineering to the Project Cycle. In *The First Annual Symposium of National Council on System Engineering* (pp. 1–12).

Froehle, C., Roth, A. V., Chase, R., & Voss, C. A. (2000). Antecedents of New Service Development Effectiveness. *Journal of Service Research*, *3*(1), 3–17.

Gartner. (2014). Gartner says the Internet of Things will transform the data center. Retrieved from https://iot.do/gartner-says-internet-things-will-t

Gassmann, O., Sandmeier, P., & Wecht, C. H. (2006). Extreme customer innovation in the front-end: Learning from a new software paradigm. *International Journal of Technology Management*, *33*(1), 46–66. https://doi.org/10.1504/IJTM.2006.008191

Gemser, G., Candi, M., & van den Ende, J. (2011). How Design Can Improve Firm Performance. *Design Management Review*, *22*(2), 72–77. https://doi.org/10.1111/j.1948-7169.2011.00128.x

Gemsera, G., & Leendersb, M. A. A. M. (2001). How integrating industrial design in the product development process impacts on company performance. *Journal of Product Innovation Management*, *18*(1), 28–38. https://doi.org/10.1111/1540-5885.1810028

Gerring, J., & McDermott, R. (2007). An Experimental Template for Case Study Research. *American Journal of Political Science*, *51*(3), 688–701. https://doi.org/10.1111/j.1540-5907.2007.00275.x

Gershenfeld, N., Krikorian, R., & Cohen, D. (2004). The Internet of Things. *Scientific American*, *291*(4), 76–81.

Ghanbari, A., Laya, A., & Markendahl, J. (2016). Value Creation and Coopetition in M2M Ecosystem - The Case of Smart City. In *IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications*.

Gibson, J. (1977). The theory of affordances. In *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67–82). Hillsdale, New Jersey: Erlbaum.

Gibson, J. (1986). *The Ecological Approach to Visual Perception*. Routledge.

Gil, N., & Tether, B. S. (2011). Project risk management and design flexibility: Analysing a case and conditions of complementarity. *Research Policy*, *40*(3), 415–428. https://doi.org/10.1016/j.respol.2010.10.011

Gill, J., & Johnson, P. (2002). *Research methods for managers* (1st ed.). SAGE.

Glanville, R. (2015). The sometimes uncomfortable marriages of design and research. In P.

Rodgers & J. Yee (Eds.), *The Routledge companion to design research* (1st ed., pp. 9–22). Routledge.

Goffin, K., & Koners, U. (2011). Tacit Knowledge, Lessons Learnt, and New Product Development. *Journal of Product Innovation Management*, *28*(2), 300–318. https://doi.org/10.1111/j.1540-5885.2010.00798.x

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, *8*(4), 597–606. Retrieved from http://www.nova.edu/ssss/QR/QR8-4/golafshani.pdf

Gold, R. L. (1958). Roles in sociological field observations. *Social Forces*, *36*(3), 217–223. https://doi.org/10.2307/2573808

Gordijn, J., Weigand, H., Reichert, M., & Wieringa, R. (2008). Towards Self-Configuration and Management of e-Service Provisioning in Dynamic Value Constellations. In *Symposium on Applied Computing* (pp. 566–571).

Gorman, G. E., & Clayton, P. (2005). *Qualitative Research for the Information Professional: A Practical Hand Book* (2nd eds). London, England.: Facet Publishing.

Goulding, C. (1999). *Grounded theory: some reflections on paradigm, procedures and misconceptions* (June).

Gray, D. E. (2014). *DOING RESEARCH in the Real World* (3rd edn). London, England.: SAGE Publications Ltd.

Griffin, A. (1997). PDMA research on new product development practices: Updating trends and benchmarking best practices. *Journal of Product Innovation Management*, *14*(6), 429–458. https://doi.org/10.1016/S0737-6782(97)00061-1

Grönroos, C. (2008). Service logic revisited: Who creates value? And who co-creates? *European Business Review*, *20*(4), 298–314. https://doi.org/10.1108/09555340810886585

Grönroos, C., & Voima, P. (2013). Critical service logic: Making sense of value creation and co-creation. *Journal of the Academy of Marketing Science*, *41*(2), 133–150. https://doi.org/10.1007/s11747-012-0308-3

Gruber, M., De Leon, N., George, G., & Thompson, P. (2015, February 1). Managing by design: From the Editors. *Academy of Management Journal*. Academy of Management. https://doi.org/10.5465/amj.2015.4001

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries.

Educational Communication & Technology, *29*(2), 75–91. https://doi.org/10.1007/BF02766777

Guba, E. G., & Lincoln, Y. S. (2005). Paradigmatic Controversies, Contradictions, and Emerging Confluences. In Norman K. Denzin & Y. S. Lincolm (Eds.), *The Sage handbook of qualitative research* (pp. 191–215). London, England.: SAGE Publications Ltd.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, *29*(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010

Gummerus, J. (2013). Value creation processes and value outcomes in marketing theory. *Marketing Theory*, *13*(1), 19–46. https://doi.org/10.1177/1470593112467267

Gummesson, E. (2000). *Qualitative Methods in Management Research* (2nd eds). Thousand Oaks, CA: SAGE.

Hagen, C., Khan, K., Ciobo, M., Miller, J., Wall, D., Evans, H., & Yadava, A. (2013). *Big Data and the Creative Destruction of Today's Business Models*. Chicago,IL.

Hamel, G. (2000). *Leading the Revolution*. Boston, Massachusetts: Harvard Business School Press.

Harte, R. P., Glynn, L. G., Broderick, B. J., Rodriguez-Molinero, A., Baker, P. M. A., McGuiness, B., … ÓLaighin, G. (2014). Human centred design considerations for connected health devices for the older adult. *Journal of Personalized Medicine*, *4*(2), 245–281. https://doi.org/10.3390/jpm4020245

Hartmann, P. M., Zaki, M., Feldmann, N., & Neely, A. (2016). Capturing value from big data-a taxonomy of data-driven business models used by start-up firms. *International Journal of Operations & Production Management*, *36*(10), 1382–1406.

Hartsell, C., Mahadevan, N., Nine, H., Bapty, T., Dubey, A., & Karsai, G. (2020). Workflow Automation for Cyber Physical System Development Processes. In *IEEE Workshop on Design Automation for CPS and IoT, DESTION 2020*. Retrieved from https://cps-vo.org/group/ALC

Heinis, T., Gomes Martinho, C., & Meboldt, M. (2017). FUNDAMENTAL CHALLENGES IN DEVELOPING INTERNET OF THINGS FOR ENGINEERS AND PRODUCT DESIGNERS. In *International Conference on Engineering Design (ICED 17)*.

Henfridsson, O., Mathiassen, L., & Svahn, F. (2014). Managing technological change in the digital age: The role of architectural frames. *Journal of Information Technology*, *29*(1), 27–43. https://doi.org/10.1057/jit.2013.30

Henfridsson, O., Nandhakumar, J., Scarbrough, H., & Panourgias, N. (2018). Recombination in the open-ended value landscape of digital innovation. *Information and Organisation*, *28*, 89–100. https://doi.org/10.1016/j.infoandorg.2018.03.001

Heskett, J., & Liu, X. (2012). Models of developing design capacity: Perspective from China. In *The 18th DMI: Academic Design Management Conference*.

Higgins, J., & Green, S. (2011). *Cochrane Handbook for Systematic Reviews of Interventions*. West Sussex: The Cochrane Collaboration and Wiley-Blackwell.

Hillebrand, B., Kok, R. A. W., & Biemans, W. (2001). Theory testing using case studies. *International Marketing Management*, *30*(8), 651–657. https://doi.org/10.1016/s0019-8501(00)00115-2

Holbrook, M. B. (1987). O, consumer, how you've changed: Some radical reflections on the roots of consumption. In F. Fariat, N. Dholakia, & R. Bagozzi (Eds.), *Philosophical and radical though in marketing* (pp. 156–177). Lexington, MA: Lexington Books.

Holbrook, M. B. (1994). The Nature of Customer's Value: An Axiology of Service in Consumption Experience. In R. T. Rust & R. L. Oliver (Eds.), *Service Quality: New Directions in Theory and Practice* (pp. 21–71). Thousand Oaks,: SAGE.

Holbrook, M. B. (1999). *Consumer Value: A Framework for Analysis and Research*. New York: Routledge.

Holbrook, M. B. (2006). Consumption experience, customer value, and subjective personal introspection: An illustrative photographic essay. *Journal of Business Research*, *59*(6), 714–725.

Holloway, I. (1997). *Basic Concepts for Qualitative Research*. Wiley.

Huang, G., He, J., Chi, C.-H., Zhou, W., & Zhang, Y. (2015). A Data As A Product Model for Future Consumption of Big Stream Data in Clouds. In *IEEE International Conference on Services Computing* (pp. 256–263). Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7207361

Hui, G. (2014). How the Internet of Things Changes Business Models. *Harvard Business Review*. Retrieved from https://hbr.org/2014/07/how-the-internet-of-things-changes-business-models

Iansiti, M., & Lakhani, K. R. (2017). The Truth About Blockchain. *Harvard Business Review*, 4–11.

IDC. (2012). *The Digital Universe in 2020: Big Data, Bigger Digital Shadows, and Biggest Growth in the Far East*.

IEEE. (2014). *Special report: The Internet of Things*.

Ikävalko, H., Turkama, P., & Smedlund, A. (2018). Enabling the mapping of Internet of Things ecosystem business models through roles and activities in value co-creation. In *International Conference on System Sciences* (pp. 4954–4963). Retrieved from http://hdl.handle.net/10125/50509

International Organisation for Standardization. (2015). *ISO 9000: Quality management systems*. Retrieved from https://asq.org/quality-press/display-item?item=T1039E

IoTUK. (2016). *UK Enterprise & The IoT*. London, England.

ITU. (2001). *The Internet of Things*.

Jaakkola, E. (2020). Designing conceptual articles: four approaches. *AMS Review*, *10*, 18–26.

Jacobs, N., & Cooper, R. (2018). *Living in digital worlds : designing the digital public space*. Routledge.

JANG, B., PARK, S., LEE, J., & HAHN, S.-G. (2018). Three Hierarchical Levels of Big-Data Market Model Over Multiple Data Sources for Internet of Things. *IEEE Access*, *6*.

Janne, van K., & Bogers, S. (2019). *Data-enabled design: a situated design approach that uses data as creative material when designing for intelligent ecosystems*. Technische Universiteit Eindhoven.

Jevons, W. S. (1871). *Theory of Political Economy*.

Jick, T. D. (1979). Mixing Qualitative and Quantitative Methods: Triangulation in Action. *Administrative Science Quarterly*, *24*(4), 602–661. Retrieved from http://links.jstor.org/sici?sici=0001-8392%28

Johansson-Sköldberg, U., Woodilla, J., & Çetinkaya, M. (2013). Design Thinking: Past, Present and Possible Futures. *Creativity and Innovation Management*, *22*(2), 121–146. https://doi.org/10.1111/caim.12023

Johne, A., & Storey, C. (1998). New service development: a review of the literature and annotated bibliography. *European Journal of Marketing*, *32*(3/4), 184–251. https://doi.org/10.1108/03090569810204526

Johnson, J. S., Friend, S. B., & Lee, H. S. (2017). Big Data Facilitation, Utilization, and Monetization: Exploring the 3Vs in a New Product Development Process. *Journal of*

Product Innovation Management, *34*(5), 640–658. https://doi.org/10.1111/jpim.12397

Johnson, S. P., Menor, L. J., Roth, A. V., & Chase, R. B. (2000). A Critical Evaluation of the New Service Development Process: Integrating Service Innovation and Service Design. In J. A. Fitzsimmmons & M. Fitzsimmons (Eds.), *New Service Development: Creating Memorable Experiences* (pp. 1–32). Thousand Oaks, CA: SAGE Publications, Inc. https://doi.org/10.4135/9781452205564.n1

Jonsson, K., Holmström, J., & Lyytinen, K. (2009). Turn to the material: Remote diagnostics systems and new forms of boundary-spanning. *Information and Organization*, *19*(4), 233–252. https://doi.org/10.1016/j.infoandorg.2009.07.001

Kahle, J. H., Marcon, É., Ghezzi, A., & Frnak, A. G. (2020). Smart Products value creation in SMEs innovation ecosystems. *Technological Forecasting & Social Change*, *156*.

Kahn, K. B. (2005). *The PDMA Handbook of New Product Development*. (S. Kay, R. Slotegraaf, & S. Uban, Eds.) (2nd Editio). Hoboken, New Jersey: John Wiley & Sons, Inc.

Kallinikos, J., Aaltonen, A., & Marton, A. (2013). THE AMBIVALENT ONTOLOGY OF DIGITAL ARTIFACTS. *MIS Quarterly (Management Information Systems Quarterly)*, *37*(2), 357–370.

Kandel, S., Paepcke, A., Hellerstein, J. M., & Heer, J. (2012). Enterprise Data Analysis and Visualization: An Interview Study. *IEEE Transactions on Visualization and Computer Graphics*, *18*(12), 2917–2926.

Kang, M. (2015). "Smart logis 2015"-IoT & Logistics: Internet of Things and logistics convergence. *Maritime Korea*, 76–81.

Karababa, E., & Kjeldgaard, D. (2014). Value in marketing. *Marketing Theory*, *14*(1), 119–127. https://doi.org/10.1177/1470593113500385

Karie, N., Sahri, N., & Haskell-Dowland, P. (2020). IoT Threat Detection Advances, Challenges and Future Directions. In *IEEE workshop on Emerging Technologies for Security in IoT*.

Kessler, E. H., & Bierly, P. E. (2002). Is faster really better? An empirical test of the implications of innovation speed. *IEEE Transactions on Engineering Management*, *49*(1), 2–12. https://doi.org/10.1109/17.985742

Khurana, A., & Rosenthal, S. (1997). Integrating the fuzzy front-end of new product development. *Sloan Management Review*, *38*(2), 103–120.

Kim, J. (2015). A review on recent Geo-IoT technologies and services. *Telco Journal*, *3*, 121–143.

Kim, Jongbae., & Wilemon, D. (2002). Focusing the fuzzy front-end in new product development. *R&D Management*, *32*(4), 269–279.

Kim, M.-J., Lim, C.-H., Lee, C.-H., Kwang, •, Kim, J., Park, Y., & Choi, S. (2018). Approach to service design based on customer behavior data: a case study on eco-driving service design using bus drivers' behavior data. *Service Business*, *12*, 203–227. https://doi.org/10.1007/s11628-017-0343-8

King, R., Churchill, E. F., & Tan, C. (2017). *Designing with Data: Improving the User Experience with A/B Testing* (1st ed.). O'Reilly.

Kleinschmidt, E. J., & Cooper, R. G. (1991). The Impact of Product Innovativeness on Performance. *Journal of Product Innovation Management*, *8*(4), 240–251.

Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. In N. Rosenberg & R. Landau (Eds.), *The Positive Sum Strategy* (1st ed., pp. 275–305). Washington, DC: National Academy Press. https://doi.org/10.1142/9789814273596_0009

Kogut, B., & Metiu, A. (2001). OPEN-SOURCE SOFTWARE DEVELOPMENT AND DISTRIBUTED INNOVATION. *OXFORD REVIEW OF ECONOMIC POLICY*, *17*(2), 248–264.

