Tampere University

ANTERO JOHANNES TOSSAVAINEN

Reduction of Market and Technology Uncertainty during the Front End of New Product Development

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Dedicated to family.

PREFACE

My doctoral dissertation in Industrial Engineering and Management is soon completed and it's time to think back this five-year journey. Also, I want to take this opportunity to thank some of my colleagues in the academy and industry who have supported me through this demanding project.

Early 2013 I returned my home country from California where I had been working in new product development for the U.S. smartphone carriers. After relocation I wanted new academic challenge and started to pursue the highest degree in Industrial Management. During the rest of the decade I was able to experience very closely the transformational journey of the Finnish high-technology industry, and during my Ph.D. project I got a chance to get insight from the technology and product development processes and practices in some of the world's largest and the most successful high-technology corporations at Nokia, Microsoft and Huawei. Even though my daily job activities transformed several times in the fast-paced industry, this academic doctoral project always remained on the side, bringing some stability to the daily activities.

Without the superior colleagues and mentors this work would not have been possible to finish on the side of my daily jobs, therefore I want to address my thanks for some of the influential persons.

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From the industry, I want to thank my previous managers Matti Hämäläinen and Ari Koski in Tampere for understanding this energy consuming "hobby", and also enabling me the opportunity to spend some time writing this thesis in the Stanford

University and the University of California San Diego. Also, I want to thank Petri Soronen for showing the high standard of technology development already during my very early professional career in Oulu. Furthermore, I want to express thanks to Dr. Asta Kärkkäinen for the numerous inspiring conversations and your viewpoints during the technology and product development projects we have carried out in the Finnish industry.

I want to thank my father Markku Tossavainen for the kickstart and all the support I have received, and for your great inspiring example of always pursuing forward in your own fields of academy and business.

Finally, I want to thank my beautiful girlfriend Anni for your love and caring. You have become very important to me.

Helsinki, February 27th, 2020

Antero Johannes Tossavainen

ABSTRACT

The management of the fuzzy front-end (FFE) phase of innovation is pivotal to the underlying success of new product development (NPD) initiatives. A crucial challenge that research and development (R&D) teams face at this early, and often chaotic, FFE phase is dealing with market and technology uncertainty related to product and technology innovation under development.

A remarkable cause of new product defects and serious delays is a failure to adequately define the product concept, target market, positioning, and requirements before beginning product development. Successful NPD teams are capable of performing uncertainty reduction during the FFE phase, and the more the innovation team reduces uncertainty with regard to user needs and technology, the higher the possibilities of producing a commercially successful product.

This study employs the technology acceptance model 3 (TAM3) as the voice of the customer (VoC) to a robotics FFE project, with the aim of understanding the extent to which TAM3 can be applied beyond its typical information technology (IT) product development (PD) phase setting to reduce market- and technology-based uncertainty during the FFE phase. The market is divided into early and late adopters of technology based on the diffusion of innovations theory. Further, the applicability of TAM3 is evaluated for both market segments.

The multimethod research setup is implemented in two phases. In Phase 1, a quantitative study is conducted in which 121 test users evaluated a technology prototype and participated in a survey based on TAM3 theoretical constructs. Survey data is analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) technique. In Phase 2, the technology acceptance data collected from the early and late market segments was tested by a robotics R&D team to evaluate the capability of TAM3 to reduce market and technology uncertainty in the FFE phase.

The findings suggest that there are significant differences in how the TAM3 performs in the robotics FFE phase compared to earlier findings mostly done in an IT PD setting. A few of the inner and outer constructs of TAM3 perform fundamentally differently in FFE. This research also reveals differences between the early and late market segments based on the TAM3 model. In addition, the results offer insight into how the TAM3-based VoC can reduce market and technology uncertainty during the important and challenging FFE phase.

Keywords: Technology acceptance model 3, fuzzy front-end, new product development, voice of the customer, market and technology uncertainty, early adopters of technology

TIIVISTELMÄ

Tuotekehityksen alkuvaiheiden johtaminen on äärimmäisen tärkeää organisaation tutkimus- ja kehitystoiminnan menestymiselle, sillä tässä vaiheessa tehdyt päätökset vaikuttavat olennaisesti myös kehitystyön myöhempiin vaiheisiin. Keskeinen haaste tuotekehitysprosessin varhaisessa alkuvaiheessa on teknologiseen innovaatioon liittyvien markkina- ja teknologiaepävarmuuksien vähentäminen ja näihin liittyvän ymmärryksen lisääminen.

Merkittävä syy uusien tuotteiden puutteille ja vakaville viivästymisille on epäonnistuminen tuotekonseptin, kohdemarkkinan ja tuotevaatimusten asianmukaisessa määrittelyssä ennen varsinaisen tuotekehityksen aloittamista. Menestyvät tutkimus- ja kehitysorganisaatiot kykenevät vähentämään markkinaan ja teknologiaan liittyviä epävarmuuksia jo tuotekehityksen alkuvaiheiden aikana. Mitä enemmän käyttäjän tarpeisiin ja teknologiaan liittyviä epävarmuuksia kyetään vähentämään, sitä paremmat mahdollisuudet kaupallisesti menestyvän tuotteen kehittämiselle ovat.

Tämä tutkimus soveltaa viimeisintä teknologian käyttöönoton mallia (engl. Technology Acceptance Model 3, TAM3) tuomaan asiakkaan vaatimuksia tuotekehityksen alkuvaiheessa olevaan robottiteknologian kehitysprojektiin. Tutkimuksen tarkoituksena on ymmärtää missä määrin TAM3:a voidaan soveltaa vähentämään markkinaan ja teknologiaan liittyviä epävarmuuksia jo tuotekehityksen alkuvaiheen aikana. Tutkimuksessa markkinat jaetaan teknologian varhaisiin ja myöhäisiin käyttöönottajiin perustuen innovaation diffuusioteoriaan, ja TAM3-mallin soveltuvuus arvioidaan myös markkinasegmenteille erikseen koko markkinan ohella.

Tämän tutkimuksen monimenetelmällinen tutkimusasetelma jaetaan kahteen vaiheeseen. Vaiheessa 1 suoritetaan kvantitatiivinen tutkimus jossa 121 koekäyttäjää evaluoivat robottiteknologiaprototyyppiä ja osallistuvat TAM3-mallin teoreettisiin konstruktioihin perustuvaan kyselytutkimukseen. Kyselytutkimuksen aineistoa tulkittiin ja mallinnettiin rakenneyhtälömalleilla. Vaiheessa 2 vaiheen 1 TAM3-aineisto ja tulokset esitetään robotiikan alueen tuotekehityksen asiantuntijaryhmälle, tarkoituksena arvioida TAM3-mallin tuottaman tietämyksen mahdollisuudet vähentää markkinaan ja teknologiaan perustuvaa epävarmuutta jo tuotekehityksen alkuvaiheessa.

Tutkimuksen havainnot viittaavat merkittäviin eroihin TAM3-mallin käyttäytymisessä robotiikan teknologia-alueen tuotekehityksen alkuvaiheessa verrattuna mallin aiempiin sovelluksiin lähinnä tietojärjestelmäprojektien myöhemmässä kehitysvaiheessa. Osa TAM3-mallin sisäisistä ja ulkoisista konstruktioista käyttäytyvät perustavanlaatuisesti eri tavalla robotiikan tuotekehityksen alkuvaiheessa. Tämä tutkimus myös tuo esiin eroja teknologian varhaisten ja myöhäisten käyttöönottajien välillä perustuen TAM3-malliin. Lisäksi, tutkimuksen tulokset tarjoavat näkemyksiä, miten TAM3-malliin pohjautuva asiakasnäkökulma voi vähentää markkinaan ja teknologiaan liittyvää epävarmuutta tuotekehitysprosessin tärkeän ja haastavan alkuvaiheen aikana.

Avainsanat: Teknologian käyttöönoton malli 3, tuotekehityksen alkuvaiheet, tuotekehitysprosessi, asiakastarve, markkina- ja teknologiaepävarmuus, teknologian varhaiset käyttöönottajat

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ABBREVIATIONS

AVE	Average Variance Explained
BI	Behavioral Intention to use (data variable)
CANX	Computer Anxiety (data variable)
CPLAY	Computer Playfulness (data variable)
CSE	Computer Self-efficacy (data variable)
DEM	Demographic (data variable)
DOI	Diffusion of Innovations
EA	Early Adopters of Technology
f^2	Effect size
FEI	Front End of Innovation
FFE	Fuzzy Front End
FFEI	Fuzzy Front End of Innovation
FUD	Fear, Uncertainty, and Doubt factor
HRC	Human-Robot Collaboration
HTMT	Heterotrait-monotrait ratio
HW	Hardware
IA	Information Acceleration
ICT	Information and Communication Technologies
IMG	Image (data variable)
iNPD	User-centered integrated new product development
IT	Information Technology
MM	Mass Market
NCD	New Concept Development
NPD	New Product Development
OU	Objective Usability (data variable)
OUT	Output Quality (data variable)
p	p-value
PD	Product Development
PEC	Perceptions of External Control (data variable)
PEOU	Perceived Ease of Use (data variable)

PLS	Partial Least Squares
PU	Perceived Usefulness (data variable)
R^2	Coefficient of Determination
RES	Result Demonstrability (data variable)
ROI	Return on Investment
R&D	Research and Development
R&We	Customer-driven innovation process
SEM	Structural Equation Modeling
SN	Subjective Norm (data variable)
SW	Software
t	t-value
TAM	Technology Acceptance Model
TAM2	Technology Acceptance Model two
TAM3	Technology Acceptance Model three
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
TUT	Tampere University of Technology
USE	Use Behavior (data variable)
UTAUT	Unified Theory of Acceptance and Use of Technology
UTAUT2	Unified Theory of Acceptance and Use of Technology two
VIF	Variance Inflation Factor
VoC	Voice of the Customer
VOL	Voluntariness (data variable)
q^2	Effect size
Q^2	Stone-Geisser's indicator of model's predictive power
QFD	Quality Function Deployment
ZMET	Zaltman Metaphor Elicitation Technique

1 INTRODUCTION

The management of the fuzzy front-end (FFE) phase of innovation is crucial to the ultimate success of new product initiatives (Rizova et al., 2018). For modern companies, it is not enough to merely be profitable and have a working business model; markets require companies to also be notably innovative. Companies that fail to succeed in innovation and bring new products to the market will ultimately disappear. "It's a war: Innovate or die!" (Cooper, 2005, p.4). Technological innovation is commonly the most important competitive driver in numerous industries, and a large number of firms receive over one-third of their profits from products developed within the last five years (Schilling, 2010). Moreover, it has been stated that the foundation for successful new product innovations is generated in the front-end of the innovation process (Poskela, 2009). While the government plays a significant role in innovation, it is the industry that provides the majority of research and development (R&D) funds that are utilized for technological innovation (Schilling, 2010). It has been noted that marketing, design, and production teams need to work closely together to successfully develop and design new products (Stevenson, 2009).

On the flip side, the failure rate of new products has remained unchanged for several decades, remaining at approximately 30%–80% (Castellion and Markhan, 2013; Yoon and Jetter, 2015). The emergence of more complex and fast-changing technologies may have actually increased the difficulty of developing winning products; thus, the forecasting of future customer needs and desires for the development of future technologies is particularly challenging (Shillito, 2001; Yoon and Jetter, 2015).

Collecting relevant customer knowledge at the FFE of NPD to enable the development of solid strategies remains challenging, and the ability to acquire and build future customer needs in product development organizations affects the performance and innovativeness of financial NPD (Stanko and Bonner, 2013; Yoon and Jetter, 2015). The role of the voice of the customer (VoC) during the R&D process in an organization is also noted as one of the dilemmas of an innovator, where occasionally it can be a fatal mistake to blindly follow the maxim of keeping close to customers (Christensen, 2003). Even more important than the innovations that a company is able to produce are those innovations which customers are willing to adopt; therefore, successful technology organizations need to incorporate customers into their NPD processes (Mohr, Sengupta, and Slater, 2010). End-user's interests must be among the driving factors in the critical decision-making (Cagan and Vogel, 2008).

1.1 Background and motivation

This section discusses the background of this research, briefly visits the relevant theory topics, and describes the research gap in prior work.

Innovative products show glorious opportunities for firms seeking growth, as significant innovations enable firms to establish competitively dominant positions in the market (Danneels and Kleinschmidt, 2001; Pauwels et al., 2009; Artz et al., 2010). It has been argued that it is the overlap among marketing, design, and engineering that makes a product a successful combination of certain attributes (Cagan and Vogel, 2008).

The innovation process can be divided into three parts: the FFE, the NPD process, and commercialization. The front-end is frequently imagined as a linear process of three stages separated by management decision gates: pre-work for the discovery of new opportunities, scoping stage, and final business case development stage (Koen, Bertels, and Kleinschmidt, 2014). There are several activities that must be performed in a well-performing NPD. Scholars have proposed that the NPD process comprises five types of activities: opportunity identification and screening, product design, testing, product commercialization, and post-launch activities (Urban and Hauser, 1993; Song, Montoya-Weiss and Schmidt, 1997). The fundamental way to win with NPD is implementing projects in the right manner by building cross-functional teams, VoC mechanisms, idea-to-launch processes as well as succeeding in portfolio management to select appropriate projects to invest in (Cooper, 2005). Koen et al. (2001) indicate that the FFE is defined by the activities that come before the formal and well-structured PD phase of the NPD process. The activities that occur in the FFE are often described as chaotic, unpredictable, and unstructured (Koen et al., 2001).

The market as a whole can be divided into early and late market segments, which comprise individuals possessing different characteristics and representing various types of consumer behavior. The diffusion of innovations, originally ideated by

Rogers in 1962, is described as a process in which the few first members of a social system (early adopters) adopt an innovation; thereafter, over time, more individuals (mass market representatives) adopt the innovation until all or most members have adopted the idea (Ryan and Gross, 1943; Rogers, 1983; Valente, 1993; Valente, 1996). Innovators form the first 2.5% of the individuals in a system to accept a new innovation. The next group to adopt an innovation are the early adopters (13.5%), often described as a more integrated part of the local system than innovators but with the highest degree of opinion leadership. The early majority (next 34%), late majority (34%), and laggards (16%) are the late adopters that will only accept a new idea when they are surrounded by peers who have already adopted a new idea (Rogers, 2002).

Cooper (2005) argues that a significant cause of new product failures and serious delays is a failure to define the product concept, target market, benefits, positioning, requirements, and features well before beginning a product's development. Technology uncertainty can be inherent in the technology choices, product feature combinations, components and materials, the capability of key suppliers, manufacturability, and regulatory or standardization topics (Chen et al., 2005; Zhang and Doll, 2001; Lynn and Akgun, 1998; Moenaert et al., 1995; Poskela, 2009). Technology and market uncertainties are linked by organizational uncertainties regarding knowledge, capability, and resource availability to execute tasks (Poskela, 2009).