Komoto, H., & Tomiyama, T. (2009). Design of competitive maintenance service for durable and capital goods using life cycle simulation. *International Journal of Automation Technology*, *3*(1), 63–70. Retrieved from https://www.fujipress.jp/main/wp-content/themes/Fujipress/pdf_subscribed.php

Kotler, P. (2000). *Marketing Management* (milleneum). Upper Saddle River: Prentice Hall.

Krefting, L. (1991). Rigor in Qualitative Research: The Assessment of Trustworthiness. *The American Journal of Occupational Therapy*, *45*, 214–222.

Kretzschmar, A. (2003). *The Economic Effects of Design*. Copenhagen.

Krippendorff, K. (1989). On the Essential Contexts of Artifacts or on the Proposition That "Design Is Making Sense (Of Things)." *Design Issues*, *5*(2), 9–39.

Krishnan, V., & Ulrich, K. T. (2001). Product Development Decisions: A Review of the Literature. *Management Science*, *47*(1), 1–21.

Kubler, S., Yoo, M.-J., Cassagnes, C., Främling, K., Kiritsis, D., & Skilton, M. (2015). Opportunity to leverage Information-as-an-Asset in the IoT - the road ahead. In

International Conference on Future Internet of Things and Cloud.

Kugler, P. (2020). Approaching a Data-Dominant Logic. *Technology Innovation Management Review*, *10*(10), 16–28.

Kwon, O., & Sim, J. M. (2013). Effects of Data Set Features on the Performances of Classification Algorithms. *Expert Systems with Applications*, *40*(5), 1847–1857.

Lai, C. T., Jackson, P. R., & Jiang, W. (2017). Shifting paradigm to service-dominant logic via Internet-of-Things with applications in the elevators industry. *Journal of Management Analytics*, *4*(1), 35–54. https://doi.org/10.1080/23270012.2016.1259967

Larman, C., & Basili, V. R. (2003). Iterative and Incremental Development: A Brief History. *Computer*, 47–56. Retrieved from https://ieeexplore-ieee-org.ezproxy.lancs.ac.uk/stamp/stamp.jsp?tp=&arnumber=1204375

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business and Information Systems Engineering*, *6*(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

Latin Dictionary of the University of Notre Dame. (n.d.).

Lee, I., & Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Business Horizons*, *58*, 431–440. https://doi.org/10.1016/j.bushor.2015.03.008

Lee, S.-E., Choi, M., & Kim, S. (2017). How and what to study about IoT: Research trends and future directions from the perspective of social science. *Telecommunications Policy*, *41*, 1056–1067.

Leffingwell, D., & Widrig, D. (2010). *Agile Software Requirements: Lean Requirements Practices for Teams, Programs, and the Enterprise (Agile Software Development)*. Addison-Wesley.

Lehoux, P., Hivon, M., Williams-Jones, B., & Urbach, D. (2011). The worlds and modalities of engagement of design participants: A qualitative case study of three medical innovations. *Design Studies*, *32*, 313–332. https://doi.org/10.1016/j.destud.2011.01.001

Leminen, S., Westerlund, M., Rajahonka, M., & Siuruainen, R. (2012). Towards IoT Ecosystems and Business Models. In *Conference on Internet of Things and Smart Spaces International Conference on Next Generation Wired/Wireless Networking* (pp. 15–26).

Leonardi, P. M. (2011). When Flexible Routines Meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies. *MIS Quarterly (Management Information Systems Quarterly)*, *35*(1), 147–167.

Leszinski, R., & Marn, M. V. (1997). Setting value, not price | McKinsey. *The McKinsey Quarterly*, 99–115. Retrieved from https://www.mckinsey.com/business-functions/marketing-and-sales/our-insights/setting-value-not-price#

Lettl, C., Herstatt, C., & Gemuenden, H. G. (2006). Users' Contributions to Radical Innovation: Evidence from Four Cases in the Field of Medical Equipment Technology InnoAge View project Multi-Project Management 8th bi-annual Survey View project Users' contributions to radical innovation: evidence from fou. *R&D Management*, *36*(3), 251–272. https://doi.org/10.1111/j.1467-9310.2006.00431.x

Liedtka, J. (2015). Perspective: Linking Design Thinking with Innovation Outcomes through Cognitive Bias Reduction. *Journal of Product Innovation Management*, *32*(6), 925–938. https://doi.org/10.1111/jpim.12163

Lin, F.-R., & Hsieh, P.-S. (2011). A SAT View on New Service Development. *Service Science*, *3*(2), 141–157. https://doi.org/10.1287/serv.3.2.141

Lin, M. C., Hughes, B. L., Katica, M. K., Dining-Zuber, C., & Plsek, P. E. (2011). Service Design and Change of Systems: Human-Centered Approaches to Implementing and Spreading Service Design. *International Journal of Design*, *5*(2), 73–86. Retrieved from www.ijdesign.org

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. SAGE Publications Inc.

Lorenz, C. (1990). *The Design Dimension - The New Competitive Weapon for Product Strategy and Global Marketing* (2nd Edn). Wiley-Blackwell.

Lovelock, C., & Gummesson, E. (2004). Whither Services Marketing? In Search of a New Paradigm and Fresh Perspectives. *Journal of Service Research*, *7*(1), 20–41. https://doi.org/10.1177/1094670504266131

Lucas, H. C., & Goh, J. M. (2009). Disruptive technology: How Kodak missed the digital photography revolution. *Journal of Strategic Information Systems*, *18*(1), 46–55. https://doi.org/10.1016/j.jsis.2009.01.002

Luchs, M. G., Swan, K. S., & Creusen, M. E. H. (2016). Perspective: A Review of Marketing Research on Product Design with Directions for Future Research. *Journal of Product Innovation Management*, *33*(3), 320–341. https://doi.org/10.1111/jpim.12276

Lusch, R. F., & Nambisan, S. (2015). Service Innovation: A Service-Dominant Logic

Perspective. *MIS Quarterly (Management Information Systems Quarterly)*, *39*(1), 155–171.

Lusch, R. F., & Vargo, S. L. (2006). Service-dominant logic: reactions, reflections and refinements. *Marketing Theory*, *6*(3), 281–288. https://doi.org/10.1177/1470593106066781

MacConell, S. (1996). *Rapid Development:* (Microsoft Press, Ed.). Redmond, Washington, USA. Retrieved from https://books.google.co.uk/books/about/Rapid_Development.html?id=-Up3BQAAQBAJ&source=kp_book_description&redir_esc=y

Maffei, S., Villari, B., & Mortati, M. (2014). Design Capabilities for Value Creation. In *DMI Conference* (p. 44). London, England.

Markus, M. L., & Mao, J.-Y. (2004). Participation in Development and Implementation - Updating An Old, Tired Concept for Today's IS Contexts. *Journal of the Association for Information Systems*, *5*(11), 514–544. https://doi.org/10.17705/1jais.00057

Marques, P., Cunha, P., Valente, F., & Leitao, A. (2013). A methodology for product-service systems development. In *Forty Sixth CIRP Conference on Manufacturing Systems* (pp. 371–376).

Marshall, A., & Marshall, M. P. (1879). *The Economics of Industry*. Bristol, UK: Thoemmes Press.

Martin, R. (2009). *The Design of Business*. Boston, MA: Harvard Business School Publishing.

Martin, R. C. (2002). *Agile Software Development, Principles, Patterns and Practices* (1st ed.). Prentice Hall.

Marx, K. (1906). *Capital: A Critique of Political Economy, Vol. I. The Process of Capitalist Production* (4th ed.). Chicago: Charles H. Kerr and Co. Retrieved from https://www.econlib.org/library/YPDBooks/Marx/mrxCpA.html

Mashal, I., Alsaryrah, O., Chung, T., Yang, C., Kuo, W., & Agrawal, D. (2015). Choices for interaction with things on Internet and underlying issues. *Ad Hoc Networks*, *28*, 68–90.

Matkovic, P., & Tumbas, P. (2010). A Comparative Overview of the Evolution of Software Development Models. *Journal of Industrial Engineering and Management*, *1*(4), 163–172.

Mattern, F., & Floerkemeier, C. (2010). From the Internet of computers to the Internet of Things. In K. Sachs, I. Petrov, & P. Guerrero (Eds.), *From active data management to event-based systems and more* (pp. 242–259). Springer Berlin Heidelberg.

Maussang, N., Zwolinski, P., & Brissaud, D. (2009). Product-service system design methodology: from the PSS architecture design to the products specifications. *Journal of Engineering Design*, *20*(4), 349–366. https://doi.org/10.1080/09544820903149313

Mayer-Schönberger, V., & Cukier, K. (2013). *Big Data: A Revolution That Will Transform How We Live, Work, and Think*. Boston, MA: Houghton Mifflin Hargourt.

Mays, N., & Pope, C. (2000). Assessing quality in qualitative research. *British Medical Journal*, *320*(7226), 50–52. https://doi.org/10.1136/bmj.320.7226.50

Mazhelis, O., Luoma, E., & Warma, H. (2012). Defining an Internet-of-Things Ecosystem. In *Conference on Internet of Things and Smart Spaces International Conference on Next Generation Wired/Wireless Networking* (pp. 1–14).

McAfee, A., & Brynjolfsson, E. (2012, October). Big Data: The Management Revolution. *Harvard Business Review*, 60–68. Retrieved from https://hbr.org/2012/10/big-data-the-management-revolution

McAfee, A., & Brynjolfsson, E. (2017). *Machine, Platform, Crowd: Harnessing the Digital Revolution*. W.W. Norton & Company.

Mcconnel, S. (1996). *Rapid Development: Taming Wild Software Schedules*. Redmond, Washington, USA: Microsoft Press.

McKinsey. (2011). *Big Data: The Next Frontier for Innovation, Competition & Productivity*. Washington, DC.

McKinsey. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. *McKinsey*. Retrieved from https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/disruptive-technologies#

Mejtoft, T. (2011). Internet of Things and Co-creation of Value. In *IEEE International Conference on Internet of Things, and Cyber, Physical and Social Computing*. https://doi.org/10.1109/iThings/CPSCom.2011.75

Menger, C. (1871). *Principles of Economics*. New York: New York University Press.

Menor, L. J., Tatikonda, M. V., & Sampson, S. E. (2002). New service development: Areas for exploitation and exploration. *Journal of Operations Management*, *20*(2), 135–157.

https://doi.org/10.1016/S0272-6963(01)00091-2

Merriam, S. B. (1998). *Case study research in education: Aqualitative approach*. San Francisco, CA: Jossey-Bass.

Merriam, S. B. (2009). *Qualitative Research: A Guide to Design and Implementation* (2nd eds). Jossey-Bass.

Mertens, D. M. (1998). *Research Methods in Education and Psychology: Integrating Diversity with Quantitative and Qualitative Approaches*. SAGE Publications.

Meyer, B. (2001). *Software: Product or Service?*

Meyer, M. H., & Utterback, J. M. (1995). Product development cycle time and commercial success. *IEEE Transactions on Engineering Management*, *42*(4), 297–304.

Microsoft Team. (2003). *Microsoft Solution Framework White Papers*.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis* (2nd eds). SAGE Publications, Inc.

Mont, O. (2000). *Product-Service Systems Final Report*. Stockholm.

Morelli, N. (2002). Designing Product/Service Systems: A Methodological Exploration 1. *Design Issues*, *18*(3), 3–17.

Morgan, D. L. (1993). Qualitative Content Analysis: A Guide to Paths not Taken. *Qualitative Health Research*, *3*(1), 112–121. https://doi.org/10.1177/104973239300300107

Morse, J., & Niehaus, L. (2009). *Mixed method design: Principles and procedures*. Walnut Creek, CA: Left Coast Press.

Moultrie, J., & Livesey, F. (2014). Measuring design investment in firms: Conceptual foundations and exploratory UK survey. *Research Policy*, *43*(3), 570–587. https://doi.org/10.1016/j.respol.2013.08.005

Murphy, E., Dingwall, R., Greatbatch, D., Parker, S., & Watson, P. (1998). Qualitative research methods in health technology assessment: a review of the literature. *Health Technology Assessment*, *2*(16).

Murthy, D., Rausand, M., & Østerås, T. (2008). *Product reliability: specification and perfoemance*. London, England.: Springer.

Myers, M. D. (2009). *Qualitative research in business & management*. SAGE Publications Ltd.

Nachmias, C. F., & Nachmias, D. (1996). *Research Methods in the Social Sciences* (5th Eds). London, England.: Arnold.

Nambisan, S. (2018). Architecture vs. ecosystem perspectives: Reflections on digital innovation. *Information and Organisation*, *28*, 104–106. https://doi.org/10.1016/j.infoandorg.2018.04.003

Nasiri, M., Tura, N., & Ojanen, V. (2017). Developing Disruptive Innovations for Sustainability: A Review on Impact of Internet of Things (IOT). In *Proceedings of PICMET '17: Technology Management for Interconnected World*.

Neuman, W. Lawrence. (2006). *Basics of Social Research: Qualitative and Quantitative Approaches* (2nd eds).

Neuman, William L. (2000). *Social Research Methods: Qualitative and Quantitative Approaches* (5th edn). Allyn and Bacon.

Neuman, William L. (2011). *Social Research Methods: Qualitative and Quantitative Approaches* (7th eds). Boston, MA: Pearson Education.

Ng, I. C. L. (2014). *Creating new markets in the digital economy : value and worth*. Cambridge University Press.

Ng, I. C. L., & Smith, L. (2012a). Working Paper Series: An Integrative Framework of Value, 35.

Ng, I. C. L., & Smith, L. A. (2012b). An integrative framework of value. *Review of Marketing Research*, *9*, 207–243. https://doi.org/10.1108/S1548-6435(2012)0000009011

Ng, I. C. L., & Wakenshaw, S. Y. L. (2017). The Internet-of-Things: Review and research directions. *International Journal of Research in Marketing*, *34*(1), 3–21. https://doi.org/10.1016/j.ijresmar.2016.11.003

Nickel, P. J. (2015). Design for the value of trust. In M. J. van den Hoven, P. E. Vermaas, & I. Van de Poel (Eds.), *Handbook of Ethics, Values and Technological Design*. Springer.

Nijhuis, S., & de Vries, J. (2019). Design as Research in Landscape Architecture. *Landscape Journal*, *38*(1–2), 87–103.

Nijssen, E. J., & Lieshout, K. F. M. (1995). Awareness, use and effectiveness of models and methods for new product development. *European Journal of Marketing*, *29*(10), 27–44. https://doi.org/10.1108/03090569510098483

Noble, C. H., & Kumar, M. (2010). Exploring the Appeal of Product Design: A Grounded, Value-Based Model of Key Design Elements and Relationships*. *Journal of Product Innovation Management*, *27*(5), 640–657. https://doi.org/10.1111/j.1540-5885.2010.00742.x

Norman, D. (1988). *The Psychology Of Everyday Things* (1st ed.). Basic Books.

Norman, D., & Verganti, R. (2011). INCREMENTAL AND RADICAL INNOVATION: DESIGN RESEARCH VERSUS TECHNOLOGY AND MEANING CHANGE. In *Designing Pleasurable Products and Interfaces Conference*. Milan.

Normann, R. (2001). *Reframing Business: When the Map Changes the Landscape*. New York: John Wiley & Sons.

Normann, Richard, & Ramírez, R. (1994). *Designing Interactive Strategy: From Value Chain to Value Constellation*. Chichester ; New York: John Wiley & Sons, Inc.