According to Cooper (1990), a lack of market orientation and unqualified market assessment are consequently cited as main causes for new product failure, especially in industrial-product and high-technology companies. Marketing and R&D functions share liabilities, such as placing new product objectives, recognizing openings for the next generation of product evolution, settling engineering design and customer-need tradeoffs, and comprehending customer needs (Griffin and Hauser, 1996). In order to succeed in the marketplace, corporations must engender cooperation between their marketing and R&D functions (Griffin and Hauser, 1996). Kleef et al. state that incorporating the VoC in very early stages of the new product development process has been identified as a critical NPD success factor. NPD can originate from new technology inventions or new market opportunities; however, irrespective of where opportunities originate, the customer is the ultimate judge for determining the success of new products (Eliashberg et al., 1997; Brown and Eisenhardt, 1995; Cooper and Kleinschmidt, 1987; Kleef, Trijp, and Luning, 2005). Consumer research activities can be conducted during each of the basic NPD process stages: opportunity identification, development, testing and launch; most widely, it is applied during the development, testing, and launch stages (Suh, 1990; Urban and Hauser, 1993; Kleef, Trijp and Luning, 2005). Despite the importance of later stages, it has been increasingly recognized that successful NPD depends strongly on the quality of the opportunity identification stage (Cooper, 1985; Cooper, 1988; Cooper, 1998; McGuinness and Conway, 1989; Kleef, Trijp, and Luning, 2005). Translating customer requirements into the appropriate core technology, selecting the type and placement of features, and combining this with an appropriate set of aesthetic choices cannot be done without a good understanding and combined dialogue with the people who will use the product (Cagan and Vogel, 2008).

The most recent research in FFE deals with equivocality and social networks (Rizova et al., 2018), user consultation during the FFE (Conradie et al., 2017), proactive and responsive customer orientation in the reduction of uncertainties during the FFE (Schweitzer, 2016), and building framework for FFE and identification of the sources of fuzziness (Zhang et al., 2019). The conducted research further focuses on the extent to which a TAM3 model can be applied to the FFE phase, particularly its capability to reduce market- and technology-based uncertainty in the crucial FFE phase.

Initially, when technology had just begun to enter users' everyday life, there was a growing necessity for comprehending the reasons why the technology was accepted or rejected (Marangunic and Granic, 2015). The initial theories attempting to explain and predict those decisions related to the acceptance of technology were grounded in the field of psychology—in the theory of reasoned action (TRA) and the theory of planned behavior (TPB) (Ajzen, 1985; Ajzen and Fishbein, 1980; Marangunic and Granic, 2015). A tremendous amount of research has been conducted in applying the Technology Acceptance Model (TAM), originally introduced by Fred Davis, from its first appearance more than a quarter of a century ago, which is a strong indicator of the model's popularity in the field of technology acceptance. The TAM has become a prevailing model in examining factors affecting users' acceptance of technology. The TAM assumes a mediating role of two variables—perceived ease of use and perceived usefulness—in a tortuous connection between system characteristics (external variables) and potential use of the system. Faqih and Jaradat (2015) continue that TAM3 has not yet been widely explored in various areas of business and only a few published papers use TAM3 as a theoretical framework; therefore, the general applicability of the TAM3 model in the context of various information technologies (IT) in different settings is unknown to academics and practitioners; further research is called for in order to focus on investigating similar research in other contexts and domains (Venkatesh and Bala, 2008; Faqih and Jaradat, 2015).

This research targets to investigate the use of TAM3 model outside of its typical IT setting in a robotics project. Robotics is interesting and growing interdisciplinary technology area that includes many fields of engineering and science. Robotics are still relatively little studied compared to many other fields of technology. There are also similarities between IT and robotics as both technology fields involve development of complex solutions that target to help end-user carry out certain tasks in their duties.

The following section presents the existing research gap and the research questions that the present research aims to answer.

1.2 Research objectives

The purpose of this study is to improve the use of customer input in the early phases of NPD. Hence, this research targets to investigate the capabilities of the TAM3-based VoC mechanism to reduce market- and technology-related uncertainty during the early FFE phase of NPD as part of a robotics project. TAM3, illustrated in the chapter 2.5.5, is the latest version of the Technology Acceptance Model (Venkatesh and Bala, 2008) and therefore the most relevant model to test in this research for the Robotics FFE project.

It is held that the TAM3 has not yet been widely explored in various areas of business; therefore, the general applicability of the TAM3 model in the context of different settings is unknown and further research is called for to focus on investigating similar research in other contexts and domains (Venkatesh and Bala, 2008). Turner et al. (2010) indicate that employing the TAM model outside the context in which it has been adequately validated must be cautiously approached. Bröhl et al. (2011) investigated the acceptance model for human-robot collaboration (HRC) in industrial production systems also taking into account ethical, legal, and social implications. The authors state that the original model is transferrable to the domain of HRC in production systems. Further, Lotz et al. (2019) recently applied the TAM3 model to examine the main influencing factors for HRC acceptance from the perspective of factory employees. There are three key concerns in this regard from the employees' viewpoint: being injured by a robot, losing their job, and robot anxiety. Two key factors fostering HRC acceptance are improved output quality and enhanced enjoyment. Researchers indicate that hands-on experience is crucial to understanding the actual usage of technologies and their acceptance and recommend including this insight in future research (Lotz et al., 2019). Chu et al. (2019) conducted a research using the unified theory of acceptance and use of technology (UTAUT) model to compare the acceptance of Taiwanese elderly people towards service-oriented and companion-oriented robots. According to researchers, elderly adults prefer more functional and humanlike robots (Chu et al., 2019). Yagoda (2013) built over traditional TAMs and human-robot interaction (HRI) research, aiming to investigate barriers such as operational risk and lack of trust in HRI in the acceptance of unmanned ground vehicle (UGV) robots.

The current knowledge about TAM3 includes numerous studies among IT hardware (HW) and software (SW) type of applications, but TAM3 is still rarely employed in other technology areas like robotics. A typical setting for TAM3 is a mature product (in PD phase), which has been placed among pilot testers. In prior research, TAM3 has not often been applied in the early FFE phase, where a mass market does not yet exist for service robots. There is also a research gap for TAM3 model applications in a setting in which the entire market is divided into early adopters and the mass market segments under study. None of the prior researches describe that the TAM3 model was tested with a service robot technology prototype during the early FFE phase of the research; rather, they imply commercial applications of the TAM3 in the industry setting.

As previously discussed in Chapter 1.1, current knowledge about the FFE of NPD is limited to the development of best operational processes and classification of key activities that must be implemented in well-performing FFE. Currently, there is a research gap in terms of how to best use the VoC mechanism to reduce technology and market-based uncertainty that often makes the early FFE stage challenging and more chaotic than the PD phase.

Research questions:

- **Research question 1:** How does the TAM3 model perform in robotics FFE compared to the IT PD phase?
- **Research question 2:** How does the TAM3 model differ in the early and late market segments of robotics FFE?
- **Research question 3:** How can market information based on the TAM3 model be used to reduce market and technology uncertainty in the FFE phase?

The quantitative Research Phase 1 answers to the Research questions 1 and 2. The more qualitative Research Phase 2 answers to the Research question 3. The research is carried out in two phases as the results of the Research Phase 1 are used as input material for the Research Phase 2.

1.3 Scope of the research

The research is conducted in a robotics NPD project, which is at the FFE stage. The TAM3 model is tested among possible end-user representatives. End-user candidates represent both the early adopters of technology and the mass market, as the latter does not actually yet exist for this type of radical new innovation. At the time that this research was conducted, service robots were not yet at mass-market stage in Finland.

Figure 1 below illustrates the research setting for implementing VoC at the FFE phase of NPD.

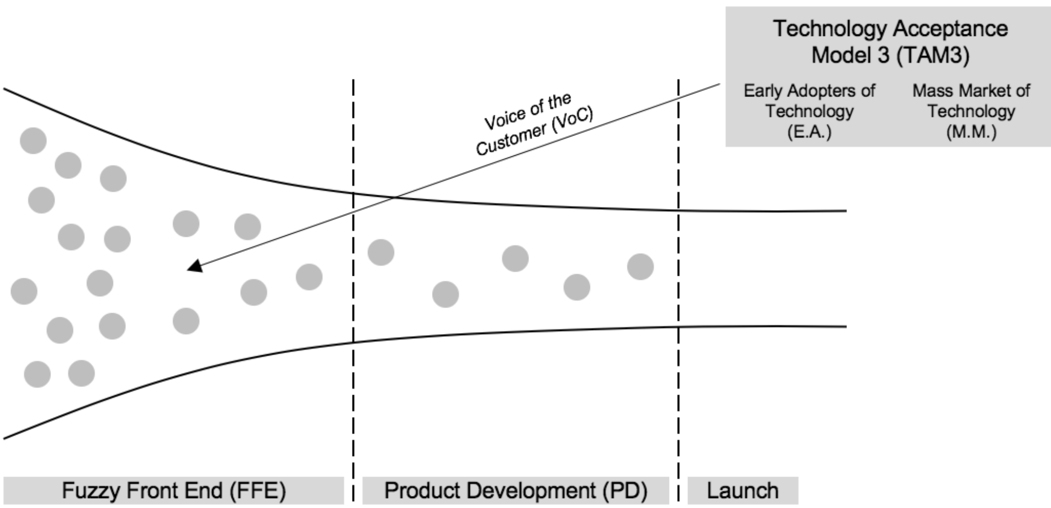


Figure 1. Research setting

This research approaches the search for answers to how the TAM3 applies to the scenario in which the technology under development is not IT, as the product under development is a service robot application. Moreover, an interesting difference from the original TAM3 setting is the fact that the technology under evaluation is not yet ready for the PD phase, as the NPD project is still at FFE stage. The third major difference in the TAM setting is that participants are not considered as organization workers performing a job, as participants are those with consumer-like potential end-users who are voluntarily participating in technology evaluation.

1.4 Structure of the thesis

The remainder of this thesis is organized in the following manner: Chapter 1 is the "Introduction" chapter. The background and motivation, research objectives, scope of the research and structure of the thesis are discussed in this chapter; in addition, the research gap is presented.

Chapter 2 is the "Theoretical background" section that highlights literature relevant to the conducted research, as illustrated in Figure 2 below. The theory chapters close to the core of the research are related to the FFE, market and technology uncertainty, segmentation of early and late markets, and the key models for acceptance of new technologies. Other theory sections that are relevant in enabling the reader of this thesis to understand the broader background of the research are related to NPD, VoC, innovation adoption and diffusion, product innovativeness, R&D, marketing co-operation, and product market selection.

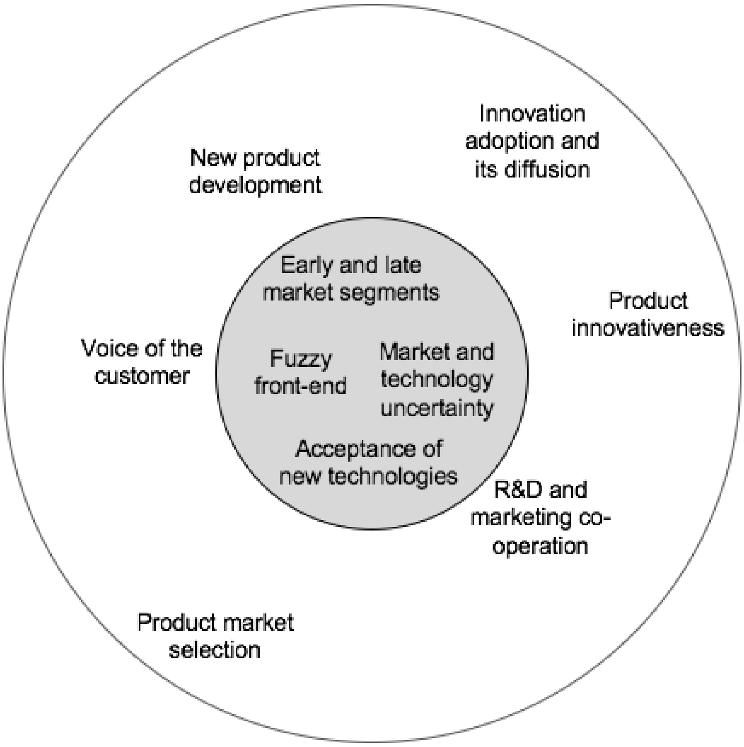


Figure 2. The theoretical context of this thesis

Chapter 3 describes the multi-method research and Research Phases 1 and 2. In addition, questionnaire development and research data handling are explained in detail.

Chapter 4 is the "Results and discussion" section and presents the research findings and answers to the three research questions.

Finally, chapter 5 is the "Conclusion" and ends the thesis with a discussion of the theoretical and managerial contributions of this research. In addition, the research limitations are discussed and suggestions for future research avenues are provided.

2 THEORETICAL BACKGROUND

The literature review begins with an examination of product innovativeness, incremental and radical innovation, newness of technologies in the market and the company developing it, and innovation adoption and diffusion. Thereafter, market and technology uncertainty, product market selection, and timing of entry are reviewed. NPD is examined as a strategic activity of an organization. This includes reviews on different NPD process variations, FFE of innovation operation models and activities, and front-end performance characteristics. The VoC and marketing activities in NPD and FFE are also examined. A description of the TAM ends the theory chapter.

2.1 Technological innovation and its evolution

It has been argued that innovative products present great opportunities for firms seeking growth or expansion into new areas, as significant innovations enable firms to establish competitively dominant positions and afford newcomers an opportunity to gain a foothold in the market (Danneels and Kleinschmidt, 2001). However, significant innovations are also associated with high risks and management challenges (Danneels and Kleinschmidt, 2001). Significantly innovative products require a larger number of firm resources and a different development approach to be successful (Colarelli-O'Connor, 1998; Lynn, 1998; Lynn, Morone, and Paulson, 1996; Veryzer, 1998).

Scholars describe that it is the overlap among marketing, design, and engineering that makes a product a successful combination of usefulness, desirability, and usability, targeting to well cover well attributes such as lifestyle image, ease of use, aesthetics, manufacturability, functionality, safety, reliability, production cost, etc. that make a product great (Cagan and Vogel, 2008).

Further, market opportunity must be assessed before building a prototype; even if this sounds obvious, this important phase is often omitted (Lynn and Akgun, 2003). According to Cooper's industry research, insufficient market evaluation is one of the causes why new products fail (Cooper, 1994). An organization not only needs good market assessment but also someone who can translate business requirements into technical ones (Lynn and Akgun, 2003). Marketing assistance for new product entry incorporates market research and design, consumer education, development of channel relationships, and promotion plans for the launch of the new product (Lilien and Yoon, 1990). Three stages of promotion efforts are needed for the diffusion of a new technology: concept, product, and brand promotion (Goldish, 1982; Lilien and Yoon, 1990). Early market entrants require more investment in concept and product promotions, whereas late entrants require more investment in brand promotion (Lilien and Yoon, 1990).

2.1.1 Product innovativeness

In this thesis, disruptive and radical product innovativeness is considered as newness to the R&D organization and to the market. This chapter addresses these aspects.

Scholars consider firms' R&D as a primary driver of innovation (Schilling, 2010). Established firms tend to be successful at enhancing what they have been long great at doing, and entrant companies appear better fit for making use of radically new technologies (Christensen, 2003). However, even though large companies often have a bureaucratic mindset and possess more to lose in radical innovations, it has been studied that large and established firms have introduced more radical innovations than small firms and new entrants (Mohr, Sengupta, and Slater, 2010).

Innovation can be described and differentiated in various ways. Different dimensions are used to distinguish the categories of innovation: product versus process innovation, radical versus incremental innovation, competence-enhancing versus competence-destroying innovation, and architectural versus component innovation (Schilling, 2010). Breakthrough products create new markets or redefine existing markets, support customers' experience in using the product, create a lifestyle fantasy for the customer, and generate higher profits for the company producing them (Cagan and Vogel, 2008).

Scholars broadly agree that radical or discontinuous new products play an essential role in creating competitive advantage and can contribute substantially to a company's growth and profitability (Ali, 1994; Calantone and Di Benedetto, 1988; Kleinschidt and Cooper, 1991; Robertson, 1971; Veryzer, 1998). Further, discontinuous innovation infers to radically new products that include strong strides in terms of customer familiarity and product use (Meyers and Tucker, 1989; Veryzer, 1998). Airplanes, automobiles, personal computers (PC), and televisions are examples of discontinuous innovations at the time when first introduced (Veryzer, 1998). In many of these cases, the products based on new technology actually defined a new industry and entailed unique development and commercialization challenges due to the high level of uncertainty regarding market and technological feasibility (Veryzer, 1998).

Companies that deal with radical innovations face more challenging tasks in translating new customer needs into new technical features than companies dealing with incremental products, as there does not exist a lot of knowledge available in-house and, thus, the company must be involved in heavy external information collection; therefore, radical innovations may require learning-based innovation strategies to set course and define targets (Lynn and Akgun, 1998; Poskela, 2009).

Crawford discussed three levels of innovation—pioneering, adaptation, and imitation—reflecting the degree to which technology is applied in a new manner and the degree to which it is based on an existing product (Crawford, 1994; Veryzer, 1998). In Crawford's classification, the pioneering level is the "highest" level of innovativeness and is the closest match in his classification system to the scope of innovation discussed in this thesis.

Wheelwright and Clark have suggested that determining the degree of change represented by a product is the most useful means to classifying development projects (Wheelwright and Clark, 1992; Veryzer, 1998). Further, a product/technology novelty view has also been developed (Ali, 1994; Tushman and Nadler, 1986; Veryzer, 1998). Lee and Na have distinguished "incrementally improving innovativeness" and "radical innovativeness," excluding commercial performance as the basis for classifying innovations (Lee and Na, 1994; Veryzer, 1998).

Danneels and Kleinschmidt listed several different labels used by scholars to classify new products on the basis of their relative newness: "innovative/noninnovative," "discontinuous/continuous," "evolutionary/revolutionary," "incremental/radical," "major/minor," "really new," and "breakthrough" (Danneels and Kleinschmidt, 2001).

The Booz, Allen, and Hamilton typology (illustrated in Figure 3) is the most often used typology of new products, distinguishing product newness by categorizing it into customer's and firm's perspectives (Booz, Allen, and Hamilton, 1982). In the Booz, Allen, and Hamilton typology, products can be classified into several categories. The most innovative type is the "New to world products," which are new to both the firm and the market. The least innovative type is the "Cost reduction products," which provide similar attributes as existing products but at a lower cost.

"Repositionings" are existing products pointed to new markets. "Additions to existing product lines" are rather new to the market and to the organization. "Improvements/revisions to existing products" are somewhat new to the company but not to the market. "New product lines" are novel to the company but not to the market (Booz, Allen, and Hamilton, 1982; Danneels and Kleinschmidt, 2001).

The type of innovation, or degree of innovativeness—which is the focus of this thesis—is positioned in upper right corner in the Booz, Allen, and Hamilton typology (Figure 3).

Newness to Company \ Newness to Market	Low		High
High	New Product Lines		New-to-World Products
	Improvements/Revisions to Existing Products	Additions to Existing Product Lines	
Low	Cost Reductions	Repositionings	

Figure 3. The Booz, Allen, and Hamilton typology. Adapted from Booz, Allen, and Hamilton (1982); Danneels and Kleinschmidt (2001).

Scholars argue that apart from market and technology intimacy, how the market and technology are suited into a company's existing capabilities and competencies has a great impact on project performance, as a product targeting new markets and applying new technologies is "not so new" if there are synergies between the organization's internal and existing resources (Danneels and Kleinschmidt, 2001).

Product innovativeness can be distinguished from both customer's and firm's perspectives. From the customer's perspective, product newness includes innovation attributes, risks of adoption, and levels of change in established conduct models. From the firm's perspective, environmental familiarity, project-firm fit, and marketing and technological aspects are dimensions of product innovativeness (Danneels and Kleinschmidt, 2001). The summarized comparative overview of prior empirical product innovativeness research is illustrated in Appendix 1.

Certain scholars warn that strong competitor orientation commonly leads firms' ability to invest in existing products, resulting in incremental innovation, when customer orientation is more strongly associated with a firm's tendency to invest in new knowledge and skills, thereby resulting in breakthrough innovations (Mohr, Sengupta, and Slater, 2010). The processes and procedures needed for flourishing radical innovation are fundamentally different from those for incremental projects (Lynn, Morone, and Paulson, 1996; O'Connor and DeMartino, 2006).

2.1.2 Innovation adoption and diffusion

This section addresses the diffusion of innovations (DOI) theory. This thesis employs the DOI theory when characterizing the individual adopters used in the data collection to early and late market segments.

The diffusion of innovations, originally ideated by Rogers (1962), is described as a process in which a few members of a social system first adopt an innovation; thereafter, over time, more individuals adopt the innovation until all or most members have adopted the idea (Ryan and Gross, 1943; Rogers, 1983; Valente, 1993; Valente, 1996). As discussed in chapter 2.1.1, product innovativeness can be distinguished from both customer's and firm's perspectives, and from customer's perspective product newness includes innovation attributes, adoption risks, and levels of change in established behavior patterns. It is evident that different individuals have different levels of readiness to take risks in adopting a new idea or product. Certain individuals accept the risk of adopting a new idea, product, or behavior before others; moreover, in contrast, most people are unwilling to accept a new idea or product and like better to hold until other people have tested it first (Valente, 1996).

Rogers (1962) studied different diffusion traditions in the spirit of logical empiricism and has published several books on this subject (Diffusion of Innovations, 1962 and Communication of innovations, 1971 with Shoemaker), which are among the top cited works in innovation diffusion literature. Further, Tarde (1962) described that social change requires acceptance of inventions that diffuse through the process of imitation, when people imitate beliefs and desires or motives that are transmitted from one individual to another. Tarde (1962) formulates that imitation can also be referred to as adoption of an innovation. According to Kinnunen (1996), diffusion refers to the spreading of social or cultural attributes from one society or environment to another. Berry and Berry defined diffusion as the process by which an innovation is translated through certain channels over time among individuals of a social system (Berry and Berry, 1999; Stone, 2012). A social network can be described as a pattern of friendship, advice, communication, or support, which exists among the members of a social system (Knoke and Kuklinski, 1982; Burt and Michael, 1983; Wellman, 1988; Scott, 1991; Valente, 1996).

Rogers (1995) describes diffusion as a process through which an innovation is communicated via particular channels over time among the individuals of a social system. Rogers (2002) also lists four main elements in the diffusion of new ideas: innovation that is an idea, practice, or object that is perceived as new by an individual; communication channels; time; and the social system. In Roger's more recent work, several characteristics of an innovation have been described to determine its rate of adoption: Relative advantage" implies the degree to which an innovation is perceived as better than the idea it is aiming to replace. Compatibility refers to the degree to which an innovation is discovered as being coherent with present values, past experiences, and needs of potential adopters. Complexity is the degree to which an innovation is perceived as challenging to use and understand. Trialability implies the degree to which an innovation may be experimented with on a restricted basis. Observability is the state to which the outcome of an innovation is apparent to others. The innovations that are found by individuals as having more relative benefit, compatibility, trialability, observability, and less complexity are expected to be adopted more quickly than other innovations (Rogers, 2002).

As a communication channel, mass media has been found to be more effective in creating initial knowledge of innovations and interpersonal channels, which in turn are more effective in forming and changing the attitudes of people toward a new idea. Diffusion is essentially a social process through which people talking to other people spread an innovation, as most individuals evaluate an innovation through the subjective evaluations of near-peers who have already adopted the innovation and not based on scientific research by experts (Rogers, 2002). Rogers (2002) describes the innovation-decision process as a mental five-step process; this begins from the initial knowledge of an innovation, to forming an attitude toward the innovation, to a decision to adopt or reject the innovation, to implementation of the new idea, finally to confirmation of the decision.

Table 1. The stages of the innovation adoption process. Adapted from Rogers (1962 and 2002).

Stage	Definition
Knowledge	When an individual becomes knowledgeable to the existence of the innovation and gathers comprehension of how the innovation behaves.
Persuasion	The individual constructs a positive or unfriendly mindset toward the innovation.
Decision	The individual commits in action that result in a selection to either adopt or discard the innovation.
Implementation	The individual puts the innovation to use.
Confirmation	The individual looks for establishment of an innovation-decision already done, but he/she may inverse this resolution if exposed to dissonant findings regarding the innovation.

Scholars describe five adopter categories or classes of the social system members regarding their innovativeness: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2002).

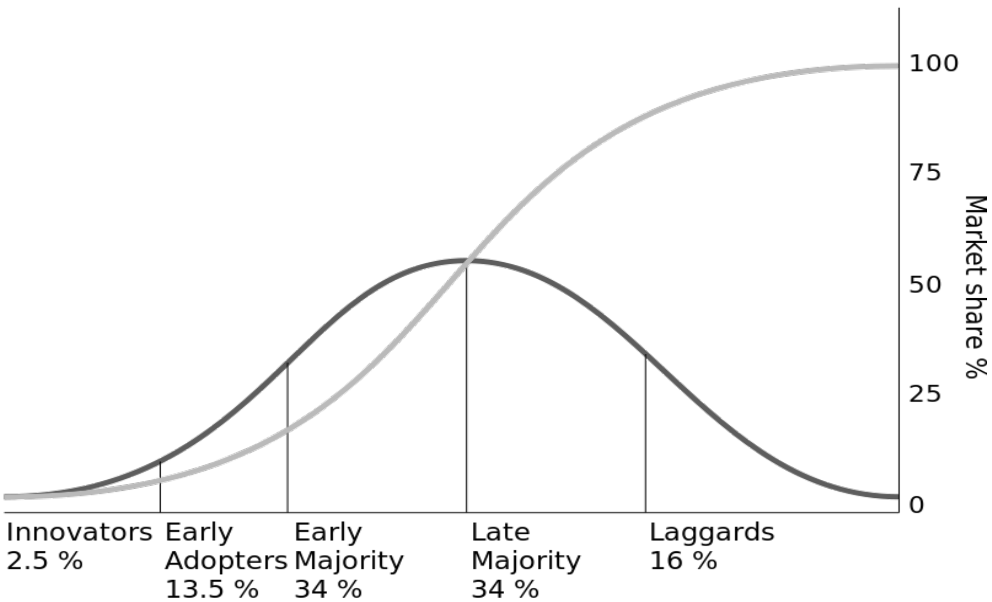


Figure 4. The diffusion of innovations. Adapted from Rogers (1962).

Figure 4 above illustrates the categorization based on the percentage of individuals under each portion of the normal curve, marked off by standard deviations from the mean (Rogers, 2002). Innovation adopter categories are described in Table 2 below.

Innovators are the first 2.5% of the individuals in a system to adopt an innovation when their interest in new concepts leads them out of closest networks and into more universal social relationships. Early adopters (13.5%), the next group to adopt an innovation, are a tauter part of the local system as compared to innovators but have the greatest opinion leadership. Early majority (next 34%), late majority (34%), and laggards (16%) are later adopters who only accept a new idea when they are surrounded by individuals who have already adopted it and are convinced with the new idea (Rogers, 2002).

In this thesis, the market is divided into two segments based on individual innovativeness:

- An early market: includes the "early adopter" (subsequently also referred to as "EA") segment comprising both innovators and early adopters, and
- A late market: includes the "mass market" (subsequently also referred to as "MM") segment comprising the rest of the individuals (early majority, late majority, and laggards).

This coarse segmentation enables a differentiation among individuals participating in the research to groups of mass markets and individuals that tend to have an early adopter approach and attitude toward new technologies and products that introduce new technology.

Adopters' ability and motivation have a great impact on a potential adopter's probability to accept an innovation (Ferlie et al., 2001). Motivation can come from the meaning that the innovation holds or the symbolic value of the innovation (Eveland, 1986). The overall connectedness of a potential adopter to the broad community impacts adoption—for example, potential adopters who frequent metropolitan areas are more likely to adopt an innovation (Ryan and Gross, 1943). Moreover, potential adopters who have the power to create change are more likely to adopt an innovation as compared to someone with less power over his choices (Rogers, 1995). Definitions of different adopter categories are illustrated in Table 2.

Table 2. Characteristics of individual adopters. Adapted from Rogers (1962 and 2003).

Adopter category	Definition
Innovators	Innovators are the first of the individuals in a system to adopt an innovation. Innovators are venturesome, eager to try new ideas, have the financial freedom to accept the potential loss of a losing innovation, and are able to emerge from a high level of uncertainty surrounding an innovation at the time of adoption. Innovators are cosmopolites.
Early adopters	Early adopters are more integrated to the regional social system than innovators and have the highest degree of opinion leadership in most social systems. Early adopters are the "missionaries" for speeding the diffusion process and serve as respected role models in the social system; they decrease uncertainty about a new idea by adopting it and providing a subjective evaluation for the innovation.
Early majority	Those who are part of the early majority adopt an innovation before the average number of people in a social system. The early majority may consider for some time before entirely adopting a new concept, and their innovation-decision process takes more time than that of innovators and early adopters. The early majority rather follow than lead in adopting a new innovation.
Late majority	Those who are part of the late majority adopt an innovation after the average members of a social system and approach innovations with a skeptical and cautious air; they do not adopt until most others in their social system have already done so.
Laggards	Laggards are the last to adopt an innovation and possess almost no opinion leadership. Laggards have a point of reference in the past and often make decisions based on how things have been done in previous generations. Laggards have limited resources and must be relatively sure that a new idea will not fail before they can choose to adopt. When laggards adopt an innovation, it may already be superseded by a newer innovation, which is already being adopted by the innovators.