O'Neil, C., & Schutt, R. (2013). *Doing Data Science*. (M. Loukides & C. Nash, Eds.) (4th Editio). Sebastopol, CA: O'Reilly Media Inc. Retrieved from https://semanticommunity.info/Data_Science/Doing_Data_Science

OECD. (2012). *OECD Digital Economy Papers: Machine-to-machine communications, connecting billions of devices*. Retrieved from http://dx.doi.org/10.1787/5k9gsh2gp043-en

Oh, H., Park, S., Lee, G. M., Choi, J. K., & Noh, S. (2020). Competitive Data Trading Model With Privacy Valuation for Multiple Stakeholders in IoT Data Markets. *IEEE INTERNET OF THINGS JOURNAL*, *7*(4), 3623–3640.

Oliver, D., Serovich, J. M., & Mason, T. L. (2005). Constraints and Opportunities with Interview Transcription: Towards Reflection in Qualitative Research. *Social Forces*, *84*(2), 1273–1289.

Oracle. (2012). *Big Data for the Enterprise. Redwood Shores*. California.

Ostrom, A. L., Parasuraman, A., Bowen, D. E., Patrício, L., & Voss, C. A. (2015). Service Research Priorities in a Rapidly Changing Context. *Journal of Service Research*, *18*(2), 127–159. https://doi.org/10.1177/1094670515576315

Ovesen, N., & Sommer, A. F. (2013). Scrum in the traditional development organisation: Adopting to the legacy. In *Modelling and Management of Engineering Processes* (pp. 87–99). Berlin: Springer Verlag.

Owen, G. T. (2014). The Qualitative Report Qualitative Methods in Higher Education Policy Analysis: Using Interviews and Document Analysis. *The Qualitative Report*, *19*(26), 1–

19. Retrieved from http://www.nova.edu/ssss/QR/QR19/owen52.pdf

Owens, J., & Davies, J. (2000). The Importance of a New Product Development (NPD) process: Getting Started. In *European Conference on KM* (Vol. 1).

Paananen, A., & Seppänen, M. (2013). Reviewing customer value literature: Comparing and contrasting customer values perspectives. *Intangible Capital*, *9*(3), 708–729. https://doi.org/10.3926/ic.389

Page, A. L., & Schirr, G. R. (2008). Growth and Development of a Body of Knowledge: 16 Years of New Product Development Research, 1989–2004. *Journal of Product Innovation Management*, *25*(3), 233–248. https://doi.org/10.1111/j.1540-5885.2008.00297.x

Pahl, G., Beitz, W., Feldhusen, J., & Grote, K.-H. (2007). *Engineering Design: A systematic Approach*. London, England.: Springer.

Papazoglou, M. P., Van Den Heuvel, W.-J., Papazoglou, M. P., & Van Den Heuvel, W.-J. (2007). Service oriented architectures: approaches, technologies and research issues. *The International Journal on Very Large Data Bases*, *16*(3), 389–415. https://doi.org/10.1007/s00778-007-0044-3

Patel, K., & Patel, S. M. (2016). Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges. *International Journal of Engineering Science and Computing*, *6*(5), 6122–6131.

Patel, M., Shangkuan, J., & Thomas, C. (2017). What's new with the Internet of Things? | McKinsey. *McKinsey*. Retrieved from https://www.mckinsey.com/industries/semiconductors/our-insights/whats-new-with-the-internet-of-things

Patton, M. Q. (2002). Two Decades of Developments in Qualitative Inquiry A Personal, Experiential Perspective. *Qualitative Social Work*, *1*(3), 261–283.

Patton, M. Q. (2014). *Qualitative research and evaluation methods: Integrating Theory and Practice* (4th eds). SAGE Publications Inc.

Pennell, J., Winner, R., Bertrand, H., & Slusarszuk, M. (1989). Concurrent Engineering: An Overview for Autotestcon. In *The System Readiness Technology Conference* (pp. 88–99). Philadelphia, PA. Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=64049

Penrose, E. T. (1959). *The Theory of the Growth of the Firm*. London: Basil Blackwell and Mott.

Perks, H., Cooper, R., & Jones, C. (2005). Characterizing the role of design in new product development: An empirically derived taxonomy. *Journal of Product Innovation Management*, *22*(2), 111–127. https://doi.org/10.1111/j.0737-6782.2005.00109.x

Petter, J., & Peppard, J. (2012). *Harnessing the Growth Potential of Big Data. Why the CEO Must Take the Lead*. Brentford.

Peyne, A., Storbacka, K., & Frow, P. (2008). Managing the co-creation of value. *Journal of the Academy of Marketing Science*, *36*, 83–96. https://doi.org/10.1007/s11747-007-0070-0

Polit, D. F., & Hungler, B. P. (1987). *Nursing research: Principles and methods*. (J. B. Lippincott, Ed.) (3rd eds). Philadelphia, PA.

Poppendieck, M., & Poppendieck, T. (2003). *Lean Software Development: An Agile Toolkit*. Addison-Wesley Professional.

Porter, M. E., & Millar, V. E. (1985). How Information Gives You Competitive Advantage. *Harvard Business Press*. Retrieved from https://hbr.org/1985/07/how-information-gives-you-competitive-advantage[28/11/201611:34:33]

Porter, M., & Heppelmann, J. (2014). How Smart, Connected Products Are Transforming Competition. *Harvard Business Review*. Retrieved from https://hbr.org/2014/11/how-smart-connected-products-are-transforming-competition

Potter, S. (2006). *Doing Postgraduate Research* (2nd eds). SAGE Publications, Ltd.

Prahalad, C.-K., & Ramaswamy, V. (2004). Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing*, *18*(3), 5–14.

Press, Mike, & Cooper, R. (2003). *The Design Experience: The Role of Design and Designers in the Twenty-First Century* (1st Editio). London, England.: Routledge. https://doi.org/10.4324/9781315240329

Prosser, J. (1998). *Image-based Research: A Sourcebook for Qualitative Researchers*. Taylor and Francis.

Psomakelis, E., Nikolakopoulos, A., Marinakis, A., Psychas, A., Moulos, V., Varvarigou, T., & Christou, A. (2020). A scalable and semantic data as a service marketplace for enhancing cloud-based applications. *Future Internet*, *12*(5), 77. https://doi.org/10.3390/FI12050077

Radziwon, A., Bilberg, A., Bogers, M., & Madsen, E. S. (2014). The smart factory: Exploring adaptive and flexible manufacturing solutions. In *Procedia Engineering* (Vol. 69, pp.

1184–1190). Elsevier Ltd. https://doi.org/10.1016/j.proeng.2014.03.108

Ragin, C. C. (1997). TURNING THE TABLES: HOW CASE-ORIENTED RESEARCH CHALLENGES VARIABLE-ORIENTED RESEARCH. *Comparative Social Research*, *16*, 27–42.

Ramaswamy, R. (1996). *Design and Management of Service Processes* (1st Editio). Addison-Wesley Pub. Co.

Ravasi, D., & Stigliani, I. (2012). Product Design: A Review and Research Agenda for Management Studies. *International Journal of Management Reviews*, *14*(4), 464–488. https://doi.org/10.1111/j.1468-2370.2012.00330.x

Redström, J. (2006). Persuasive Design: Fringes and Foundations. In *PERSUASIVE' 06: Proceedings of the First International Conference on Persuasive Technology for Human Well-Being* (Vol. 3962, pp. 112–122).

Reichert, C. (2017). Cisco: Most IoT projects are failing due to lack of experience and security | ZDNet. Retrieved February 11, 2020, from https://www.zdnet.com/article/cisco-most-iot-projects-are-failing-due-to-lack-of-experience-and-security/

Reinertsen, D. G. (1999). Taking the fuzziness out of the fuzzy front-end. *Research Technology Management*, *42*(6), 25–31.

Remenyi, D., Williams, B., Money, A., & Swartz, E. (1998). *Doing Research in Business and Management: An Introduction to Process and Method*. London: SAGE.

Reynolds, E. B., & Uygun, Y. (2015). Strengthning advanced manufacturing innovation ecosystems: the case of Massachusetts. *Technological Forecasting and Social Change*.

Ricardo, D. (1821). *On the Principles of Political Economy and Taxation* (3rd ed.). London: John Murray. Retrieved from https://www.econlib.org/library/Ricardo/ricP.html

Ridder, H. G. (2017). The theory contribution of case study research designs. *Business Research*, *10*(2), 281–305. https://doi.org/10.1007/s40685-017-0045-z

Rieke, A., Yu, H., Robinson, D., & Hoboken, J. von. (2016). *Data Brokers in an Open Society*. London, U.K: Upturn Open Soc. Found.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. https://doi.org/10.1007/BF01405730

Robson, C. (2002). *Real World Research: A Resource for Social Scientists and Practitioner-Researchers* (2nd eds). Wiley-Blackwell.

Roper, S., Micheli, P., Love, J. H., & Vahter, P. (2016). The roles and effectiveness of design in new product development: A study of Irish manufacturers. *Research Policy*, *45*(1), 319–329. https://doi.org/10.1016/j.respol.2015.10.003

Rothwell, R. (1993). Successful industrial innovation: critical factors for the 1990s. *R&D Management*, *22*(3), 1. Retrieved from https://www.jstor.org/stable/pdf/24128263.pdf

Rothwell, R., & Zegveld, W. (1985). *Reindustrialization and Technology*. New York: Longman Group Limited.

Royce, W. W. (1970). MANAGING THE DEVELOPMENT OF LARGE SOFTWARE SYSTEMS. In *IEEE WESCON* (pp. 1–9).

Ruparelia, N. B. (2010). Software Development Lifecycle Models. *ACM SIGSOFT Software Engineering Notes*, *35*(3), 8. https://doi.org/10.1145/1764810.1764814

Rymaszewska, A., Helo, P., & Gunasekaran, A. (2017). IoT powered servitization of manufacturing–an exploratory case study. *International Journal of Production Economics*, *192*, 92–105.

Saarijärvi, H., Karjaluoto, H., & Kuusela, H. (2013). Customer relationship management: the evolving role of customer data. *Marketing Intelligence and Planning*, *31*(6). https://doi.org/10.1108/MIP-05-2012-0055

Said, O., & Masud, M. (2013). Towards internet of things: survey and future vision. *International Journal of Computer Networks*, *5*(1), 1–17.

Salomonson, N., Åberg, A., & Allwood, J. (2012). Communicative skills that support value creation: A study of B2B interactions between customers and customer service representatives. *Industrial Marketing Management*, *41*(1), 145–155. https://doi.org/10.1016/j.indmarman.2011.11.021

Sambamurthy, V., Bharadwaj, A., & Grover, V. (2003). Shaping Agility through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms. *MIS Quarterly (Management Information Systems Quarterly)*, *27*(2), 237–263.

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *CoDesign*, *4*(1), 5–18. https://doi.org/10.1080/15710880701875068

Sands, E. G. (2018, October). How to Build Great Data Products. *Harvard Business Review*. Retrieved from https://hbr.org/2018/10/how-to-build-great-data-products

Saren, M. A. (1984). A classification and review of models of the intra-firm innovation process. *R&D Management*, *14*.

Saunders, M., Thornhill, A., & Lewis, P. (2006). *Research Methods for Business Students* (4th ed). Prentice Hall.

Scheuing, E. E., & Johnson, E. M. (1989). A proposed Model for New Service Development. *The Journal of Service Marketing*, *3*(2), 1–25.

Schön, D. (1990). The Design Process. In V. A. Howard (Ed.), *Varieties of Thinking*. New York: Routledge.

Schroeck, M., Shockley, R., Smart, J., Romero-Morales, D., & Tufano, P. (2012). *Analytics: The Real-World Use of Big Data. How Innovative Enterprises Extract Value from Uncertain Data*. Oxford, UK. Retrieved from www.sbs.ox.ac.uk

Schuler, D., & Namioka, A. (1993). *Participatory design: Principles and practices*. Lawrence Erlbaum Associates.

Schumpeter, J. A. (1934). *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. Cambridge, MA: Harvard University Press.

Schwaber, K., & Beedle, M. (2002). *Agile Software Development with Scrum*. Prentice Hall.

Schwandt, T. A. (2001). Dictionary of qualitative inquiry, xxxiv, 281–xxxiv, 281.

Seidel, V. P., & Fixson, S. K. (2013). Adopting Design Thinking in Novice Multidisciplinary Teams: The Application and Limits of Design Methods and Reflexive Practices. *Journal of Product Innovation Management*, *30*, 19–33. https://doi.org/10.1111/JPIM.12061@10.1111/(ISSN)1540-5885.MANAGING-THE-FRONT-END-OF-INNOVATION

Seidman, I. (1991). *Interviewing As Qualitative Research: A Guide for Researchers in Education And the Social Sciences* (1st eds). Teachers College Press.

Shin, H., & Ji, S. (2016). Normative study on personal information protection in IoT era. *Law and Policy*, *22*(2), 427–454.

Sidi, F., Panahy, P. H. S., Affendey, L. S., Jabar, M. A., Ibrahim, H., & Mustapha, A. (2012). Data Quality: A Survey of Data Quality Dimensions. In *International Conference on Information Retrieval & Knowledge Management* (pp. 300–304). Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6204995

Siggelkow, N. (2007). PERSUASION WITH CASE STUDIES. *Academy of Management Journal*, *50*(1), 20–24.

Silverman, D. (2017). *Doing Qualitative Research* (4th eds). London, England.: SAGE.

Simon, H. (1969). *The sciences of the artificial*. London, England.: [M.I.T. Press].

Simon, M. (2011). *The Role of the Researcher*.

Smedlund, A., & Toivonen, M. (2005). The role of KIBS in the IC development of regional clusters. *Journal of Intellectual Capital*, *8*(1), 567–574.

Smith, A. (1776). *The Wealth of Nations*.

Smith, A. (1904). *An Inquiry into the Nature and Causes of the Wealth of Nations* (5th ed.). London; Edinburgh: Methuen & Co., Ltd. Retrieved from https://www.econlib.org/library/Smith/smWN.html

Smith, P. G., & Reinertsen, D. G. (1992). SHORTENING THE PRODUCT DEVELOPMENT CYCLE. *Research-Technology Management*, *35*(3), 44–49.

Sparke, P. (2004). *An introduction to design and culture*. Abington, UK: Routledge.

Speed, C., & Maxwell, D. (2015, September 1). Designing through value constellations. *ACM Interactions Magazine*, *22*(5), 38–43. https://doi.org/10.1145/2807293

Speed, C., & Oberlander, J. (2016). Designing from, with and by Data: Introducing the ablative framework. In *DRS- Design Research Society Conference*.

Spradley, J. (1979). *The ethnographic interview*. New York: Holt, Rinehart & Winston.

Stake, R. E. (1994). Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 236–247). SAGE.

Stake, R. E. (1995). *The Art of Case Study Research*. Thousand Oaks, CA: SAGE. Retrieved from https://books.google.co.uk/books/about/The_Art_of_Case_Study_Research.html?id=ApGdBx76b9kC&printsec=frontcover&source=kp_read_button&redir_esc=y#v=onepage&q&f=false

Stake, R. E. (2005). Qualitative Case Studies. In N. K. D. & Y. S. Lincoln (Ed.), *The Sage handbook of qualitative research*. SAGE Publications Ltd. Retrieved from https://psycnet.apa.org/record/2005-07735-017

Stake, R. E. (2006). *Multiple Case Study Analysis*. The Guilford Press.

Stark, J. (2011). *Product Lifecycle Management: 21st Century Paradigm for Product Realisation*. London, U.K: Springer.