An individual's decision to adopt new technology is impacted by the perceived related advantages and risks. Scholars describe that innovation adoption risk affecting the decision to adopt and the timing of the adoption of an innovation arises from several factors. The lack of standards to evaluate the innovation create uncertainty risk. Performance risk is related to whether the innovation will perform as expected. Social risk is connected with reduced social status by making an adoption mistake. The physical risk relates to actual physical harm to the end user (Gatignon and Robertson, 1991).

There is also some critics towards the adopter categories proposed by Rogers. Dedehayir et al. (2017) argue that innovator characteristics may vary per product category and describe that for example the same individuals who are innovators in fashion not necessarily are innovators in IT. Also, the earliest adopters are not necessarily younger and less dogmatic than later adopters (Dedehayir et al., 2017). Labay and Kinnear (1981) state that there are also similarities between the early adopters and early rejecters. There is also some critics towards the idea that early adopters are also opinion leaders (Dedehayir et al., 2017).

The meta-analysis carried out by Dedehayir et al. (2017) suggests that variables such as age, education level and gender are not consistent descriptors of innovators and early adopters. By contrast, other specific variables such as innovativeness, knowledge, technology orientation and economic values seem to show consistency in their description of innovators and early adopters (Dedehayir et al., 2017).

Ostlund (1974) argues that based on evidence gathered from two studies of new consumer packaged goods, it can be suggested that the perceptions of innovations by potential adopters by potential adopters can be very effective predictors of innovativeness, even more than the personal characteristic variables. Perceptual variables are found more successful as predictors of the purchase decision than the personal characteristics of respondents (Ostlund, 1974).

Schilling (2010) adds to the discussion on the factors influencing an individual's technology adoption by mentioning that the rate at which technology improves over time is commonly faster than the rate at which customer requirements increase over time; therefore, technologies that initially met the requirements of the mass market may eventually exceed the demands of the market and capture market share that initially went to a better-performing technology. Numerous technologies demonstrate growing returns to adoption, thereby implying that the more these technologies and innovations are adopted, the more valuable they will become (Schilling, 2010). Study on innovation adoption and diffusion helps to understand how innovation characteristics impact innovation decisions and timing (Matzler and Hinterhuber, 1998).

Customer satisfaction is the strongest indicator for a firm's future as a high level of customer satisfaction leads to a high level of customer loyalty (Matzler and Hinterhuber, 1998). High levels of perceived quality and customer satisfaction have a positive word-of-mouth effect, as illustrated in Figure 5 below.

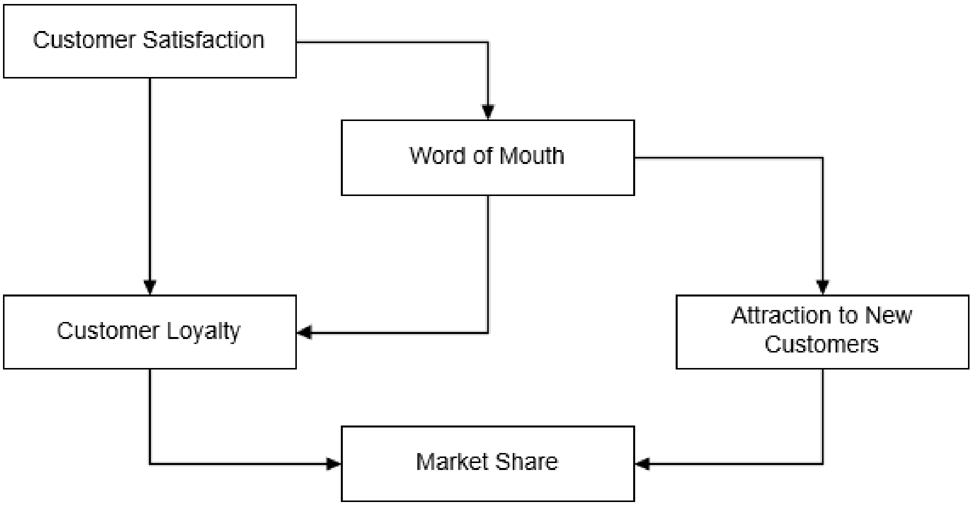


Figure 5. Market share as a consequence of customer satisfaction. Adapted from Matzler and Hinterhuber (1998) and Kordupleski et al. (1994).

The Figure 5 above focuses on the demand side of the market. In practice the market share is dependent on the interaction of both supply and demand side factors of a market. In practice, some new markets, such as service robotics, may suffer from the supply side challenges and therefore building market share is not only demand side challenge. Both supply and demand side play an important role.

2.1.3 Market and technology uncertainty

Market and technology uncertainty, discussed in this chapter, is relevant to this thesis as these are among the strongest sources of uncertainty during the FFE, occasionally making the first steps of the R&D activities in NPD slightly chaotic and unclear. This thesis studies how the VoC can be used to reduce these challenges.

Cooper (2005) argues that a significant cause of new product failures and serious delays is a failure to define the product concept, target market, benefits, positioning, requirements, and features well before beginning product development. In addition, uncertainty has been stated as a fundamental problem that top-level organization administrators must cope with (Thompson, 1967; Milliken, 1987). Market uncertainty commonly arises from consumer fear, uncertainty, and doubt (FUD factor) regarding what needs or problems will be addressed by new technology, thereby causing a delay in customers adopting to new innovations (Mohr, Sengupta and Slater, 2010).

Further, scholars describe that based on early studies in psychology, uncertainty has come to mean the absence of information—as information increases, uncertainty decreases (Daft and Lengel, 1986; Miller and Frick, 1949; Shannon and Weaver, 1949; Garner, 1962). Two complementary forces exist in organizations that influence information processing: uncertainty that reflects the absence of answers to explicit questions, and equivocality that originates from ambiguity and confusion (Marschak and Radner, 1972; Baligh and Burton, 1981; Daft and Lengel, 1986). Uncertainty is a measure of the firm's ignorance of the value for a variable in the space, while equivocality is a measure of the organization's ignorance of whether a variable exists; each aspect leads to different behavioral outcomes (Daft and Lengel, 1986).

Figure 6 below presents the two forces originating from the absence of answers, ambiguity, and confusion.

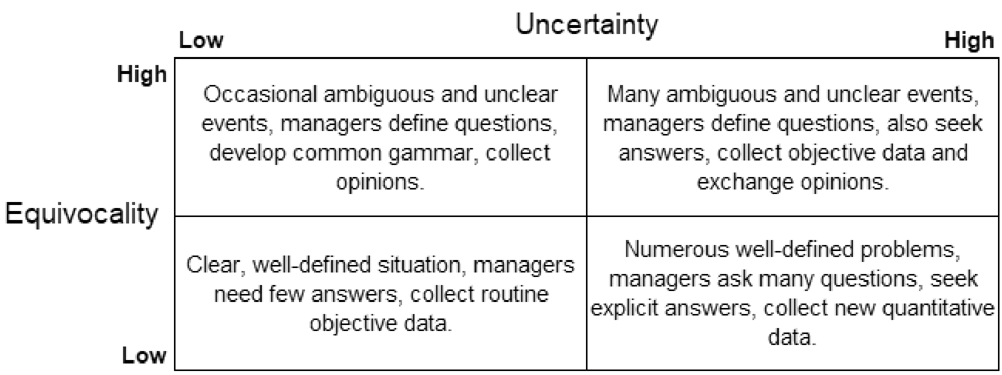


Figure 6. Uncertainty and equivocality. Adapted from Daft and Lengel (1986).

Several different concepts have been introduced by scholars to explain and describe uncertainty from different perspectives. According to Poskela (2009), uncertainty has been discussed in the literature mainly as a characteristic of the business environment (Hatch, 1997), lack of clarity of information (Lawrence and Lorsch, 1967), difference between the required and possessed amount of information (Galbraith, 1973), perceived environmental uncertainty (Duncan, 1972; Milliken, 1987), risks and risk management (Ward and Chapman, 2003), task variability and task analyzability (Perrow, 1967), difference between uncertainty and equivocality (Daft and Lengel, 1986; Conrath, 1967), and complexity (Thompson, 1967; Tidd et al., 2001).

Perrow distinguished task uncertainty as task variability and analyzability, referring to the number of exceptions confronted during task execution and the degree to which known procedures exist for task execution. Routine technologies are best dealt with formal and centralized structures, whereas non-routine technologies require more flexibility and polycentralized structures. (Perrow, 1967)

Scholars connect task analyzability and variability as being related to the newness of a project in terms of technology and the market (Moenaert et al., 1995). In new market entries or new applied technologies, the ability to analyze tasks is lower and variability of tasks is greater compared to cases where markets and technologies are familiar to the organization (Perrow, 1967). High market uncertainty implies that stepping into new markets causes a lack of information about customers' needs and market characteristics (Poskela, 2009). Other sources of market uncertainty can be responses of competitors, adoption of technology, company's internal development, the demand level of offerings, product lifecycle duration, and not clear customer affections in terms of product attributes (Chen et al., 2005; Zhang and Doll, 2001; Lynn and Akgun, 1998; Moenart et al., 1995; Poskela, 2009).

According to Poskela (2009), high technology uncertainty can be explained in terms of which product structure and functionalities are understood. Technology uncertainty can be inherent in the choice of technology, combination of product features, materials and components, suppliers' capability, manufacturability, and regulatory or standardization topics (Chen et al., 2005; Zhang and Doll, 2001; Lynn and Akgun, 1998; Moenaert et al., 1995; Poskela, 2009). Further, technology and market uncertainties are linked by organizational uncertainties regarding knowledge, capability and resource availability to execute the task (Poskela, 2009). The level of uncertainty can also be used to distinguish radical innovations from incremental innovations—when both market and technology uncertainties are high, the innovation is typically considered radical and incremental in the opposite scenario (Herstatt et al., 2004; Lynn and Akgun, 1998; Balachandra and Friar, 1997; Poskela, 2009).

Scholars argue that successfully operating NPD project teams are able to reduce uncertainty during the front-end phase of the innovation process, and the more an innovation team reduces uncertainty related to user needs, technology, competition, and the required resources, the higher its possibilities are to produce a commercially successful product (Moenaert et al., 1995). Successfully reducing uncertainty in the FFE phase decreases the need for change in the subsequent phases of the process, thereby resulting in higher product development success (Poskela, 2009).

Ward and Chapman (2003) suggest that all current project risk management processes have a restricted focus on the management of project uncertainty, as managing uncertainty is not merely about managing perceived threats and opportunities but about identifying and managing all the numerous sources of uncertainty that give rise and shape to the perceptions of threats and opportunities, thereby implying the exploring and understanding of the origins of project uncertainty before seeking to manage it. Further, a threat and event-based perspective in risk management can result in a lack of attention to many important areas of uncertainty related to the project, including diversity that arises from lack of knowledge, the basis of projections, treatment of hypotheses regarding operating conditions, and the development of appropriate goals and associated tradeoffs (Ward and Chapman, 2003). Podolny (1994) proposed that organizations overcome problems of market uncertainty by adopting the principle of exclusivity in selecting exchange partners; this implies adopting a more social orientation and selecting partners with whom they have transacted in the past.

2.1.4 Product market selection and timing of entry

This section describes the product market selection and timing of entry as essential parts of the marketing of a technological innovation. In addition, different marketing strategies such as pioneering and following are addressed. Product market selection and timing of entry are interesting in the scope of this thesis work in a sense that those are open questions in the FFE stage and potential areas of use of VoC for better clarity.

The choice of market-entry timing has been described as one of the major causes for new product success or failure (Hopkins and Bailey, 1971; Booz, Allen, and Hamilton, 1982; Lilien and Yoon, 1990). Lilien and Yoon (1990) argue that in a dynamic environment with competition, the market entering decision must be scheduled to take into account the risks of premature entry and the missed opportunity caused by an entry that is too late. The market needs to be ready to adopt the new innovation. Typically, the process starts from the innovators and early adopters of technology, described in chapter 2.1.2. Kotler & Keller (2012) note that a company must identify which market segments it is able to serve effectively; once market segments are identified, the marketer decides which markets segments offer the greatest opportunities and targets those market segments. According to Schilling (2010), the perfect scheduling of entry takes into account several factors, including the benefits offered by new invention, the status of equipping technologies and complements, the state of customer anticipations, the risks of rival entry, whether the industry faces increasing returns, and a company's resources.

Marketers must track the following technology trends: the progressive pace of change, unlimited avenues for innovation, fluctuating R&D budgets, and growing regulation of technological change (Kotler and Keller, 2012). The advantage for a first mover may be the capacity to build brand loyalty and a fame for technological leadership, preemptively capturing meager resources, and exploiting buyer switching costs (Schilling, 2010). However, certain studies argue that first movers may have elevated failure rates; this makes sense, as they need to justify R&D expenses and may face significant consumer ambiguity. In contrast, second movers can build on the R&D and marketing investments of the first mover, generating innovations that costs less to construct and correcting the first mover's mistakes (Schilling, 2010).

On the other hand, the greatest disadvantage first movers face is uncertainty related to customer requirements, as customers may be uncertain regarding which features they desire in a new innovation; therefore, a firm may have to withstand significant losses before customer preferences are clarified (Schilling, 2010). This is always good to bear in mind when utilizing the VoC in the R&D and marketing processes in the FFE.

Technology cycles

Technology efficiency over cumulative endeavor invested often performs an s-shape curve (Figure 7 below); this proposes that performance refinement in a new technology is initially challenging and expensive, but when the profound principles or the technology are coped with, it begins to accelerate as the technology becomes better realized and eventually reaches decreasing returns as the technology comes near its natural borders (Schilling, 2010).

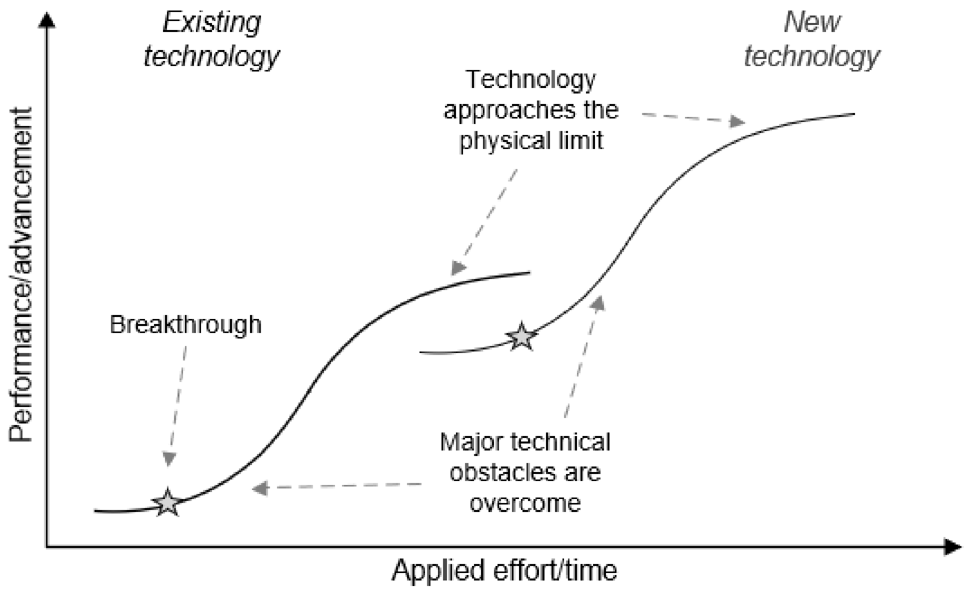


Figure 7. Technology performance s-curve. Adapted from Christensen (2003).

Christensen (2003) describes the movement along the s-curve as generally being the result of incremental improvements within an existing technological approach, whereas jumping onto the next technology curve is described as a result of adopting a radically new technology. Technological change often follows a cyclical pattern, where the first technological discontinuity causes a period of turbulence and uncertainty, thereby causing producers and consumers to explore the different possibilities enabled by the new technology (Schilling, 2010). Then, a dominant design emerges as producers and customers begin to converge on a consensus of the desired technological configuration and, finally, the existing design provides a robust benchmark for the industry, thereby enabling producers to turn their focus to growing production efficiency and incremental product improvements; the cycle begins again with the next technological discontinuity (Schilling, 2010). The traditional view in industrial organizations is that new industries follow a product life cycle pattern that consists of an initial period of intense competition, significant entry and exit of firms, and fragmented market shares, which is eventually followed by a shakeout when a number of firms fall, thereby leading to greater industry concentration (Gort and Klepper, 1982; Bayus and Agarwal, 2007).

Further, the risks and opportunities of a new product vary due to changes in the general economy, changes in customer preferences, and evolution of the industry life cycle. The decision to enter the market must be timed to balance the risks of entering too early or missing opportunities by entering too late. The R&D and marketing investments change the level of the opportunities and risks of the new product, as late entry enables more investments for designing a better product, providing appropriate technology support and building influential marketing activities to reduce the risk of failure (Lilien and Yoon, 1990).

Pioneering or following?

Scholars state that there is a broad consensus supported by empirical work that pioneering provides a certain form of advantage, typically either in increased sales or market share (Biggadike, 1976; Bond and Lean, 1977; Robinson, 1988; Robinson and Fornell, 1985; Urban et al., 1986; Whitten, 1979; Moore, Boulding, and Goodstein, 1991). According to Lilien and Yoon (1990), the timing of a market entry is a quantitative, tactical decision and a qualitative strategic decision. The qualitative aspect can be addressed as an entry-strategy problem: Should a firm attempt to be a pioneer or a follower? The quantitative decision can be addressed as an entry-time problem: When must a new product enter the market?

The compromise between the benefits and disadvantages of being a pioneer or a follower is a fundamental issue in the entry-strategy solution. A potential pioneer firm must decide its entry schedule to make a trade-off between the opportunities and benefits with innovation and the risks and costs associated with product development and marketing. A follower company must look on the marketing activities of the early entrants, the development of the industry, and the rivalry of other plausible entrants (Lilien and Yoon, 1990).

If pioneering improves firm performance, why is a first-entry strategy not adopted by all firms? Scholars argue that this can be explained mainly by two claims. In a pure luck model, all firms attempt to enter first, but only the lucky firm wins the race. Alternatively, not all firms have the same entry costs and skills, and entry timing reflects a mixture of the effects of entry costs and skill differences (Moore, Boulding, and Goodstein, 1991).

The same market entry strategy obviously does not necessarily fit all companies in different circumstances. Certain firms excel at leading, whereas some excel at following (Moore, Boulding, and Goodstein, 1991). Capon (1978) discussed four different company entry strategies that possibly lead to success, but each requires different capabilities. “Pioneer” strategy for the introduction stage requires heavy investments in R&D to develop products as perfectly as possible. The “Follow-the-leader” strategy for early growth requires investments and product and market development. The "Segmenter" strategy for late growth requires a company to commit resources to market research and product design in order to identify and satisfy the specific needs of particular segments. "Me too" companies in the maturity period must promote and price their products aggressively against an entrenched competitive environment (Capon, 1978; Lilien and Yoon, 1990).

A pioneer company considers both advantages and disadvantages when being the first to enter the market. On the demand side, the first entrant can acquire acknowledgement and build a reputation in the marketplace, which can produce word-of-mouth effects (Porter, 1985). Pioneers can dominate the desired market position (Urban, Carter, and Gaskin, 1986). Existing products have an advantage because of consumer traits that tend to lead to stable preference patterns; when buyers use the first entrant's product, they are willing to pay more for it than for other new products (Bain, 1956; Lane and Wiggins, 1981; Schmalensee, 1982). The experience-curve effect increases the first entrant's cost advantage and profit potential, and production costs tend to be lower for the pioneer than for the late entrants (Abell, 1978; Hammond, 1979; Robinson, 1988). However, the pioneer must take care of most of the investments and risks of maturing the product and the market for the product, and the first entrant needs to also digest the risk of later entrants copying the innovation quickly and with less cost (Mansfield, Schwartz, and Wagner, 1981).

Pioneering entrants generally maintain their gained market share advantage, and pioneering has been noted as a major determinant of long-term success for a new product; moreover, pioneers tend to have better quality products, wider product lines, and stronger distribution support (Biggadike, 1976; Dillon, Calantone, and Worthing, 1979; Robinson and Fornell, 1985). The brand that enters first can receive a substantial sales advantage; however, later entrants in rapidly growing markets or with significantly differentiated products can gain substantial shares or even displace the first entrant from its dominant market position (Whitten, 1979).

Further, the level of market potential at the chosen time of entry is an essential factor for the pioneer's success, and it has been described that there are only restricted periods of time during which the suitability between market key requirements and firm's competence is at optimum balance (Abell, 1978). From the perspective of demand existence, there are three cases: when the window is ready, timing is optimal for an entry; when the window moves, timing is poor; and when the window does not exist, market assessment is inadequate (Bucknell, 1982).

There are factors that a follower company must consider for the timing of entry. Entering into a market with existing competitors must consider various market uncertainties associated with entry competition, industry evolution, R&D capability, and competitive marketing responses (Lilien and Yoon, 1990). As the existence of demand for a certain product is already proven by a pioneer company, other firms are attracted to enter the market as followers (Lilien and Yoon, 1990). Moreover, obstacles when entering new markets typically make a new entrant less profitable than the established companies in the area of industry (Bain, 1968; Stigler, 1968; Ferguson, 1974). Entry barriers can be originated from scale factors, learning curve effects, proprietary technology, intellectual property protection, or other benefits of the pioneer company (Lilien and Yoon, 1990). Follower companies can reduce the market share penalty of late entry by supporting new product introduction with aggressive advertising (Urban et al., 1986).

Yoon and Lilien (1986) indicated that in a dynamic and competitive environment, the decision to enter a market must be timed to balance the risks of premature entry against the challenges of a missed opportunity.

Emerging industrial subfields

Mitchell describes that when a new technical subfield emerges, an industry incumbent company will face opposing entry incentives to either wait until technical and marketing uncertainties subside or to attempt to establish a strong position early. An incumbent company is most likely to enter a new subfield if a company's essential offerings are threatened or if it occupies industry-specialized supporting advantages (Mitchell, 1989).

Most new products can be copied somewhat quickly and there are often several firms that are capable of doing it (Levin et al., 1988; Mitchell, 1989). However, an ability to copy a product does necessarily give a company the ability to introduce it successfully into a market, as it must be developed, manufactured, and distributed to users who may demand refinement of the product (Finnegan and Goldschneider, 1981; Mitchell, 1989). Further, products often need to be coupled with supporting products and knowledge (Philips, 1966; Scherer, 1980; Mitchell, 1989).

When a product can be easily imitated, an incumbent or dominant firm will typically benefit from delaying its entry, because a company will be able to copy a product introduced by a competitor but can avoid introducing a product that would be rapidly imitated by other companies. Moreover, the incentive to avoid cutting into sales may override the incentives to compete. When only a few firms dominate an industry, parallel action may lead to delayed entry by all or most of the participants (Bain, 1956; Caves, 1972; Mitchell, 1989).

Further, risk-aversion may explain the tendency for late entry, as employees of firms that already participate in an industry possess often have more to lose than newcomers (Singh, 1986; March, 1988; Mitchell, 1989). Incumbent firms also may be constrained by structural inertia (Burns and Stalker, 1961; Crozier, 1964; Mitchell, 1989). Brittain and Freeman have argued that an organization is quick to expand when there is a significant overlap between its core capabilities and what is needed to survive in the new market (Brittain and Freeman, 1980; Mitchell, 1989).

Scholars have reflected the major benefits of pioneering as achieving technical leadership, capturing the use of limited resources, and generating buyer switching costs (Lieberman and Montgomery, 1988; Mitchell, 1989). Scholars list two categories of resources that have been found to be associated with early market entry— technology and marketing. A firm that makes significant and consistent investment in R&D clearly has the capability of creating an innovation or to be an early follower (Schoenecker and Cooper, 1998). Pioneers generally incur greater R&D costs than their rivals do (Mansfield, 1986). Incumbent firms (at least in the medical field) that possess a direct sales force tend to be earlier entrants (Mitchell, 1989).

Schoenecker and Cooper (1998) presented contrasting arguments regarding how the amount and availability of a firm's financial resources may influence its likelihood of being a pioneering firm. Troubled and poorly performing firms that possess fewer financial resources are more likely to be risk seekers in an attempt to improve their market position (Bowman, 1982; Fiegenbaum and Thomas, 1986). In contrast, the presence of slack financial resources providing buffer has been positively related to a firm's willingness to experiment with new products (Bourgeois, 1981; Moses, 1992).

High costs accompany the development of innovations. Early followers generally need to outspend later entrants on R&D to keep ahead in terms of recent developments so that they are able to enter the market quickly after the pioneer (Mansfield, 1986; Knight, 1967).

2.2 New product development

In this section, the theoretical background is discussed in the context of NPD as a strategic activity of an organization. The most common NPD processes and activities are discussed—for example, the Cooper's stage-gate model. However, even though the FFE is the early phase of the NPD and a substantial part of NPD, in this thesis, the FFE theory is discussed thoroughly in the next section, 2.3. This is on account of the utmost importance of FFE for this research and thesis as a fundamental setting for the VoC integration research.

Cooper (2005) discusses the motivation for NPD improvement by stating that a thousand of the world's largest companies spend one billion US dollars on R&D per day, and generally half of that budget is spent on projects that either do not get launched or are unsuccessful in the market. Rapidly advancing technologies, globalization of markets, and increasing competition are driving effective NPD as a crucial corporate strategic goal for the coming decades (Cooper, 2005). A company's ability to improve at the innovation process for driving new products from idea to market faster and with lesser errors is the key to win the "innovation war" (Cooper, 1990). Khurana and Rosenthal (1998) continue that any firm that hopes to compete on the basis of innovation clearly must be competent in all phases of NPD. In business and engineering, NPD is the process used to bring a new product to market, characterized in the literature as the translation of a market opportunity into a product available for sales (Krishnan and Ulrich, 2001). The product can be something physical and tangible or intangible such as a service, experience, or a belief.

The innovation process can be divided into three parts: the FFE of innovation, the NPD process, and commercialization. The front-end is often imagined as a linear process of three stages separated by management decision gates: pre-work for discovery of new opportunities, the scoping stage, and the final business case development stage (Koen, Bertels and Kleinschmidt, 2014). The FFE will be discussed thoroughly in the following section, 2.3.

According to Koen et al., the entire innovation process—including both front-end and product development—must be aligned with a firm's business strategy to secure a continuous flowing pipeline of new products and processes that contribute value to the corporation (Koen, Ajamian, Burkart, Allen et al., 2001). The FFE is a critical component of the innovation process, as decisions made at the front-end will eventually prescribe which innovation options can be considered for further development and commercialization (Koen et al., 2014).

Kahn (2012) emphasizes that a robust knowledge of customer needs and wants, the competitive environment, and the market are among the top required factors in the prosperity of a new offering. According to Griffin (1997), best-practice firms take advantage of employing multifunctional teams, measuring their NPD processes and outcomes, and expect a lot from their NPD programs. However, it is unclear if the best practices associated with continuous products also apply to discontinuous products or if some of the activities are not lucrative in the other context (Lynn et al., 1996; Morone, 1993; Veryzer, 1998). Understanding the differences between discontinuous (radical) and continuous (incremental) NPD processes is essential for the efficient management of discontinuous product development (Veryzer, 1998).

Scholars have found that firms that adopt a formal new product process obtain a positive impact on their performance, and firms that have such a process in place for the longest time fare the best (Booz, Allen, and Hamilton, 1982; Cooper, 1990). Concept development decisions define not only product specifications and a product's basic physical configuration but also extended product offerings, such as life-cycle services and after-sales supplies (Krishnan and Ulrich, 2001). When breaking down the barriers among the R&D, manufacturing, and marketing functions, techniques such as concurrent engineering and quality function deployment (QFD) can pave the way for more effective NPD (Song et al., 1997).

There are several activities that must be performed in an efficient NPD process. Scholars have proposed that the NPD process comprises five types of activities: opportunity identification and screening, product design, testing, commercialization, and post-launch activities (Urban and Hauser, 1993; Song et al., 1997). Alternatively, at a higher level, Cooper and Crawford characterized that the NPD process also includes marketing and technical activities (Cooper, 1975; Crawford, 1994; Song et al., 1997).

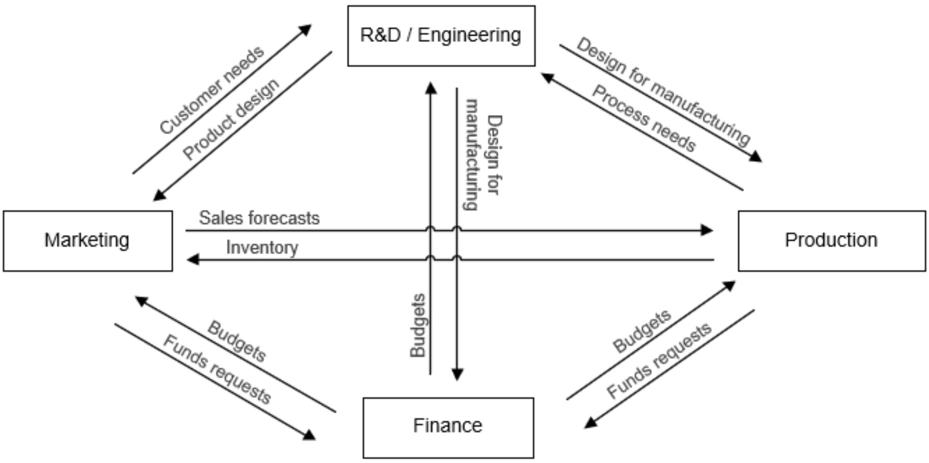


Figure 8. Cross-functional integration of R&D and other functions. Adapted from Urban and Hauser (1993).