Stark, S., & Torrance, H. (2005). Case Study. In B. Somekh & C. Lewin (Eds.), *RESEARCH METHODS IN THE SOCIAL SCIENCES* (1st eds, pp. 33–40). London, England.: SAGE

Publications Ltd.

Steinitz, C. (1995). Design is a verb, design is a noun. *Landscape Journal*, *14*(2), 188–200.

Strauss, A., & Corbin, J. M. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. SAGE Publications, Inc.

Strauss, Anselm., & Corbin, J. M. (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (1st eds). SAGE Publications.

Strovang, P., Jensen, S., & Christensen, P. R. (2014). Innovation through Design: A Framework for Design Capacity in a Danish Context. *Design Management Journal*, *9*, 9–22.

Sundbo, J. (2002). The service economy: Standardisation or customisation? *Service Industries Journal*, *22*(4), 93–116. https://doi.org/10.1080/714005099

Svahn, F., & Henfridsson, O. (2012). The dual regimes of digital innovation management. In *Proceedings of the Annual Hawaii International Conference on System Sciences* (pp. 3347–3356). IEEE Computer Society. https://doi.org/10.1109/HICSS.2012.560

Svahn, F., Henfridsson, O., & Yoo, Y. (2009). A Threesome Dance of Agency: Mangling the Sociomateriality of Technological Regimes in Digital Innovation. In *International Conference on Information Systems* (pp. 1–18).

Takeuchi, H., & Nonaka, I. (1986). The New New Product Development Game. *Harvard Business Review*. Retrieved from https://hbr.org/1986/01/the-new-new-product-development-game

Talke, K., Salomo, S., Wieringa, J. E., & Lutz, A. (2009). What about design newness? Investigating the relevance of a neglected dimension of product innovativeness. *Journal of Product Innovation Management*, *26*(6), 601–615. https://doi.org/10.1111/j.1540-5885.2009.00686.x

Tan, A. R., Matzen, D., Mcaloone, T. C., & Evans, S. (2010). Strategies for designing and developing services for manufacturing firms. *Journal of Manufacturing Science and Technology*, *3*(2), 90–97. https://doi.org/10.1016/j.cirpj.2010.01.001

Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., … C Nee, A. Y. (2018). Digital twin-driven product design framework. *International Journal of Production Research*, *57*(12), 3935–3953. https://doi.org/10.1080/00207543.2018.1443229

Terzi, S., Bouras, A., Dutta, D., Garetti, M., & Kiritsis, D. (2010). Product lifecycle management- From its history to its new role. *International Journal of Product*

Lifecycle Management, *4*(4), 360–389.

Tether, B. (2005). *The role of design in business performance. ESRC Centre for Research on Innovation and Competition*.

The Standish Group. (2014). *Chaos Report*.

Thornton, H. P. (1987, June). Why You Need the Industrial Designer. *Machine Design*, 109–113.

Tilson, D., Lyytinen, K., & Sørensen, C. (2010). Digital Infrastructures: The Missing IS Research Agenda. *Information Systems Research*, *21*(4), 748–759. https://doi.org/10.1287/isre.1100.0318

Trott, P. (2011). *Innovation Management and New Product Development* (5th ed.). Financial Times/Prentice Hall.

Trott, P. (2012). *Innovation Management and New Product Development* (5th Editio). London, England.: Pearson Education.

Trott, P., & Hartmann, D. (2009). Why "open innovation" is old wine in new bottles. *International Journal of Innovation Management*, *13*(4), 715–736. https://doi.org/10.1142/S1363919609002509

Tsang, E. W. K. (2013). Case study methodology: Causal explanation, contextualization, and theorizing. *Journal of International Management*, *19*(2), 195–202. https://doi.org/10.1016/j.intman.2012.08.004

Tsang, E. W. K. (2014). Generalizing from research findings: The merits of case studies. *International Journal of Management Reviews*, *16*(4), 369–383. https://doi.org/10.1111/ijmr.12024

Tuomi, J., & Sarajärvi, A. (2006). *Laadullinen tutkimus ja sisällönanalyysi [Qualitative research and content analysis]*. Gummerus Printing House Oy.

Turber, S., vom Brocke, J., Gassmann, O., & Fleisch, E. (2014). Designing Business Models in the Era of Internet of Things. In *International Conference on Design Science Research in Information Systems: Advancing the Impact of Design Science: Moving from Theory to Practice*.

Ulrich, K. T., & Eppinger, S. D. (2011). *Product Design and Development*. Boston, MA: McGraw-Hill.

Unger, D. W., & Eppinger, S. D. (2009). Comparing product development processes and managing risk. *International Journal of Product Development*, *8*(4), 382–402.

https://doi.org/10.1504/IJPD.2009.025253

Urgese, G., Azzoni, P., Van Deventer, J., Delsing, J., & Macli, E. (2020). An Engineering Process model for managing a digitalised life-cycle of products in the Industry 4.0. In *IEEE/IFIP Network Operations and Management Symposium 2020: Management in the Age of Softwarization and Artificial Intelligence*. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/NOMS47738.2020.9110365

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing and Health Sciences*, *15*(3), 398–405. https://doi.org/10.1111/nhs.12048

Varga-Atkins, T., & O'brien, M. (2009). From drawings to diagrams: maintaining researcher control during graphic elicitation in qualitative interviews. *International Journal of Research & Method in Education*, *32*(1), 53–67. https://doi.org/10.1080/17437270902759998

Vargo, S. L., & Akaka, M. A. (2009). Service-Dominant Logic as a Foundation for Service Science. *Clarifications. Service Science*, *1*(1), 32–41. https://doi.org/10.1287/serv.1.1.32

Vargo, S. L., & Lusch, R. F. (2004a). Evolving to a New Dominant Logic for Marketing. *Journal of Marketing*, *68*(1), 1–17.

Vargo, S. L., & Lusch, R. F. (2004b). The Four Service Marketing Myths Remnants of a Goods-Based, Manufacturing Model. *Journal of Service Research*, *6*(4), 324–335. https://doi.org/10.1177/1094670503262946

Vargo, S. L., & Lusch, R. F. (2008). Service-dominant logic: continuing the evolution. *Journal of the Academy of Marketing Science*, *36*, 1–10. https://doi.org/10.1007/s11747-007-0069-6

Vargo, S. L., Lusch, R. F., Akaka, M. A., & Maglio, P. P. (2010). Advancing Service Science with Service-Dominant Logic: Clarifications and Conceptual Development. In *Handbook of Service Science* (pp. 133–156). https://doi.org/10.1007/978-1-4419-1628-0_8

Vargo, S. L., Maglio, P. P., & Akaka, M. A. (2008). On value and value co-creation: A service systems and service logic perspective. *European Management Journal*, *26*(3), 145–152. https://doi.org/10.1016/j.emj.2008.04.003

Vasantha, G., Roy, R., Lelah, A., & Brissaud, D. (2012). A review of product-service systems design methodologies. *Journal of Engineering Design*, *23*(9), 635–659. https://doi.org/10.1080/09544828.2011.639712

Verganti, R. (2008a). Design, Meanings, and Radical Innovation: A Metamodel and a Research Agenda. *Journal of Product Innovation Management*, *25*(5), 436–456. https://doi.org/10.1111/j.1540-5885.2008.00313.x

Verganti, R. (2008b). Design, Meanings, and Radical Innovation: A Metamodel and a Research Agenda *. *Journal of Product Innovation Management*, *25*(5), 436–456. https://doi.org/10.1111/j.1540-5885.2008.00313.x

Verganti, R. (2009). Design Driven Innovation: Changing the Rules of Competition by Radically Innovating What Things Mean. *Harvard Business Press*, 288.

von Hippel, E. (1986). Lead Users: A Source of Novel Product Concepts. *Management Science*, *32*(7), 791–805. https://doi.org/10.1287/MNSC.32.7.791

Walras, L. (1874). *Elements of Pure Economics*. Illinois: Richard D. Irwin.

Walsh, V., Roy, R., Bruce, M., & Potter, S. (1992). *Winning by Design: Technology Product Design and International Competitiveness*. Oxford, UK: Blackwell Publishing.

Wamba, S. F., Akter, S., Edwards, A., Chopin, G., & Gnanzou, D. (2015). How “big data” can make big impact: Findings from a systematic review and a longitudinal case study. *International Journal of Production Economics*, *165*, 234–246. https://doi.org/10.1016/j.ijpe.2014.12.031

Ward, A., Runcie, E., & Morris, L. (2009). Embedding innovation: Design thinking for small enterprises. *Journal of Business Strategy*, *30*(2–3), 78–84. https://doi.org/10.1108/02756660910942490

Warde, A. (2005). Consumption and Theories of Practice. *Journal of Consumer Culture*, *5*(2), 131–153. https://doi.org/10.1177/1469540505053090

Weber, P., Morar, D., & Lasi, H. (2018). Transforming Value Chains into Internet-based Ecosystems. In *Technology Management for Interconnected World*.

Welch, C., Piekkari, R., Plakoyiannaki, E., & Paavilainen-Mäntymäki, E. (2011). Theorising from case studies: Towards a pluralist future for international business research. *Journal of International Business Studies*, *42*, 740–762.

Welp, E. G., Meier, H., Sadek, T., & Sadek, K. (2008). Modelling approach for the integrated development of industrial product–service systems. In *The 41st CIRP conference on manufacturing systems*.

Westcott, M., Sato, S., Mrazek, D., Wallace, R., Vanka, S., Bilson, C., & Hardin, D. (2013). The DMI Design Value Scorecard: A New Design Measurement and Management

Model. *Design Management Review*, *24*(4).

Westerlund, M., Leminen, S., & Rajahonka, M. (2014). Designing Business Models for the Internet of Things. *Technology Innovation Management Review*.

White, M. (2012). Digital Workplaces: Vision and Reality. *Business Information Review*, *29*(4), 205–214.

Wiesner, S., Guglielmina, C., Gusmeroli, S., & Dougmeingts, G. (2014). *Manufacturing Service Ecosystem*. (S. Wiesner, C. Guglielmina, S. Gusmeroli, & G. Dougmeingts, Eds.). Aachen: Mainz Verlag.

Wilson, R. (1995). Industrial Design in Practice: New Order. *Engineering Magazine*, 4–5.

Wisker, G. (2008). *The postgraduate research handbook: succeed with you MA, Mphil, and PhD*. Palgrave Macmilan.

Woodruff, R. B. (1997). Customer value: The next source for competitive advantage. *Academy of Marketing Science. Journal; Spring*, *25*(2).

Wu, D., Rosen, D. W., Wang, L., & Schaefer, D. (2015). Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. *Computer-Aided Design*, *59*, 1–14.

Wu, M., Lu, T., Ling, F., Sung, J., & Du, H. (2010). Research on the architecture of internet of things. In *3rd International Conference on Advanced Computer Theory and Engineering*. Chengdu, China.

Xu, X. (2012). From cloud computing to cloud manufacturing. *Robotics and Computer-Integrated Manufacturing*, *28*(1), 75–86. https://doi.org/10.1016/j.rcim.2011.07.002

Yazan, B. (2015). Three approaches to case study methods in education: Yin, Merriam, and Stake. *The Qualitative Report*, *20*(2), 134–152.

Yin, R. K. (1994). *Case Study Research Design and Methods: Applied Social Research and Methods Series* (2nd edn). Thousand Oaks, CA: SAGE Publications, Inc.

Yin, R. K. (2003). *Case study research: Design and methods* (3rd eds). Thousand Oaks, CA: SAGE.

Yin, R. K. (2008). *Case Study Research: Design and Methods* (5th eds). Beverly Hills, Calif: SAGE Publications.

Yin, R. K. (2009). *Case Study Research: Design and Methods* (4th ed.). SAGE. Retrieved from https://books.google.co.uk/books/about/Case_Study_Research.html?id=FzawIAdilHkC

&redir_esc=y

Yin, R. K. (2013). *Case study research: Design and methods*. SAGE Publications.

Yoo, Y. (2010). Computing in Everyday Life: A Call for Research on Experiential Computing. *MIS Quarterly*, *34*(2), 213–231.

Yoo, Y. (2013). The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research? *Journal of the Association for Information Systems*, *14*, 227–236.

Yoo, Y., Boland, R. J., Lyytinen, K., & Majchrzak, A. (2012). Organizing for innovation in the digitized world. *Organization Science*, *23*(5), 1398–1408. https://doi.org/10.1287/orsc.1120.0771

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). The new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research*, *21*(4), 724–735. https://doi.org/10.1287/isre.1100.0322

Yoo, Y., Lyytinen, K., & Boland, R. J. (2008). Distributed innovation in classes of networks. In *Proceedings of the Annual Hawaii International Conference on System Sciences*. https://doi.org/10.1109/HICSS.2008.125

Yoo, Y., Lyytinen, K. J., Boland, R. J., & Berente, N. (2010). The Next Wave of Digital Innovation: Opportunities and Challenges: A Report on the Research Workshop "Digital Challenges in Innovation Research." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1622170

Yu, S., & Yang, D. (2016). The Role of Big Data Analysis in New Product Development. In *International Conference on Network and Information Systems for Computers* (pp. 279–284).

Zainal, Z. (2007). Case study as a research method. *Jurnal Kemanusiaan Bil*, *9*.

Zeithaml, V. A. (1988). Consumer Perceptions Of Price, Quality, And Value: A Means. *Journal of Marketing*, *52*(3), 2–22.

Zeithaml, V. A., Parasuraman, A., & Berry, L. L. (1985). Problems and Strategies in Services Marketing. *Journal of Marketing*, *49*(2), 33–46.

Zimmermann, E. W. (1951). *World Resources and Industries*. New York: Harper and Row.

Zittrain, J. (2008). *The Future of the Internet and How to Stop It*. Yale University Press.

Zuboff, S. (1988). *In the Age of the Smart Machine: The Future of Work and Power*. New York: Basic Books.

Zymek, R., & Jones, B. (2020). *UK Regional Productivity Differences: An Evidence Review Industrial Strategy Council Research Paper About the Industrial Strategy Council*.

APPENDICES

Appendix A. Ethics approval forms

A-1. Participant Information sheet (Case study)

Dear Participant, we would like to invite you to participate in our research project. This sheet provides brief information about the aims of the research. Please take the time to read this information to decide if you wish to take part in the research. With this information sheet, you will be given a consent form to confirm your participation.

Research aims:

With the emergence of Internet of Things (IoT) as a new source of massive data, businesses face emergent opportunities as well as challenges. 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. However, despite the fact that academics and practitioners often critically debate these emergent opportunities and challenges to the adoption of the 'Internet of Things', less attention has been paid to: 1) how IoT products and services are developed. 2) How value propositions and turnover is created. 3) What risks they are encountered and how they manage them over the development process. 4) How designers contribute to value creation. Therefore, this research aims to develop guidelines on new product development (NPD) processes for IoT products and services which aim to increase value and turnover.

Why have I been invited?

You have been invited to participate in this research because you have been identified as a practitioner or academic who is an expert regarding the field of new product development and value creation for IoT.

What do you need from me?

If you agree to take part in this research, you will be interviewed for up to 1 hour about your observations or opinions around one or more of the topics below:

- How are IoT products and services developed?
- How do organisations create value for IoT?
- How are risks and qualities over the product development process managed?

In addition, after the researcher's analysis of the overall data for the thesis, you may be asked to comment on the findings of the research from your perspective to confirm accuracy.

What will be done with the data and my personal information?

The interviews will be audio-recorded. The audio-recorded data will be deleted from the recorder as soon as possible once they are transferred to my password protected laptop computer. Then, any identifiable data will be encrypted. Your information, if requested, will be kept anonymous. The data and all your personal information (e.g. your consent form) will be stored in my locked office desk drawer for no longer, than 5 years from the date you sign the consent form.