Figure 8 above illustrates the critical information that is exchanged across different functions in the NPD process (Moenaert and Souder, 1990; Song et al., 1997). Song et al. highlighted that a precise representation of cross-functional relationships in the NPD should possess all three functional perspectives (R&D, marketing, and manufacturing); however, most research focuses on the interaction between R&D and marketing (Song et al., 1997). Cross-functional cooperation is said to facilitate the completion of NPD projects on schedule, within budget, and with fewer design changes (Griffin, 1992; Griffin and Hauser, 1993; Hauser and Clausing, 1988; Pinto and Pinto, 1990; Song et al., 1997). However, while the cross-functional cooperation is an important determinant of new product performance, it certainly is not the only determining factor (Song et al., 1997). Scholars have categorized the factors that impact new product performance into organizational, market environment, strategic, and development process factors (Montoya-Weiss and Calantone, 1994; Song et al., 1997).

Cagan and Vogel express that in spite of the process, successful offering creation requires that engineering teams, product designers, and marketing researchers must co-operate to identify promising product directions and work through the FFE to create a product that meets the needs, wants, and desires of the customer. The aspect of understanding the customer can without difficulty be lost in product development activities, particularly in large organizations, as circumstantial factors tend to control decisions regarding cost, features, and form (Cagan and Vogel, 2008).

The fundamental means to win with NPD is implementing projects by building cross-functional teams, VoC mechanisms, and idea-to-launch processes as well as succeeding in portfolio management in order to select the right projects to invest in (Cooper, 2005). According to Kotler and Keller (2012), NPD shapes a company's future. Successful NPD requires reaching a couple of concurrent goals: maximizing fit with customer requirements, minimizing time-to-market, and governing the cost of development (Schilling, 2010).

According to Christensen (2003), the failure of successful companies to confront a technological change is explained by organizational, managerial, and cultural responses to technology change, or the capability of settled firms to deal with radically new technology. The same decision-making and resource-allocation processes—for example, listening carefully to customers—may be a key to the success of established companies but may also reject disruptive technologies, as companies do not seem to be willing to invest in radical technologies unless their already existing customers need such products (Christensen, 2003).

Typically, resources are limited and firms must ration their capital. To this end, organizations typically incorporate quantitative and qualitative methods to estimate which projects should be funded first (Schilling, 2010). A company's project portfolio typically includes projects of different types (advanced, breakthrough, platform, and derivative) that have different resource requirements and rates of return (Schilling, 2010). Marketers play a key role in NPD to identify and evaluate ideas and work with R&D and other areas at every stage of development (Kotler & Keller, 2012).

Griffin argues that NPD processes continuously evolve and sophisticate as NPD develops continually on several fronts, and organizations that fail to keep their NPD practices up-to-date will suffer competitive disadvantage. Firms operate in dynamic environments, both competitive and internal, and response management processes also need to be modified over time so that organizations can stay effective and financially profitable through changing situations. Best-practice firms may even simultaneously use more than one NPD practice to succeed in all activities associated with projects (Griffin, 1997).

Krishnan and Ulrich stated that developing new products presents an organizational challenge, as it introduces discontinuity in ongoing operations. Commonly, a team of individuals from various functions is assembled for the duration of the development process and allocated for a subset of decisions. Typically, a marketing function is accountable for numerous product specification decisions, operations for the supply-chain design decisions, and engineering design for the tasks of creating the concept and making detailed design decisions. Figure 9 below illustrates the clustering of product development decisions according to functional logic (Krishnan and Ulrich, 2001).

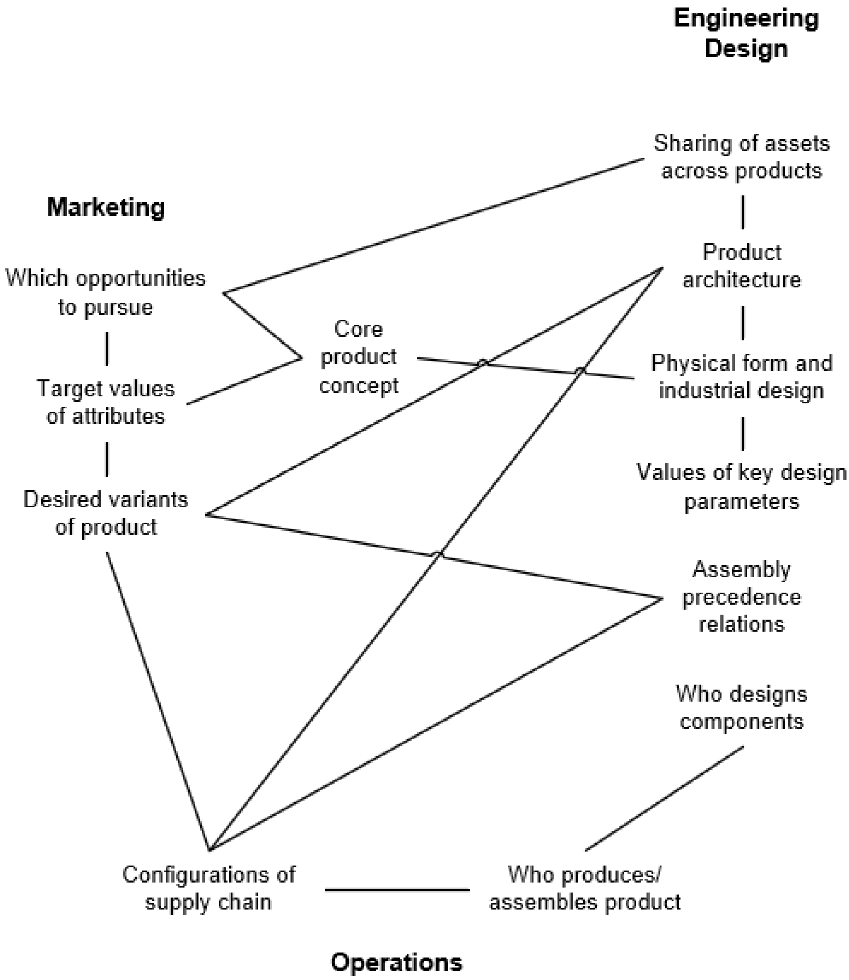


Figure 9. Product development decision functional categories. Adapted from Krishnan and Ulrich (2001).

The following subsections summarize some of the most commonly used NPD processes and the relevant activities carried out in each principle. The FFE activities and processes that typically occur prior to the actual product development (PD) phase are discussed more thoroughly in the following section, 2.3.

Stage-gate system

Cooper has proposed a stage-gate system as a conceptual and operational model for translating a fresh product from idea to launch by managing the new product process to improve its efficiency and effectiveness. Even though individual companies may refer to their systems by different names and on paper they may appear somewhat unique to that company, in practice, there is a surprising parallelism among different stage-gate approaches (Cooper, 1990). Schilling (2010) describes that stage-gate processes provide a scheme to guide firms through the NPD process, offering a series of go/kill gates in which the organization needs to decide if the project needs to be continued and how its activities need to be prioritized.

According to Cooper, almost every top-performing company has implemented some form of a stage-gate framework to drive their new products through commercialization. An effective NPD process includes the following stages: discovery and generation of ideas, scoping and preliminary investigation of the project, building the business case, actual detailed design and development, testing and validation, and commercialization (Cooper, 2005). Figure 10 below shows a high-level NPD funnel where product innovation ideas travel through different process stages and activities, from left (concept creation) to right (development), as a function of time.

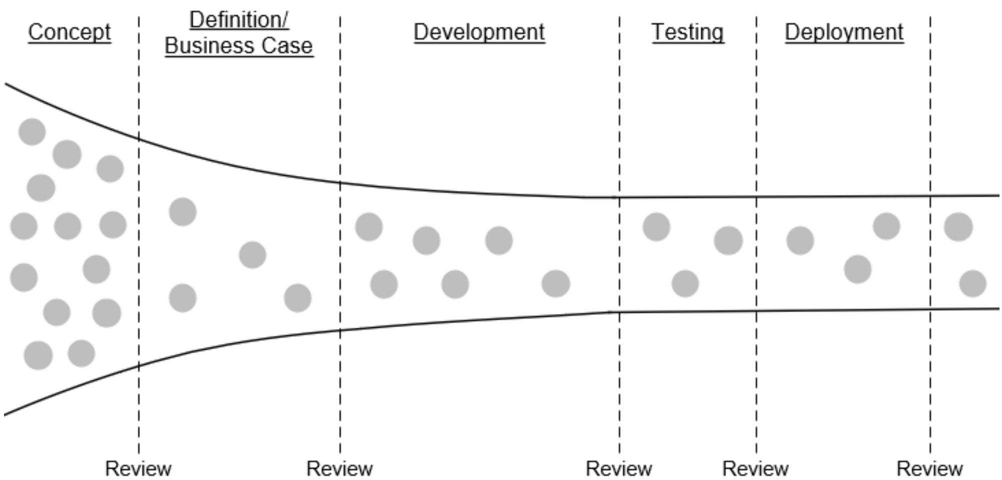


Figure 10. NPD process stages. Adapted from Cooper (1990).

In order to manage the innovation process, the stage-gate system divides the process into a predetermined set of stages, each of which comprise a group of pre-described, related, and often parallel activities (Cooper, 1990).

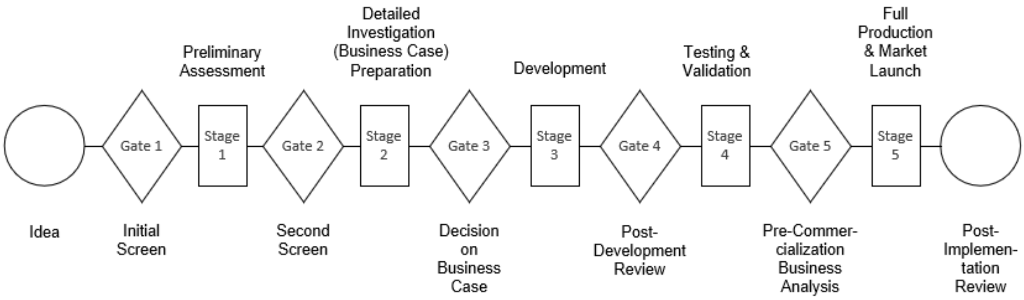


Figure 11. An overview of Cooper's Stage-Gate System. Adapted from Cooper (1990).

A typical stage-gate system (Figure 11 above) involves four to seven stages and gates, depending on the company. Cooper describes that each stage is more expensive than the stage before it. Information gets better and better with every passing stage and the risk level is managed when stages change. The entrances to stages are gates that control the process, such as checkpoints characterized by a set of inputs or deliverables, exit criteria, and an output. Cooper highlights that the most important steps of the NPD process, which usually separates winners from losers, lie in the stages that precede the actual PD phase (Cooper, 1990).

According to Cooper (1990), predevelopment activities are important as they qualify and define the project when answering key questions such as

"Is the project economically attractive?"

"Will it sell at sufficient volumes and margins to justify to investment in development and commercialization?"

"Who exactly is the target customer and how should the product be positioned?"

"What features and attributes must be incorporated into the product to give it a differential product advantage?"

"Can the product be developed at the right cost and what is the likely technical solution?"

Cooper's stage-gate system includes various stages and gates. In the "idea stage," a new product process is initiated by a new product idea. At "Gate 1—Initial Screen," the first decision is to commit resources to the project for the project to be born. "Stage 1—Preliminary Assessment" includes analyzing the project's technical and marketplace merits in terms of key users, focus groups to determine market size, and potential and likely market acceptance. At "Gate 2 – Second Screen," the project is re-evaluated in light of new information before moving into heavier spending. "Stage 2—Definition" implies that deeper market research and competitive analysis studies are undertaken to determine a customer's needs, wants, and preferences to clearly define the winning product. "Gate 3—Decision on Business Case" is the final gate before entering actual product development and heavy spending. "Stage 3—Development" involves the development of the product, a detailed test, and putting in place marketing and operation plans. "Gate 4—Post-Development Review" involves conducting a check on the progress and continued attractiveness of the product and project. During the "Stage 4—Validation Testing," the entire viability of the project is ascertained. "Gate 5—Pre-Commercialization Decision" is the final gate before complete commercialization and the final gate where project can still be terminated. "Stage 5—Commercialization" finally includes the launch and implementation of marketing and operation plans (Cooper, 1990).

The IDEO process

Moen (2001) reviewed the IDEO process, which is a California-based, widely admired, award-winning design and development firm where work is play, brainstorming is science, and the most important aspect is breaking the rules (Moen, 2001; Kelly, 2001; ABC News, 1999; IDEO San Francisco, 2001).

In the IDEO method, "hot project teams" infused with purpose and personality are the heart of the method. The method includes widely divergent disciplines; empowerment; merging fun and project development; a team including between three and twelve people; having clear and tangible goals and serious deadlines; crazy characters such as a visionary, troubleshooter, iconoclast, pulse-taker, craftsman, technologist, entrepreneur, and cross-dresser; and being passionate (Moen, 2001; Kelly, 2001; ABC News, 1999; IDEO San Francisco, 2001).

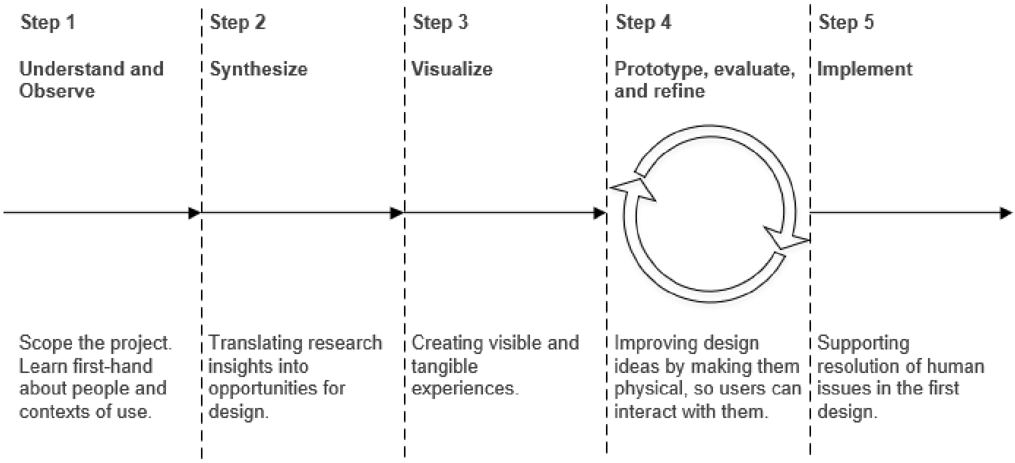


Figure 12. IDEO process steps. Adapted from Moen (2001) and IDEO, San Francisco (2001).