Where will the information be used?

Primarily it will be used as part of my written PhD thesis, and may be used in future reports, academic papers and presentations to academics and practitioners worldwide.

Do I need to participate?

Your participation would be invaluable for this research, but it is entirely up to you. You can choose freely whether to take part or not in this research project. In addition, although you do agree to participate, you will be able to withdraw at any time, without giving any reason. In order to withdraw from this research, it will be sufficient via email to me - Boyeun Lee. If you withdraw within two weeks after the individual interview, your data will be destroyed and not used.

Who do I need to contact for clarification?

Please feel free to ask any further question related to this research. Furthermore, in case of any concerns or complaints or if you wish further detailed information, you can contact Prof. Rachel Cooper OBE, the main project supervisor below.

Researcher:
Boyeun Lee
PhD Student, PETRAS
LICA Building, Lancaster University, Bailrigg, Lancaster, LA1 4YW, UK
(07828) 549549; email: b.lee12@lancaster.ac.uk

Main supervisor:
Prof. Rachel Cooper OBE.
Co-director of Imagination Lancaster
+44 (0) 1524 510871; email: r.cooper@lancaster.ac.uk

A-2. Participant Consent form (Case study)

New product development processes and value creation in IoT

Researcher: Boyeun Lee (b.lee12@lancaster.ac.uk)

1. I confirm that I have read and understand the information document dated for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐

3. I understand that any information given by me may be used in future reports, PhD thesis, articles, publications or presentations by the researcher, but my personal information will not be included, and I will not be identifiable. ☐

4. I understand that my name, my organisation's name will not appear in any reports, articles or presentation without my consent. ☐

5. I understand that interviews will be audio recorded and transcribed and that data will be protected on encrypted devices and kept secure. ☐

6. I understand that data will be securely kept according to University guidelines for a minimum of 10 years after the end of study. ☐

7. I agree to take part in the above study. ☐

____ ______________________

Name of Participant. Signature Date

____ ______________________

Researcher. Signature Date

A-3. Participant Consent form (Expert Audit Review)

Expert Reviews on the conceptual model of IoT NPD process

Researcher: Boyeun Lee (b.lee12@lancaster.ac.uk)

1. I understand that any information given by me may be used in future reports, PhD thesis, articles, publications or presentations by the researcher, but my personal information will remain anonymous. ☐

2. I understand that data will be securely kept according to University guidelines for a minimum of 10 years after the end of study. ☐

3. I agree to take part in this study. ☐

Name of Participant.	Signature	Date
Researcher.	Signature	Date

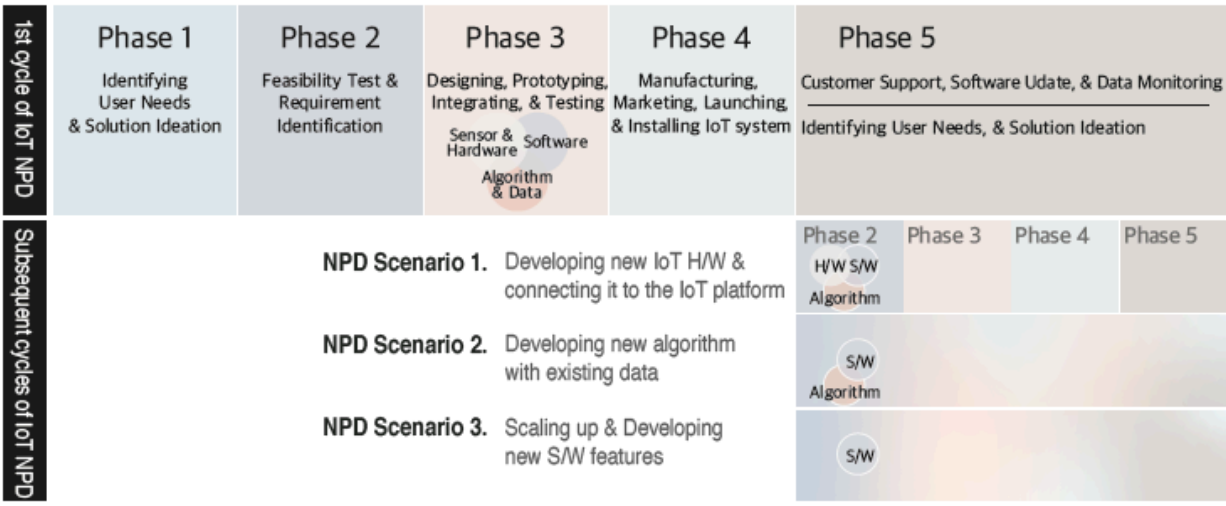
Appendix B. Report of research findings for expert audit review

Report of Case Research for Expert Review

This report is to summarise key findings of my PhD research on conceptual model and attributes of IoT NPD practice and process. Applying qualitative multiple case study methodology, six IoT development cases in the UK participated in this research. Data collection involved document reviews, semi-structured interviews, and graphic elicitation with the project leaders and managers. IoT cases were those who lead development activities of all hardware, software and data process. Six cases are from various sectors, including healthcare, smart home, drain maintenance, dairy, vertical farming and tropical farming. As a result, two key findings and associated insights were derived:

Finding 1. Five attributes of IoT NPD process:

Along with the five attributes of IoT NPD process, the five phases of IoT NPD process identified from empirical data are not that discernibly different to contemporary NPD processes as follows (Figure 01). Once the first IoT deployment is delivered, the IoT company go through subsequent cycles of NPD which are three different scenarios depending on their value creation strategy.



Although the five phases of the IoT NPD process appear to be similar to the conventional NPD processes, having a deeper investigation into the activities of IoT development, five attributes of IoT NPD process are identified.

Firstly, the IoT NPD process consists of three continuous loops, each representing the subsequent IoT NPD processes depending on the focus of development and related value creation activities. These three distinctive loops can be supported by and explained within the IoT paradigm as a result of the convergence of different visions: 1) A hardware centred, 2) a software centred, and 3) a data and algorithms centred development. Accordingly, each loop has a distinctive emphasis on developmental activities. The 1st NPD on the top left involves developing and integrating hardware, software, data and algorithms. The IoT NPD on the bottom is software-centred development, and the IoT NPD on top right is a data and algorithms centred development (Figure 02).

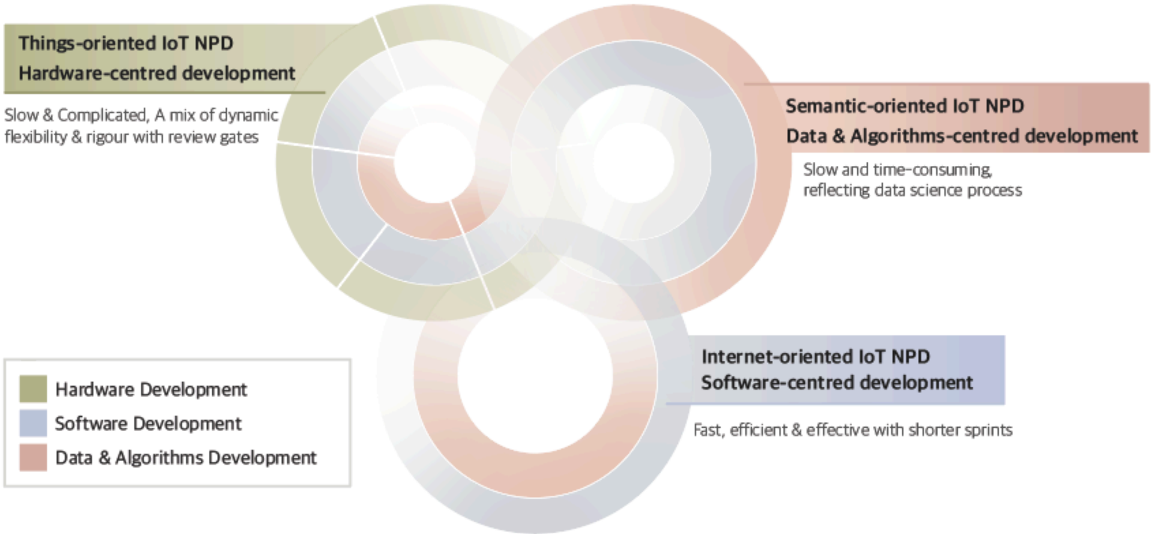


Figure 02. A conceptual model of IoT NPD process [Simple version]

Second, the IoT NPD model highlights the continuous and emergent process thanks to real-time data that helps identify new value propositions and the software elements that enable perpetual beta. From a digital component perspective, the IoT artefacts are intentionally designed to be incomplete and perpetually in development. From a data perspective, value creation with big data aligns with prevailing views that regards value as a never-ending process, thus extending far beyond the making and delivery of 'final' products and services. The IoT NPD process starts from the top left loop and continues to the top right or to the bottom of IoT NPD processes. The fifth phase of the IoT NPD process, where companies support their customers, monitor the real-time data and update software, which re-enforces this value enhancement attribute to the end-user. The development cycle may return to the 1st IoT NPD process (Top-left) if a newly identified value proposition requires new device development or modification.

Thirdly, a conceptual IoT NPD process involves three different types of subject matter which are illustrated as different colour legends. The green layer involves hardware, the blue layer is software, and the pink layer relates to data and algorithm development. Unlike other NPD, SDLC, NSD and PSS processes, developing all different types occurs tensions and challenges not only from different speeds and approaches of physical products and software development but also integrating all the different components of the IoT system. Kahle et al. (2020) point out that IoT system integration is the most difficult in respect to value creation.

Fourth, hardware, software, data, and algorithms development activities have distinctive characteristics in terms of the development speed and approaches. The first IoT NPD process is a combination of dynamic flexibility and rigour with regular design reviews as it involves hardware, software and data practice. Firms should synchronize the contrasting "clock speeds" of hardware and software development. On the contrary, the bottom centred IoT NPD process is more agile with vague distinctions between the phases as it is software centred development set of activities. The top right IoT NPD process where data and algorithm centred development is characterised as a lengthy and continuous process. Also, the model integrates all three development activities, ensuring that the first IoT NPD is more complicated than the two others.

On reflection this attribute of the IoT NPD process, the last attribute is that the IoT NPD process is a slow, complex and expensive process involving all three concurrent development activities being simultaneously addressed. Once the system is launched, the process may become a fast-flowing process that is predominantly software centred. Moreover, the temporal division between development and usage is condensed once the IoT system is launched onto the marketplace.

Finding 2. Conceptual model of IoT NPD process:

This novel approach is named the Mobius strip model for IoT NPD as it implies three infinite loops of value creation and NPD activities (Figure 03) occurring in real-time. While NPD approach of each development loop varies depending on the focus of value creation activities and subject matter, the agility of development practices is identified. The first cycle of the IoT NPD process involves all three developments, including hardware that requires robust approval, deep and thoughtful planning influenced by linear NPD process. Thus, it makes development activities and integration of all three slow and overly complicated. Whether developing a new device or merging other's devices to the existing IoT system, this point is where one of the actual values of the IoT is thoroughly realised, having more things connected and communicated with each other in a seamless manner.

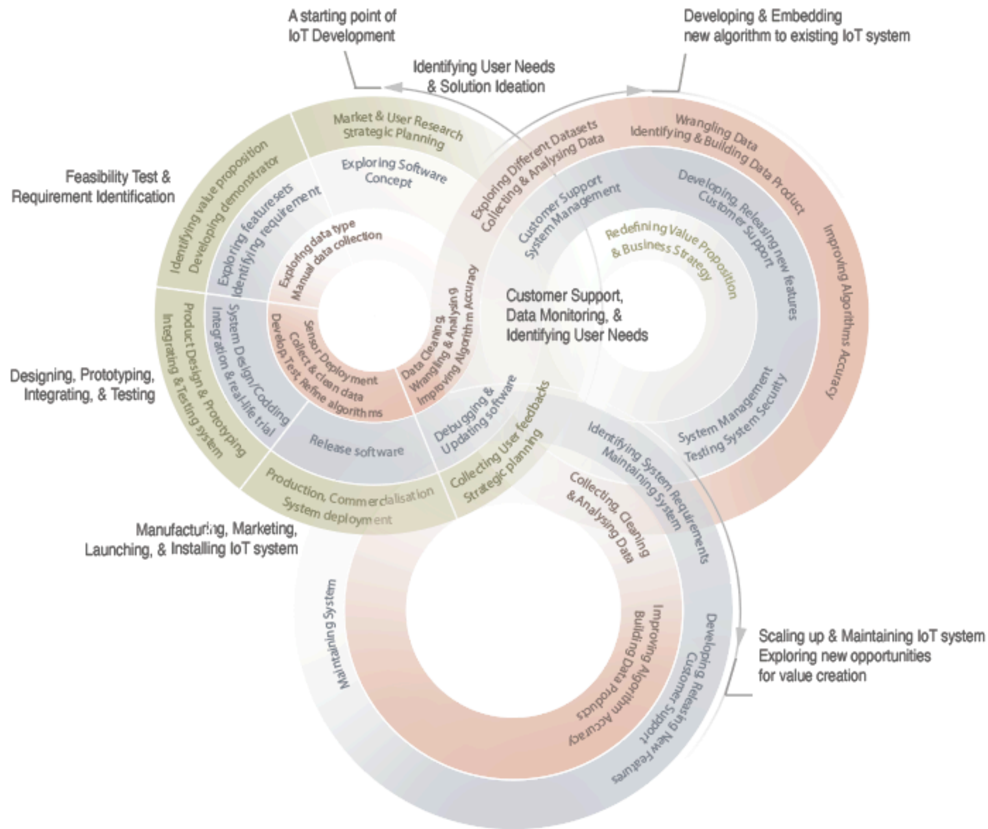


Figure 03. The Mobius strip model of IoT NPD

Once the IoT device is launched and implemented, the development activities become more agile, composed of shorter sprint cycles due to the primary focus on software development which is the bottom centred development cycle. It is characterised as more flexible, efficient and effective without major modification to the IoT system. Companies aim to scale up by increasing numbers of deployment or diversifying the IoT application areas while improving their existing system with a focus on satisfying their customers. Regarding data and algorithm development, the company develops and delivers valuable information to their customers through PR messaging, via notifications or alerts. While providing invaluable information and additional add-on services that are continuously improved and adapted to customer needs, organisations gradually transform the business model into a service provider, generating recurring profit.

The third NPD element (Top right) is novel in NPD literature through which organisations create new value propositions via adding new services through the introduction of new algorithms. The majority of IoT NPD activities over this process are related to data science practice and machine learning algorithm development. Consequently, the NPD process is slow and time-consuming, reflecting the challenges of the data science process which are discussed in established literatures. This cycle is identified as data and algorithms centred IoT NPD and value creation involves the interpretation and exploitation of complementary datasets.

Could you please give your opinions here?

Question. 1	**To what extent would you agree on the conceptual model, value creation strategies and attributes of the IoT NPD process considering your knowledge/experience?**
Your answer	
Question. 2	**Do you have any critical elements or point missing in this conceptual process, value creation strategies and attributes of the IoT NPD process?**
Your answer	
Etc.	**If you have any other comments…**
Your answer	

Thank you for your comments and opinions.