The IDEO process (illustrated above in Figure 12) includes five steps. During the "Understand and observe" step, the team gains an understanding of the market, client, technology, and the constraints of the problem by observing actual people in real-life situations to ascertain what makes them tick, what confuses them, what they like or dislike. In the "Synthesize" step, the team collects all the observed information in the project room to translate information into design opportunities. In the "Visualize" step, the team brainstorms and visualizes new-to-the-world concepts and the customers who will use the products. In the "Prototype, evaluate, and refine" step, shaping and prototyping of ideas is conducted in a series of quick iterations to fail early and learn. The "Implement" step is the longest and technically the most challenging of all IDEO process phases.

The following subsection addresses an additional NPD process, proposed by Veryzer (1998), for discontinuous and disruptive innovations that may be challenging to handle by employing the traditional NPD processes, which are developed for more incremental type of innovations.

The new product development process for discontinuous innovation

As discussed earlier in chapter 2.1.1, radical and discontinuous innovation differs from the incremental innovation in its nature. Discontinuous innovation involves an extremely high degree of technological uncertainly, a sequence of innovations, and often rather long periods of development (Ali, 1994; Lynn, Morone, and Paulson, 1996; Morone, 1993; Griffin, 1997).

Veryzer describes that factors such as the uncertainty of applicable applications for technology, more distance from the market in scheduling, and customer familiarity with the product also affect the nature of the NPD process. As a result of the factors described above, the development of discontinuous products does not appear to entirely follow the conventional stage-gate development system. Instead, the discontinuous product development process (Figure 13 below) appears to overlap among discrete events, and there is an aspect of informality with respect to how the development process for those radical products is dealt with, even though the activities take place in a consistent order (Veryzer, 1998).

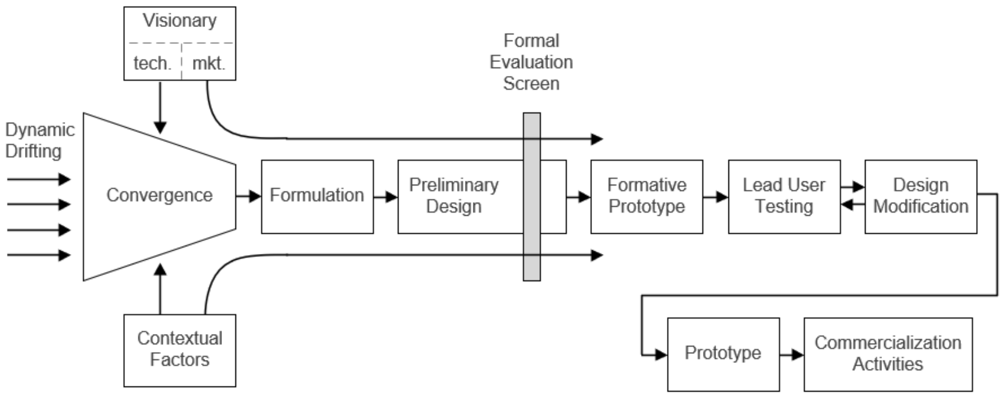


Figure 13. Discontinuous product innovation process. Adapted from Veryzer (1998).

The process is initiated by the convergence of developing technologies, various contextual or environmental factors, and the vision of a strong product champion individual (Veryzer, 1998). Lee and Na highlighted the importance of product champion roles for radically innovative products (Lee and Na, 1994; Veryzer, 1998). Out of this critical mass, winning emerging technologies are formulated into product applications (Veryzer, 1998). Unlike the process for more continuous products that typically involve market assessment and financial analysis prior to beginning development, the discontinuous development process involves the formulation of a product application for new technology, so that the direction and feasibility of a product application is determined (Cooper, 1988; Crawford, 1984; Hughes and Chafin, 1996; Ulrich and Eppinger, 1995; Veryzer, 1998).

In the discontinuous development process, a prototype is used to explore and formulate the technical aspect of the product and develop an application for the developed new technology. The formative prototype phase enables subsequent activities, such as opportunity analysis and target market selection. The activities associated with the development of continuous products are rarely possible and may not be constructive during the early development of discontinuous new products; it appears that in certain cases, activities such as concept testing and business assessment may actually discourage major innovations, as customers are not always able to fully comprehend or appreciate discontinuous products or those consequences (Veryzer, 1998). Once the product is transferred to an operating unit, a more conventional NPD process begins that is likely to involve the "pre-development" and marketing activities that are generally associated with successful new products (Cooper, 1988; Kleinschmidt and Cooper, 1991; Veryzer, 1998).

Veryzer summarizes that discontinuous innovation appears to be an inherently messy process, where coincidence and fortuitousness may play an important role in the development of such products. The initiating and driving forces of a project play an important role in advancing the project, when technical breakthroughs and the convergence of developing technologies along with the opportunistic management of the internal technological capability in search for legitimization can be rather important for launching a discontinuous innovation project. In addition, the discontinuous NPD process appears not to be as amenable to being customer-driven as the typical continuous NPD process (Veryzer, 1998).

The following subsection focuses on the early R&D stages of the NPD process before the actual product development phase.

2.3 The fuzzy front-end of new product development

This subsection focuses on the literature on FFE, illustrating the most common operation models, fundamental activities, and the evaluation of front-end performance. This portion of the literature review is essentially important for this thesis, as the empirical research is conducted in a project during the FFE phase of the R&D cycle.

Koen et al. formulate that the front-end is defined by the activities that come before the formal and well-structured PD phase of the NPD process. The activities that take place in the FFE are often described as chaotic, unpredictable, and unstructured (Koen, Ajamian, Burkart, Allen et al., 2001).

Smith and Reinertsen (1998) noted that although FFE may not be the most expensive part of the NPD project, it can consume half of the development time. Koen et al. use the term "front-end of innovation" (FEI) instead of FFE of innovation, as FFE is more expressionistic and is claimed to highlight too much the fuzziness of the front-end, thereby easily giving the impression that the front-end is not managed effectively (Koen et al., 2001).

Moenaert et al. (1995) suggest that a key task during the front-end stage is to reduce uncertainty and that this is best achieved by encouraging closer communication between R&D and marketing, having a distributed project construction, and demanding a few formal deadlines and controls even during the front-end phases. The path toward survival through the FFE phase is typically unfamiliar and challenging and has been named the "Valley of Death," as firms face challenges at this early stage of innovation in securing sufficient financial, human, and physical resources (Schoonmaker, Carayannis, and Rau, 2013; Department of Energy, 1991; Markham et al., 2002; Merrifield, 1995; Penrose, 1959; Wernerfelt, 1984; Barney, 1991; Barney, 2001).

The "Valley of Death" is explained as a phase incorporated with risks and high mortality rates, thereby implying a low probability of the innovation's survival in the next phase (from FFE to NPD) (Auerswald and Branscomb, 2003; Markham, 2002; Merrifield, 1995; Schoonmaker, Carayannis, and Rau, 2013). Figure 14 below illustrates the phase in which both research and commercialization resources are the lowest.

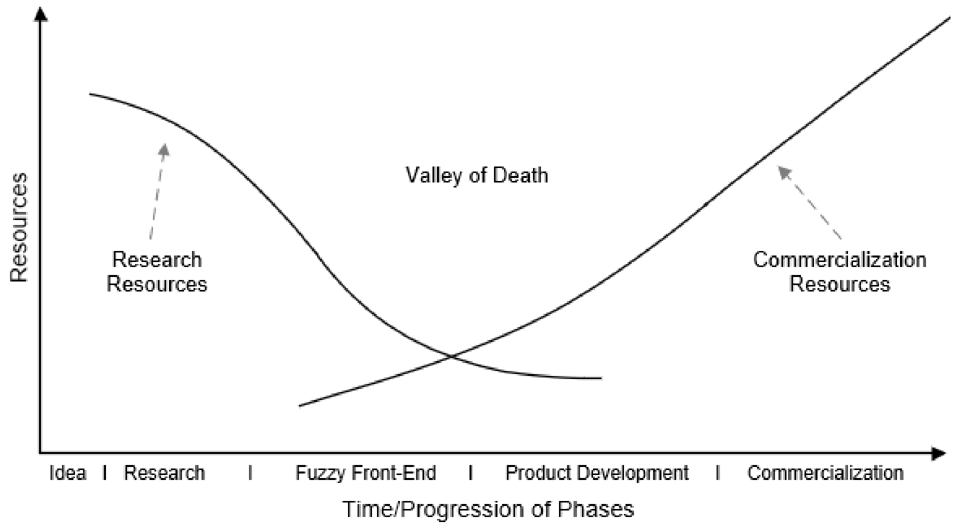


Figure 14. The "Valley of Death". Adapted from Schoonmaker et al. (2013).

The "Valley of Death" construct identifies resources, roles, and processes that are not found in technological research (R&D) or in new product development (NPD) programs (Markahm et al., 2010; Schoonmaker, Carayannis, and Rau, 2013).

As illustrated in Figure 15 below, the FFE of innovation (FFEI) has three stages of activities: awareness, demonstration, and transfer (Khurana and Rosenthal, 1997; Koen et al., 2001; Smith and Reinertsen, 1991; Smith and Reinertsen, 2001; Schoonmaker, Carayannis, and Rau, 2013). The champion adopts a project and works as its spokesman, the sponsor provides project sanction and resources, and the gatekeeper establishes the criteria and makes decisions about the future of the project (Markham et al., 2010; Schoonmaker, Carayannis, and Rau, 2013).

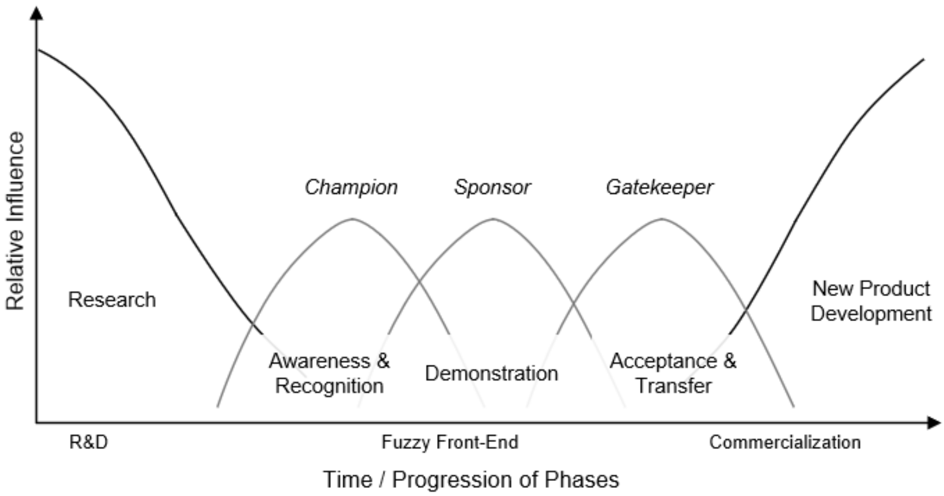


Figure 15. Roles and activities in FFEI. Adapted from Schoonmaker et al. (2013).

The proposed key interface roles that are required to succeed in the FFE phase (Figure 13 above) work in a sequential manner to advance unstructured opportunities through to the NPD (Reid and de Brentani, 2004; Schoonmaker, Carayannis, and Rau, 2013). Other forms of resources during the FFEI are external resources, partnerships, alliances, and networking (Schilling and Phelps, 2007; Harrison et al., 1991; Harrison et al., 2001; Schoonmaker, Carayannis, and Rau, 2013).

Khurana and Rosenthal (1998) noted that any firm that hopes to race on the basis of innovation must be competent in all phases of the NPD process; however, the real key to success can be found in the activities that take place before the go/no-go decision for any NPD project. Effectively structuring the early stages of the NPD process and embracing qualitative methods, enable downstream activities to become more efficient and less error-prone and lead to a greater chance of success in the marketplace (Cagan and Vogel, 2008). The front-end of innovation offers one of the best opportunities for enhancing the general innovation process (Koen et al., 2001).

Khurana and Rosenthal (1998) described that the greatest benefits can be achieved through improvements in the performance of front-end activities. Achieving a steady state between creativity and discipline is key to developing competence in the NPD front-end. Companies either employ a formal process to implement order and predictability to the front-end or strive to foster a company-wide culture in which the main participants in front-end activities stay concentrated in business vision, technical feasibility, customer orientation, schedule, resources, and coordination. The front-end approach must be compatible with the firm's product offering, market, and organizational aspects (Khurana and Rosenthal, 1998).

Table 3 below presents the fundamental differences between the front-end and product development phases of the NPD process.

Table 3. Differences between FFE and PD in the NPD process. Adapted from Koen et al. (2001).

	Front-end of Innovation (FEI)	New Product Development (NPD)
Nature of Work	Experimental, often chaotic. Challenging to plan Eureka moments.	Structured, disciplined, and goal-oriented with a project plan.
Commercialization Date	Difficult to predicts	Definable.
Funding	Lot of variation. In early phases, many projects may be "bootlegged", while others require funding to proceed.	Budgeted.
Revenue Expectations	Often uncertain. Occasionally done with a great deal of speculation.	Believable and with increasing certainty, analysis, and documentation as the product release date comes closer.
Activity	Both individual and team in areas to minimize risk and optimize potential.	Multifunctional product and/or process development team.

Koen et al. describe the nature of front-end as experimental, often chaotic, difficult to plan with variable funding and unpredictable commercialization dates (Koen, et al., 2001).

The following subsections, 2.3.1 and 2.3.2, continue to delve deeper into the FFE operation models and FFE activities.

2.3.1 FFE operation models

Cagan and Vogel (2008) state that companies must structure and navigate the FFE of the NPD process by beginning with opportunity identification and ending with a realization of a well-developed product concept. This chapter presents the literature review comprising of different front-end models and approaches used to structure the often chaotic FFE phase of NPD.

Holistic approach

Khurana and Rosenthal published the first comprehensive study of the front-end and offered a process view of the activities that the front-end comprises. Successful organizations follow a holistic approach that places the front-end within a broader context and emphasizes that success depends on both organizational and project-specific activities. The most significant benefits in improving NPD can be reached by advancements in the performance of front-end activities—delivery of product strategy, opportunity identification, idea generation, product definition, project planning, and executive reviews (Khurana and Rosenthal, 1998).

The greatest success comes to organizations that adopt a holistic approach (Figure 16 below) to the front-end by powerfully linking business strategy, product strategy, and product-specific decisions—combining these elements requires a process that integrates such links (Khurana and Rosenthal, 1998).