Appendix C. The experts' comments

<u>Profile of experts</u>

Expert	Position
Academic Expert 1	Full Professor of Innovation Management, Management School
Academic Expert 2	Full Professor of Design Engineering and Innovation, Business School
Academic Expert 3	Full Professor of Marketing and Service Systems, Manufacturing School
Academic Expert 4	Assistant Professor of Design Strategy, Management School
Academic Expert 5	Full Professor of Electronic and Electrical Engineering, Engineering School
Industry Expert 1	Founder of IoT business
Industry Expert 2	Project Manager of IoT system development
Industry Expert 3	Consultant in Innovation and Digital Transformation

<u>Experts Comments</u>

Q 1. To what extent would you agree on the conceptual model, value creation strategies and attributes of the IoT NPD process considering your knowledge/experience?	
Academic Expert 1	The conceptual diagram presented seems to be related to the characteristics of the companies surveyed in this study. Therefore, it will be necessary to carefully look at the attributes of the companies surveyed and adjust the scope of the generalization. For example, the survey does not seem to include IoT product development by information technology providers that offer data analysis platforms. In those cases, it is likely that HW will be generic and the focus will be more on data analysis platforms and related tools, data collection, and SW technologies. This case may be different from that of companies that are expected to mainly develop HW using the information technology covered in this report.
Academic Expert 2	I think it is very generic, and I agree with it, but would like to see a mapping of the planned processes with the elements specific to IOT/- in comment box have added references.
Academic Expert 3	This is a good model to describe the complex NPD process of IoT. It attempts to bring 3 major iterations - that of hardware, software and data into one space of understanding. It would help build bridges in understanding how they interact.
Academic Expert 4	The Conceptual Model is interesting and captures some peculiarities of the new product development process involving Internet of Things
Academic Expert 5	The strategies that have been identified are valid.

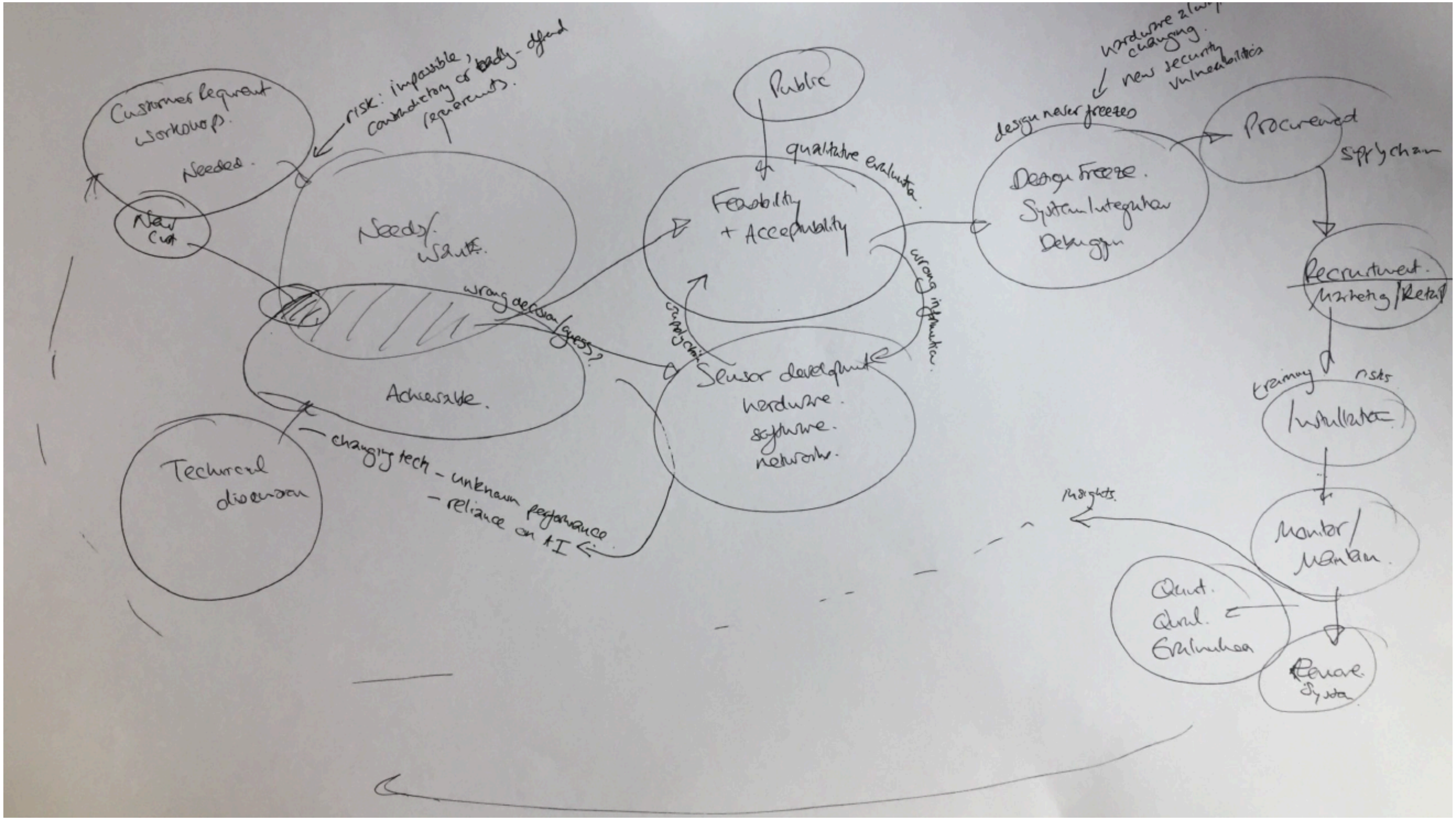
Industry Expert 1	The 3 different categories of hardware/software/data and algorithms make sense to me. It wasn't clear to me why the data and algorithms centred development would be slow (data science is just software?). I got a bit lost in your description of the "Mobius strip" so I think you need to clarify your essential argument.
Industry Expert 2	I can identify well with the model based on our experience, particularly the challenges around time, cost and complexity of the first cycle.
Industry Expert 3	Absolutely suitable. The description is valid and challenges are well captured. The different clock speed and approaches between different types is critical and is an important insight.
Q 2. Do you have any critical elements or point missing in this conceptual process, value creation strategies and attributes of the IoT NPD process	
Academic Expert 1	As indicated above, depending on the type of company, it is necessary to examine the activities and the relationship between them. In addition, development activities are not confined to a single company, but may be a collaboration with partners. Therefore, it will be important to collect more case studies using this model as a basic model and hypothesis.
Academic Expert 2	There is extensive literature on planned/ product development process, one key difference you have, is that much of the literature is for large manufacturing firms, and your work is in start-ups, explaining this is needed- see above point.
Academic Expert 3	This is a good model to start using to interrogate some of the challenges for IoT product development practices today. A few questions arise 1. The different “clock speeds” create tensions. Can the model help identify early where the tensions and challenges are and how to overcome them? 2. There are often multiple value propositions in IoT due to a wider stakeholder community engaged with the product. When is one value proposition “launched” would the rigidity of that value proposition result in prioritising one stakeholder group over another? Can the model be used to make that more transparent? 3. Multiple IoT products often interact to create a system. Can the model be used to for system design even while each NPD is being iterated upon?
Academic Expert 4	I’m not completely sure that the identification of three different “layers” of development (i.e., Hardware, Software, Data and Algorithms) can properly support “better” development strategies. It can probably support the identification of the required competences, but the three layers are so intertwined in the development that they need to be faced and managed synergically
Academic Expert 5	The process is detailed and appropriate.
Industry Expert 1	It might help to be clearer about why processes that are slow, are slow. Is it because of too much connectedness between different jobs, i.e. it is limited by people communicating? Or what?
Industry Expert 2	Worth noting that it is difficult to get beyond the first cycle without a critical mass of IoT deployments which in itself can be difficult without ongoing development and new offerings - a bit of a catch 22.

	Similarly, the second cycle can highlight additional requirements for the hardware or additional hardware in order to generate value which can leave you stranded between the cycles.
Industry Expert 3	It remains unclear why the model in fig 2 is called what is called and it is very difficult to read. I understand why you want to use the cycles, but the information in those cycles seems to be important. What I am missing is that there would be meetings with stakeholders/ managers from all three cycles somewhere

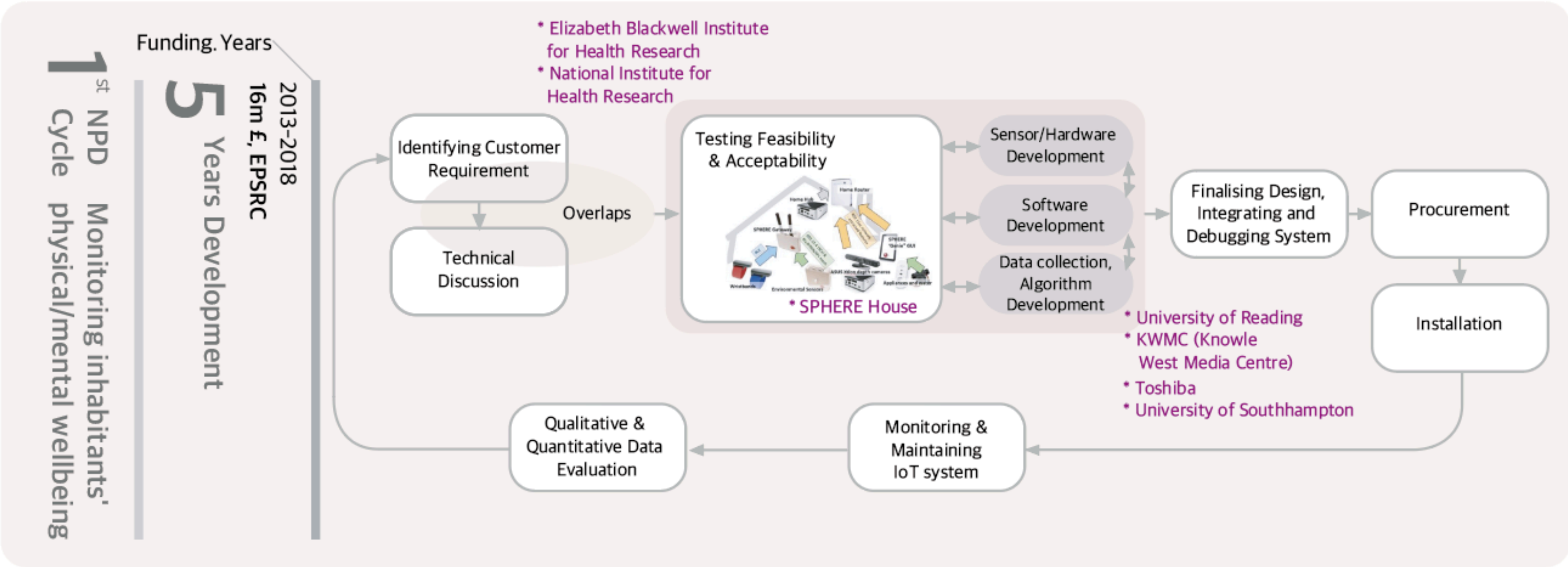
Q 3. Do you find any critical insight missing on this report?	
Academic Expert 1	This doctoral research is very interesting and is expected to provide value in companies.
Academic Expert 2	Here some suggestions: 1. It would be useful to consider how agile and stage gate models are combined- i.e. other process technologies, and if your process aligns to it. It looks like there are shared elements 2. And produced a guide for practitioners (this was a condition of the funding) of best practice/ and is freely available here 3. Some smaller points; the language, sometimes you use present and other times past tense, I would graphic elicitation in the first paragraph, what this is, is not entirely clear to me. I would add a you might have all this information in a methodology chapter).
Academic Expert 3	-
Academic Expert 4	-
Academic Expert 5	Useful capture of the NPD processes that are relevant to IoT solutions, a reference guide that supports the selection of the most appropriate approach that delivers on the requirements of the application/service.
Industry Expert 1	On first sight, it's not obvious why this data and algorithms centred IoT NPD should also be "slow". Hardware is slow because it takes time to make stuff, but software is generally fast, and data science is software. So why is this slow? Is it because the data and algorithms centred development need to be matched from one system to another?
Industry Expert 2	-
Industry Expert 3	I wouldn't agree that the data and algorithm is always super slow - but can probably be seen like this case by case. The software centered development would usually be using agile development cycles. Since you depicted stage gates I am wondering if you could also depict sprints in the blue cycle? Why would you only draw on product development literature when software is a service / solution and is developed as a learning cycle? I have a strong bias here from my past, but it could probably even help.

Appendix D. IoT NPD Process of six cases

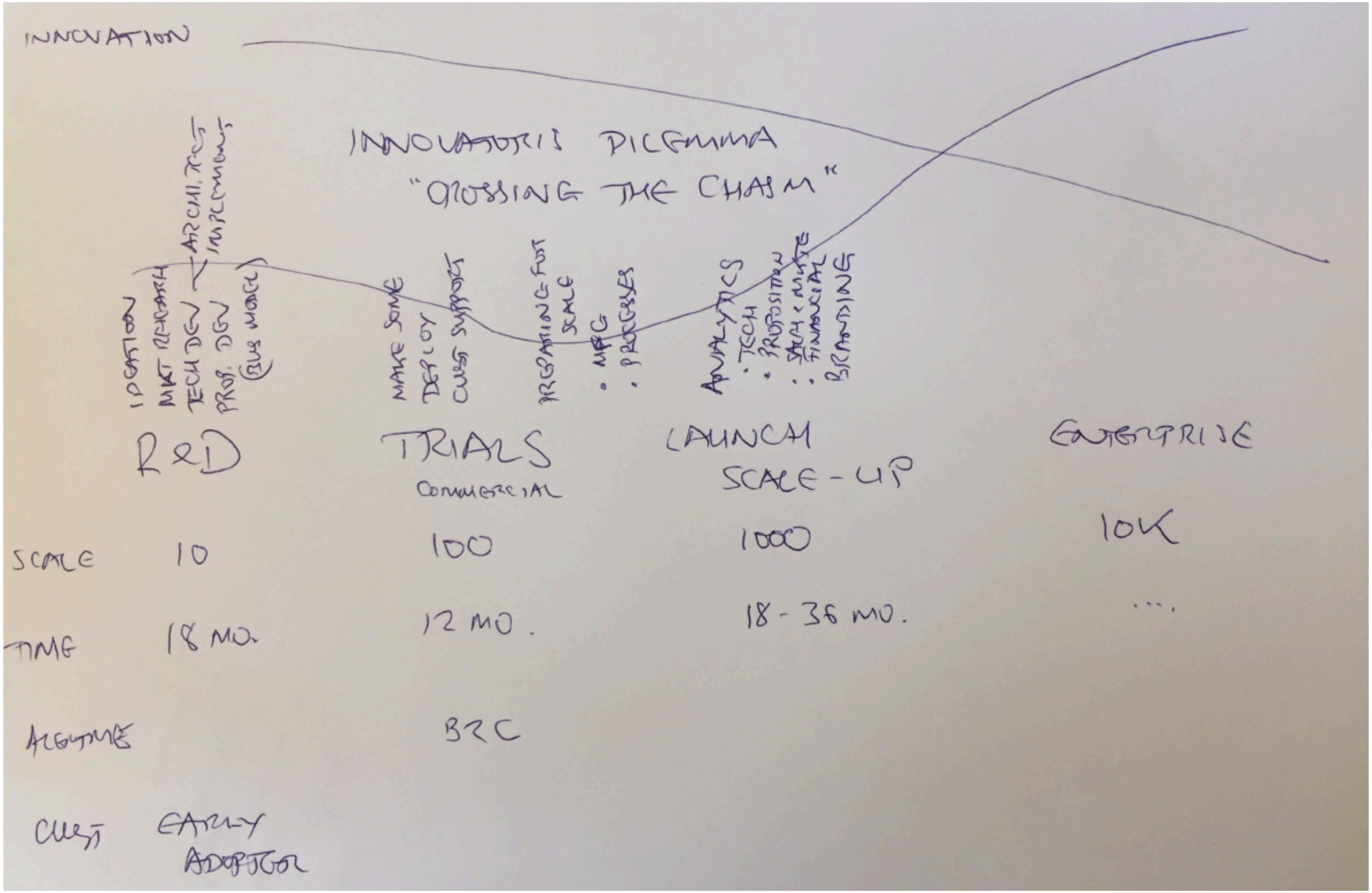
D-1. SPHERE NPD process illustrated by the informant



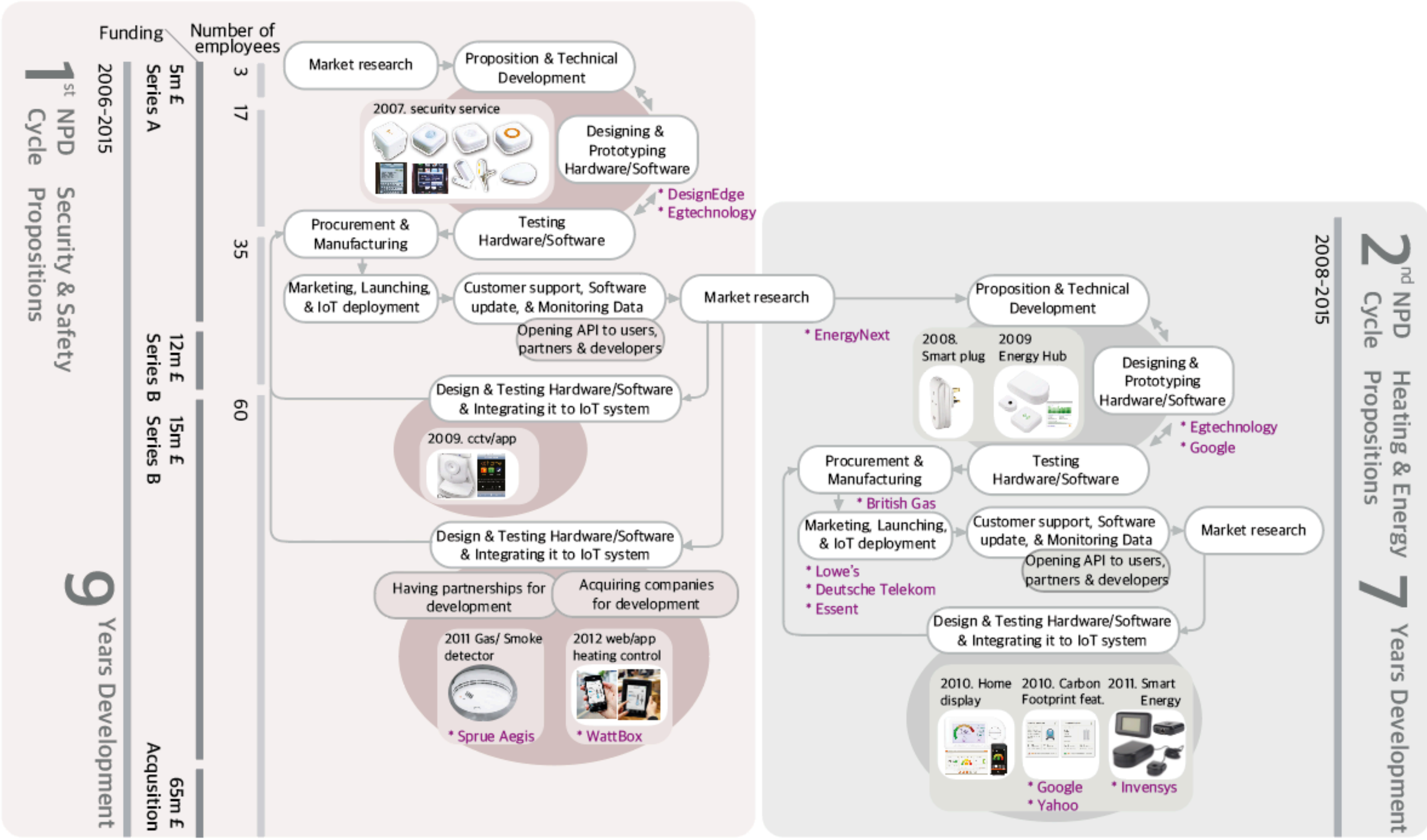
D-2. SPHERE NPD process interpreted by the researcher



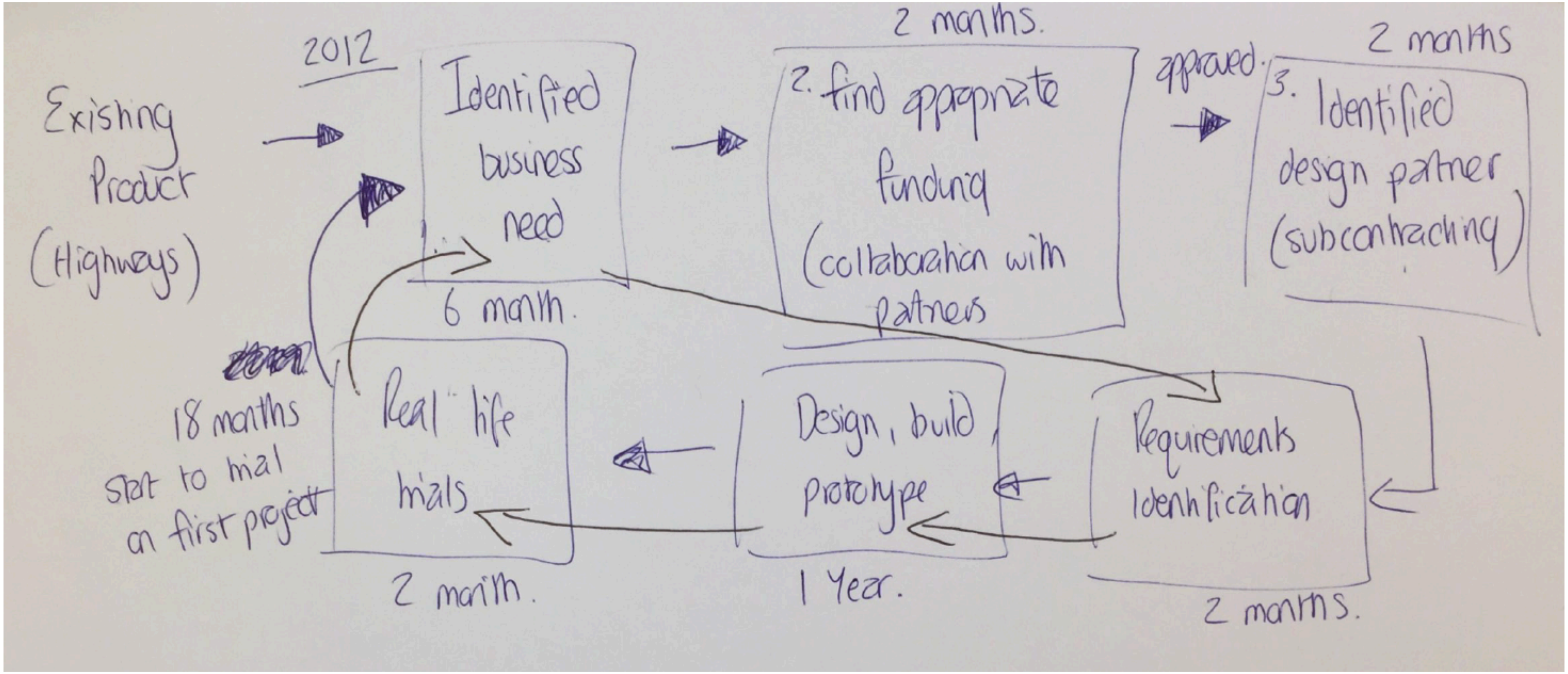
D-3. AlertMe NPD process illustrated by the informant



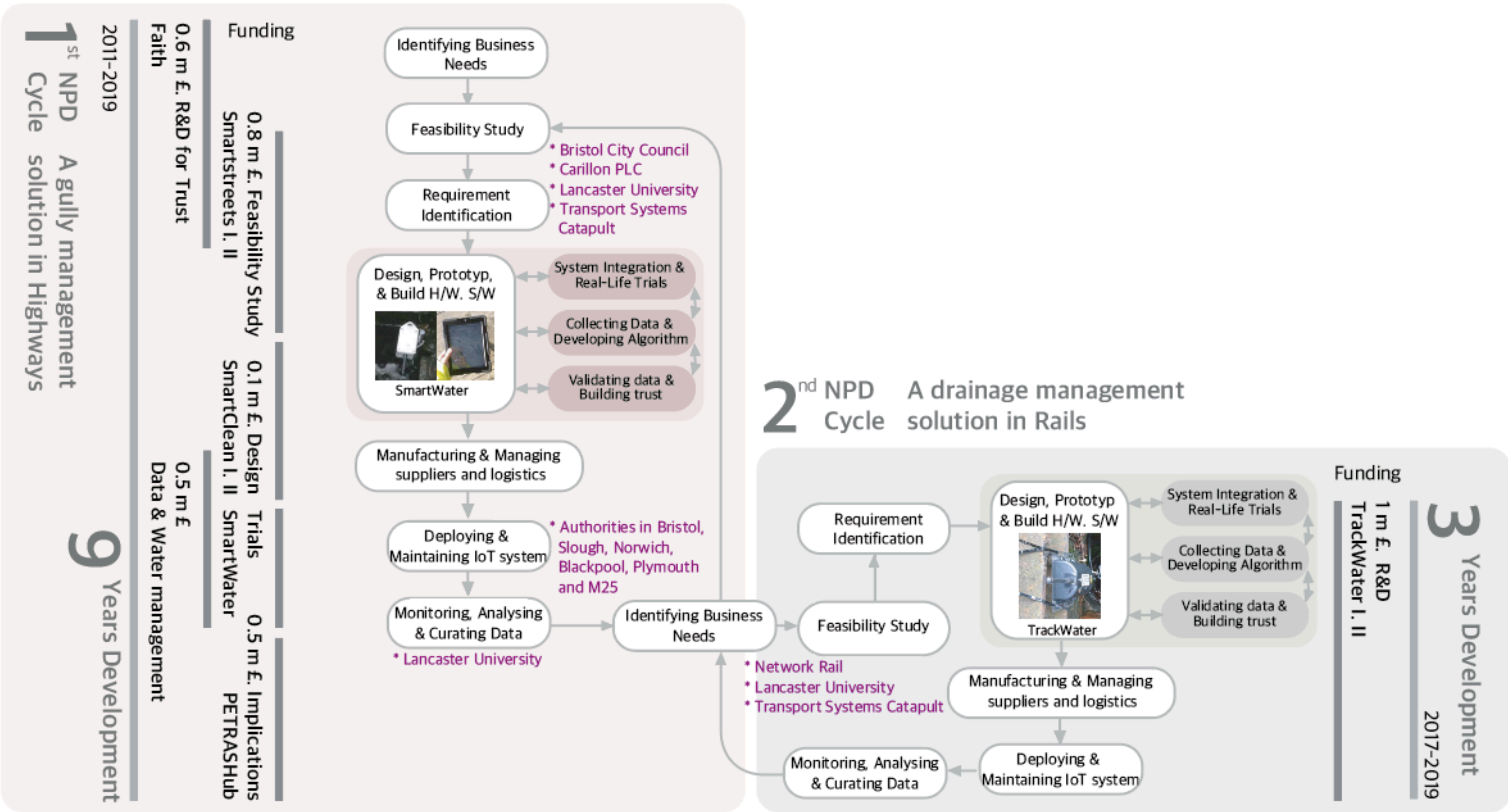
D-4. AlertMe NPD process interpreted by the researcher



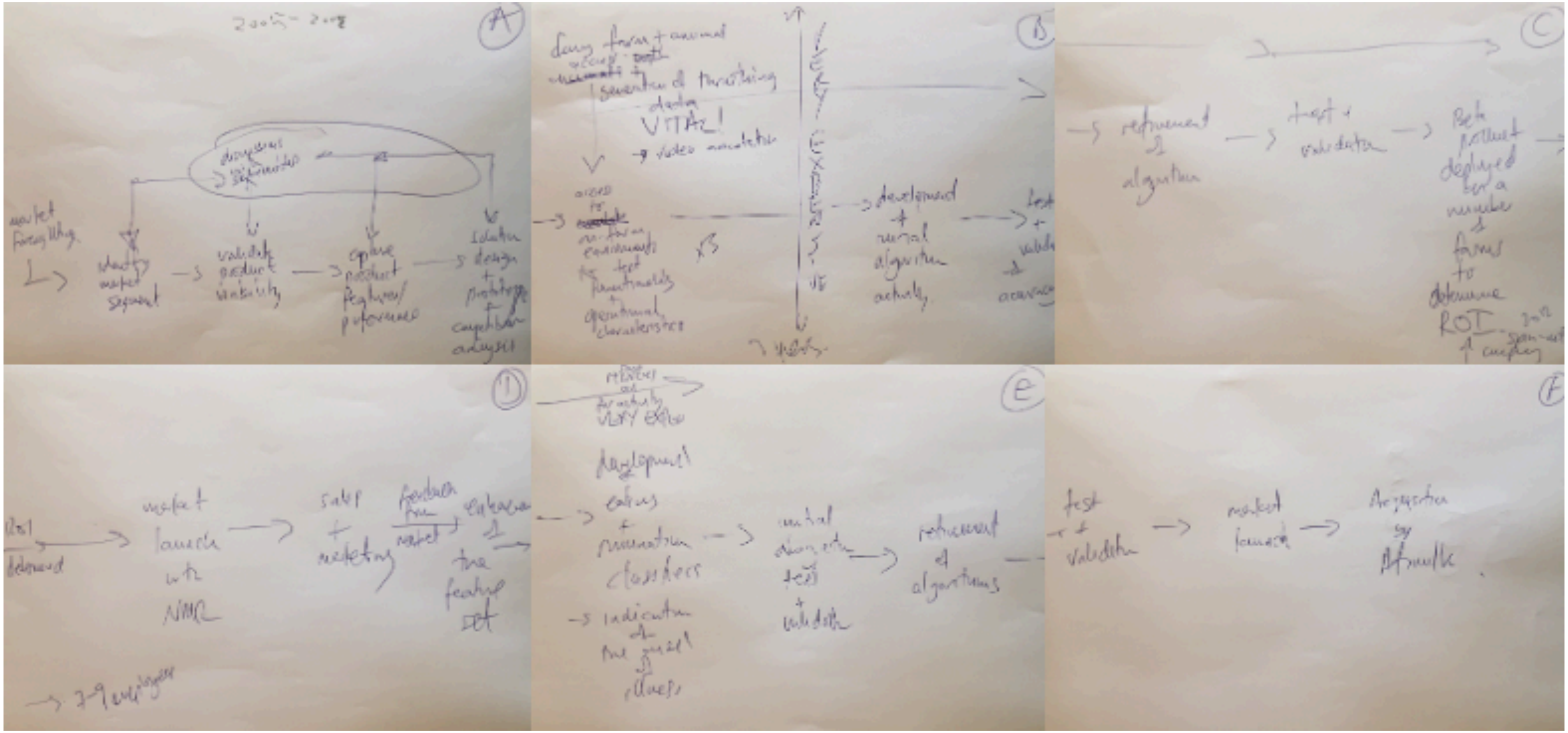
D-5. Anonymous Case NPD process illustrated by the informant



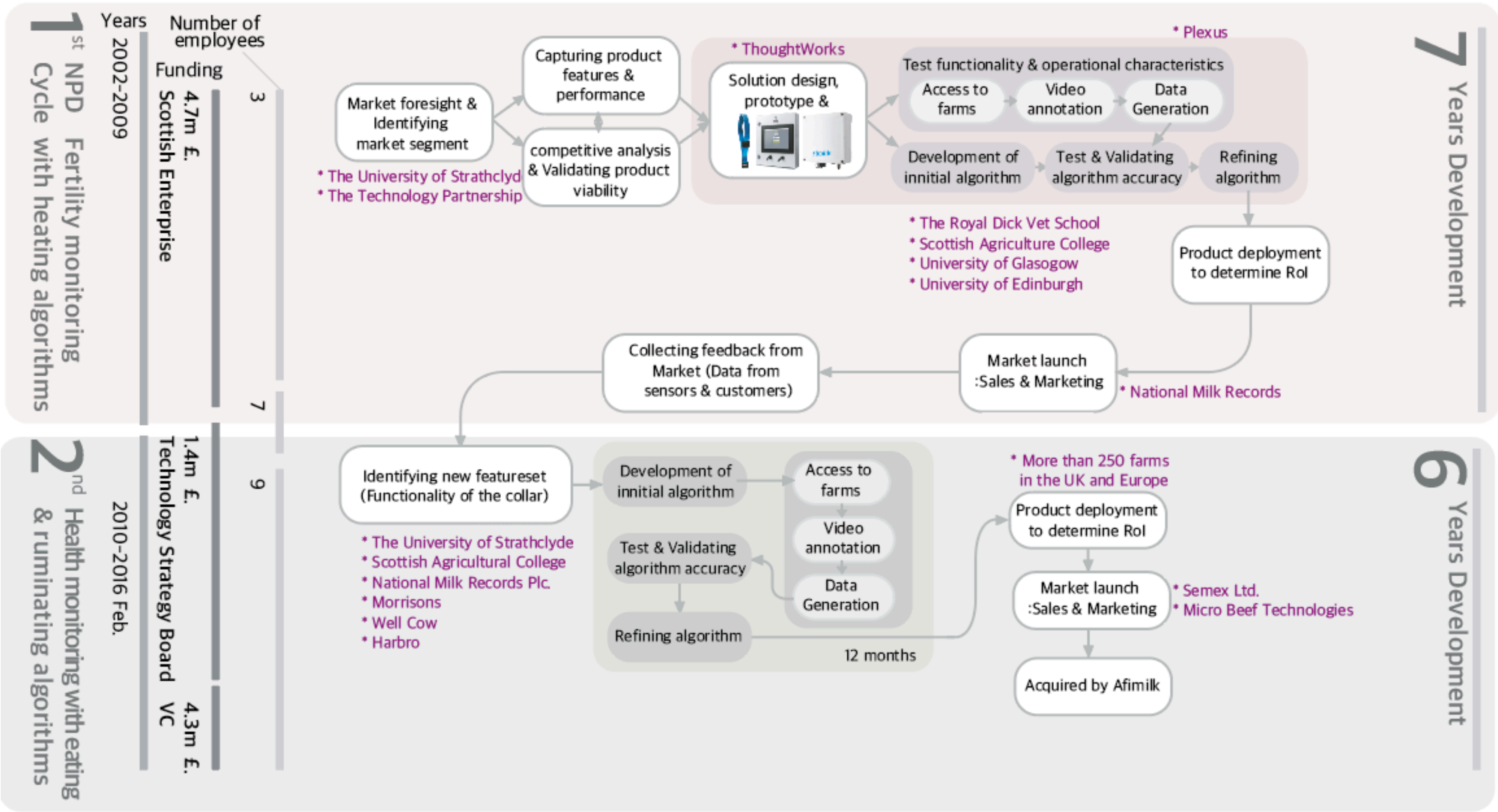
D-6. Anonymous Case NPD process interpreted by the researcher



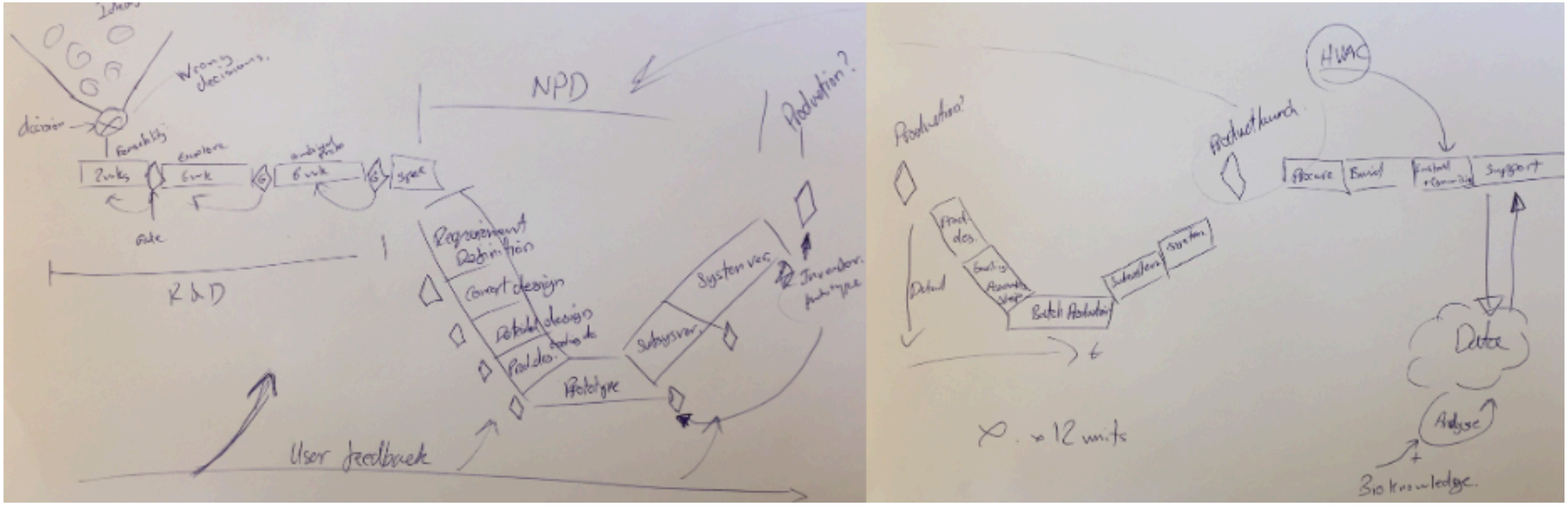
D-7. SilentHerdsman NPD process illustrated by the informant



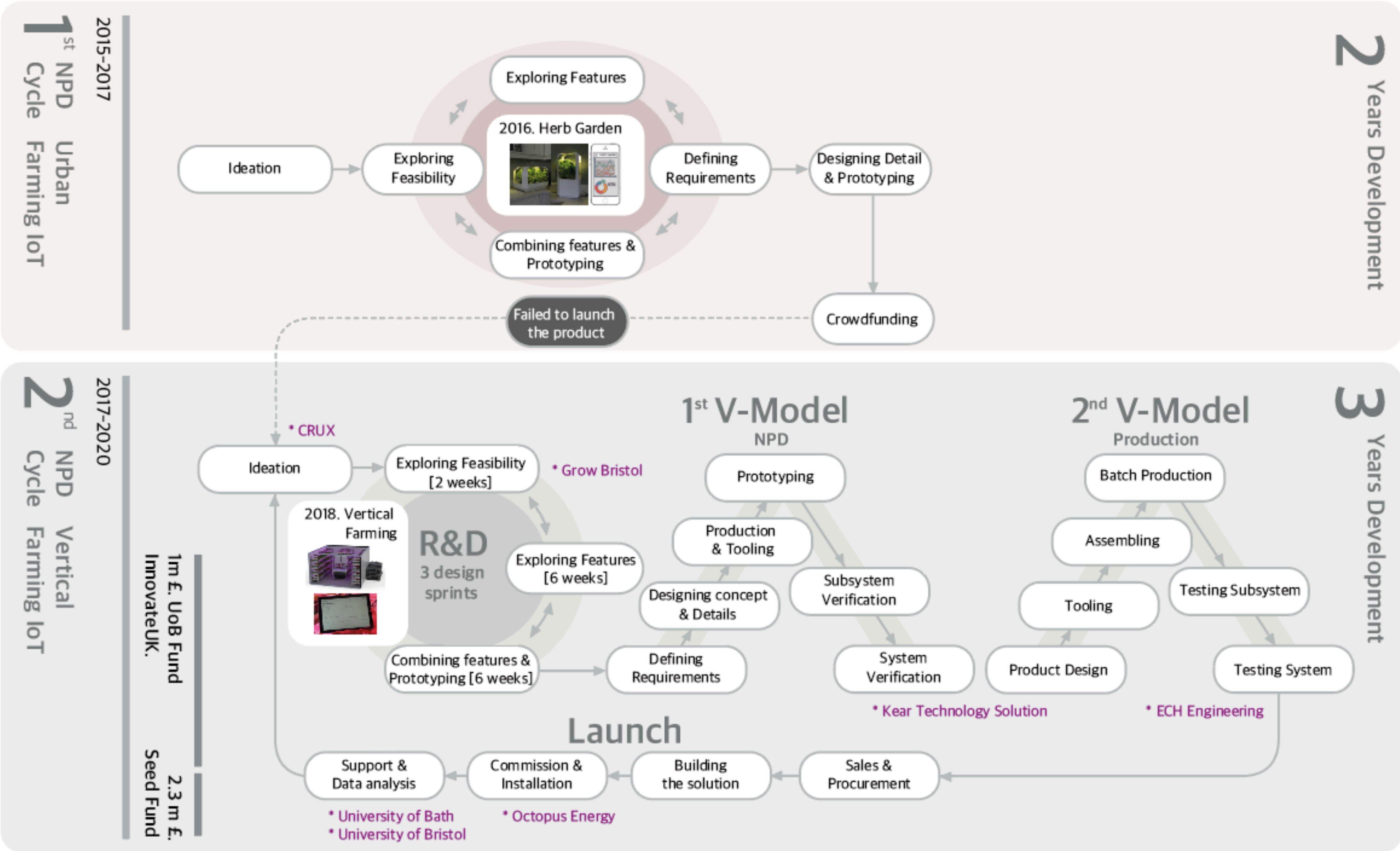
D-8. SilentHerdsman NPD process interpreted by the researcher



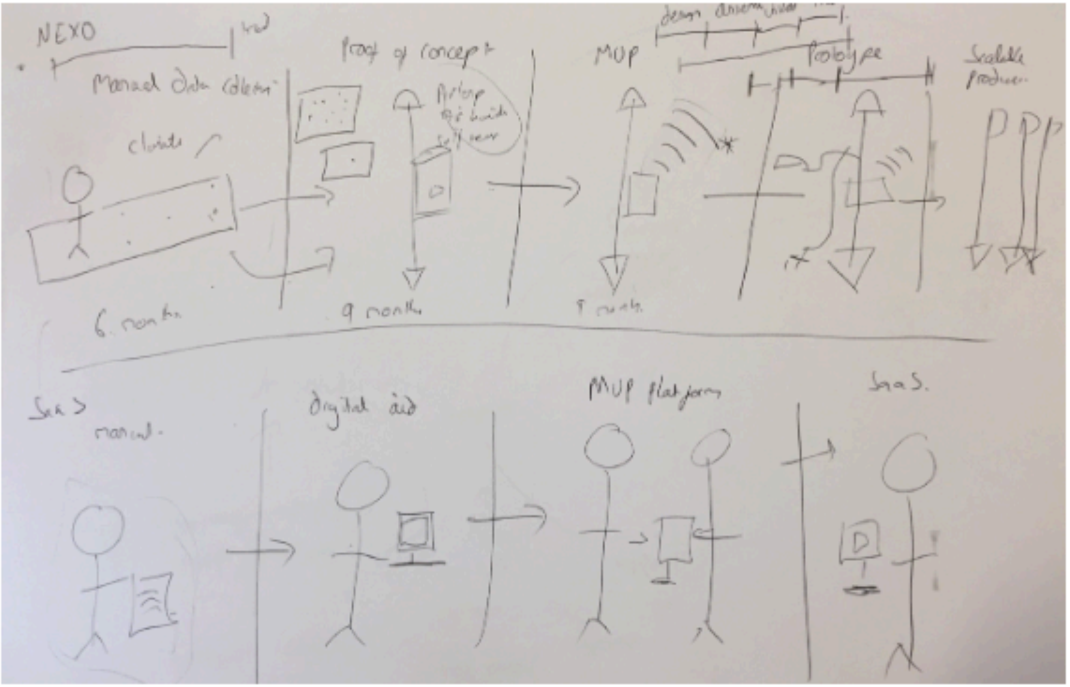
D-9. LettusGrow NPD process illustrated by the informant

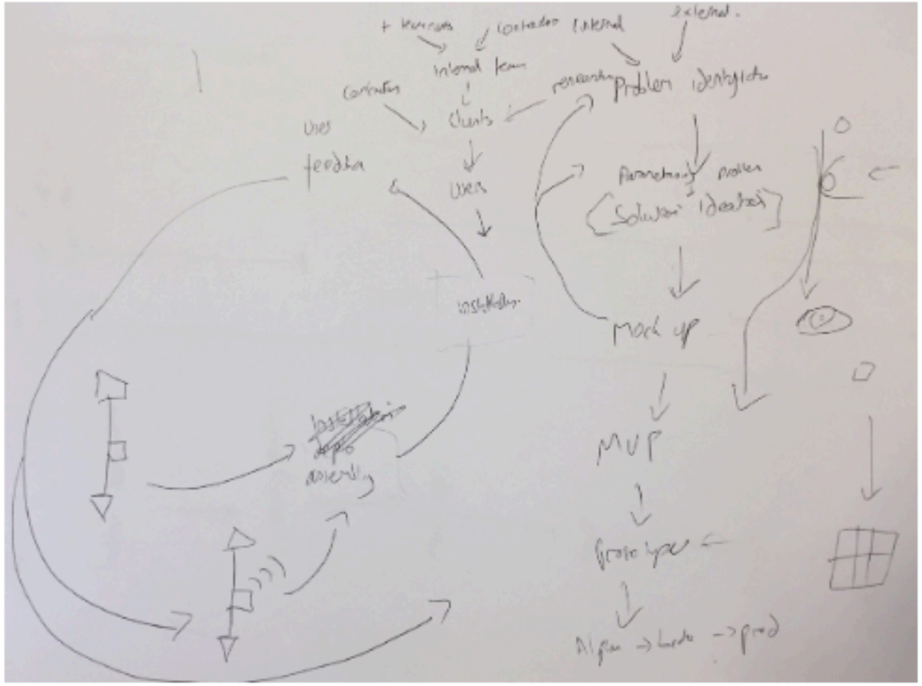


D-10. LettusGrow NPD process interpreted by the researcher



D-11. ClimateEdge NPD process illustrated by the informant





D-12. ClimateEdge NPD process interpreted by the researcher