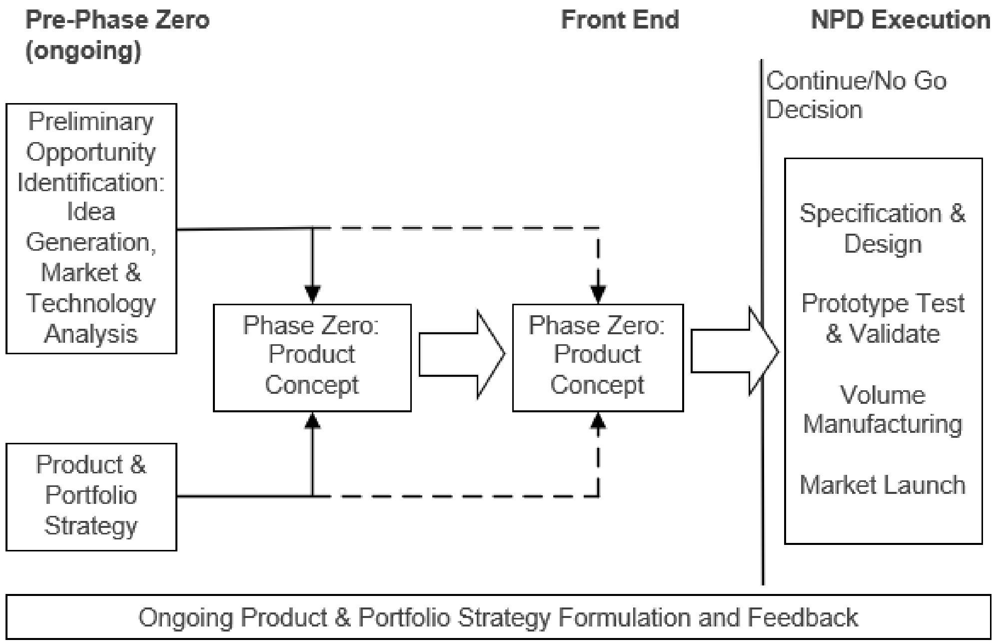


Figure 16. The holistic approach FFE process. Adapted from Khurana and Rosenthal (1998).

In Khurana's and Rosenthal's holistic approach, before possibly proceeding to the actual NPD execution phase, the FFE process undergoes phases that include opportunity identification, idea generation, market and technology analysis, product and portfolio strategy, product concept, and feasibility and project planning, leading to final project funding Go/No-go decision (Khurana and Rosenthal, 1998).

The two-track model

Reinertsen (1994) illustrated an example of a two-track front-end process (Figure 17 below), which was differentiated due to the different time and focus of various projects.

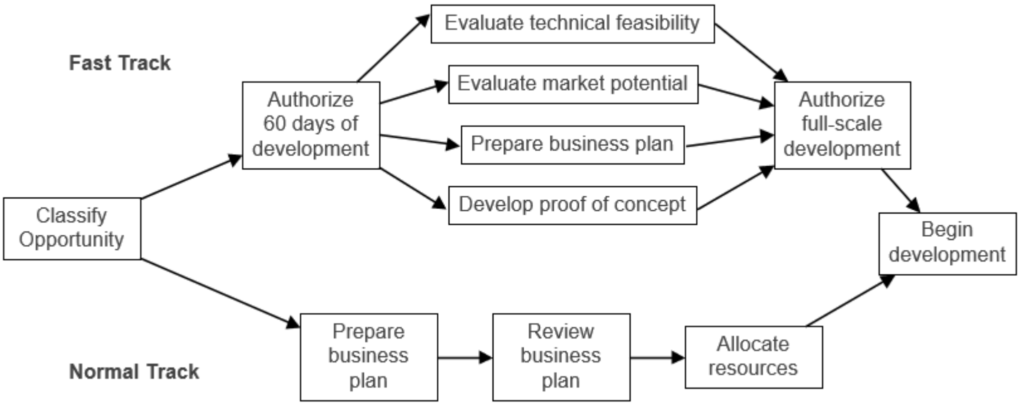


Figure 17. The two-track FFE process. Adapted from Reinertsen (1994).

Reinertsen's two front-end processes differ depending on whether the activities are conducted in sequence in the "Normal track" or in parallel in the "Fast track" (Reinertsen, 1994). Trade-off decisions deal with the benefit of gaining time and the cost of implementing a time-focused project (Nobelius and Trygg, 2002).

The stage-gate model

Cooper (1998) introduced a linear stage-gate model, illustrated in Figure 18 below, for the front-end phase, including a series of three phases and three decision gates before entering into the actual product development phase or terminating the project.

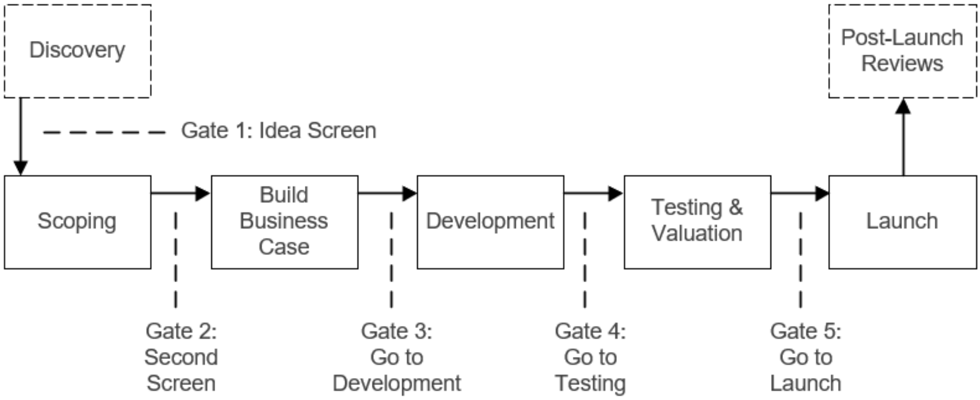


Figure 18. The Stage-Gate FFE model. Adapted from Cooper (1998).

Cooper's stage-gate model begins with the discovery phase, when ideation, generation, and conceptualization of ideas takes place. At the first gate, ideas are screened based on a set of qualitative criteria to assess the suitability of the idea. The second phase deals with acquiring more information about the idea, aiming to discard a great number of ideas at the next gate. Before the third and final gate before actual product development, a solid business case is built that includes an investigation of user's needs, the competitive situation, markets, technical feasibility, financial issues, and general testing of the product concept; the outcome of building this case is product definition, project justification, and action plan through the launch. Cooper's stage-gate model has a rather linear and formal approach for managing front-end phase activities (Cooper, 1998).

The very recent research from the NPD pioneer Robert G. Cooper (2017) updates the original stage-gate model to better adapt to the rapidly changing business environment with less relaxed budgets, more constrained resources, and global competition, as illustrated in Figure 19 below.

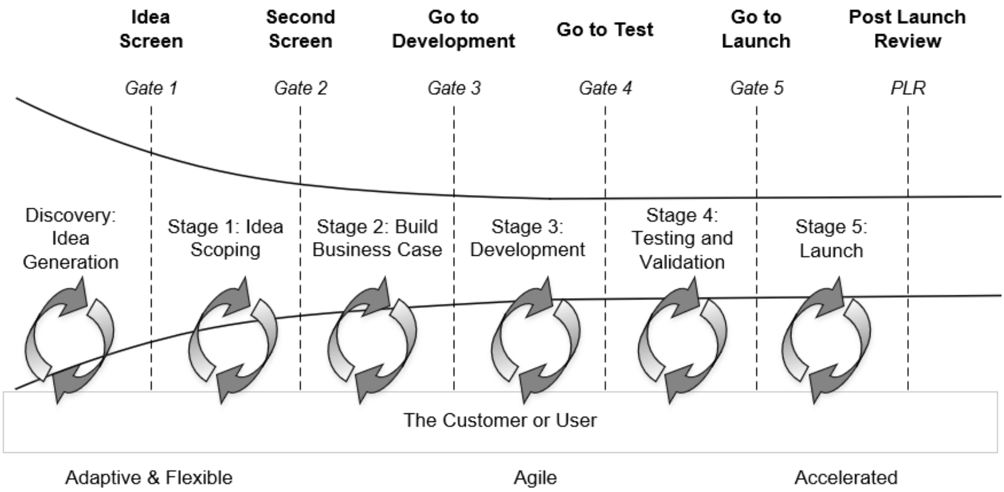


Figure 19. The "next-generation idea-to-launch system". Adapted from Cooper (2014) and Cooper (2017).

In Cooper's updated stage-gate model, the better adaptivity to a more competitive market environment is accomplished through the incorporation of iterative development cycles designed to obtain something before potential users early and often (Cooper, 2017). The build/test/feedback/revise cycle spiraling within each stage has some similarities with the lean startup method (Ries, 2011).

The new concept development model

Koen et al. attempted to provide clarity to the FFE by determining a common language, definitions of the key elements, and the best practices for the FFE and introduced new concept development model (NCD) in the process. Koen's NCD model consists of three key parts, illustrated in Figure 18: five front-end elements, an engine that powers the elements, and external influencing factors. In the NCD model, the inner area defines five key elements that comprise the FEI: idea genesis, idea selection, concept and technology development, opportunity identification, and opportunity analysis. The engine driving the five front-end elements represents leadership and executive-level support and is fueled by the culture of the organization. The outer influencing factors that affect the decisions of the two inner portions comprise organizational capabilities, business strategy, the outside world (customers and competitors), and enabling science (Koen et al., 2001).

Koen et al. (2001) also introduced term FEI to describe the front-end phase of the innovation process instead of the term FFE, thereby targeting to reduce the mysterious aspect of established terminology to increase organizational accountability on front-end activities and to provide stronger impression that front-end activities can be managed well instead of merely highlighting their "fuzziness." Figure 20 below presents how ideas are expected to flow, circulate, and iterate among all the elements of a front-end machine for NCD.

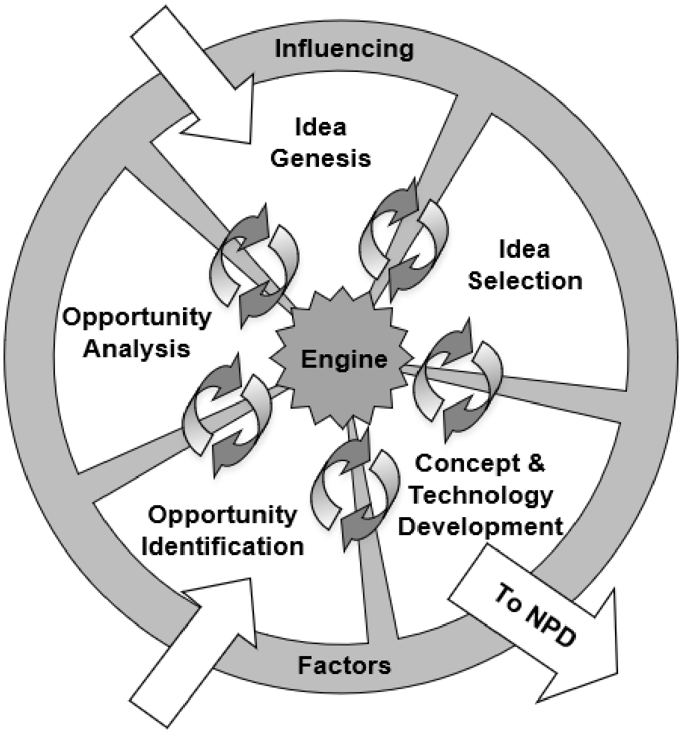


Figure 20. The NCD front-end machine. Adapted from Koen et al. (2001).

In contrast to Cooper's linear stage-gated processes, Koen's NCD engine model is circular and indicates that ideas flow, circulate, and iterate across and among the five elements after beginning from the opportunity identification or idea-generation stages (Koen et al., 2014).

The user-centered funnel model

Cagan and Vogel (2008) argued that in successful product development engineers, designers and market researchers must work in unison to recognize promising product directions and work through the FFE to create a product that meets the needs, wants, and desires of the customer. Companies must structure and navigate the FFE process using a four-phase integrated process, beginning with opportunity identification and ending with a realization of a well-developed product concept. Cagan and Vogel (2008) presented a user-centered integrated new product development (iNPD) process that consists of a series of funnel-type of phases: identifying the opportunity, understanding the opportunity, conceptualizing the opportunity and realizing the opportunity—three first phases are included in the front-end and the last one is the actual PD. The more time, money, and people a company is able to allocate from downstream to the front-end, the better the process becomes; the greater allocation of resources in the front-end will lead to a better executed product with fewer downstream catastrophes (Cagan and Vogel, 2008).

The tailored model

Nobelius and Trygg (2002) analyzed three different types of projects; research, incremental, and platform development; they found presence of remarkable variation in the FFE models with respect to the set of activities, their sequences, overlapping, relative time duration, and perceived importance of individual tasks. Figure 21 below illustrates how the flexibly tailored FFE model is able to support different types of projects: research, incremental, and platform development.

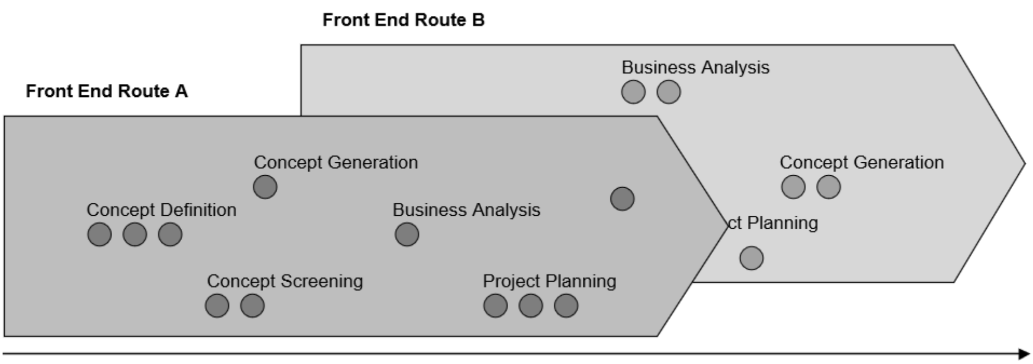


Figure 21. The flexibly tailored FFE model. Adapted from Nobelius and Trygg (2002).

Nobelius and Trygg (2002) list six activities that are implemented in the FFE after opportunity has been identified: mission clarification, concept creation, concept screening, concept definition, business analysis, and project planning. The authors argue that it appears less valuable to chase one FFE model; instead, a greater flexibility may be needed to support different types of projects by adapting the FFE model according to the type of project, staffing situation, and overall company situation.

The following subsection focuses on the various tasks and activities that must be implemented in a well-performing front-end of NPD.

2.3.2 FFE activities

A large number of the activities implemented in the actual product development (PD) phase does not apply to the front-end as the nature of the work, commercialization date, funding level, revenue expectations, and other factors are fundamentally different (Koen et al., 2001). Koen et al. (2014) created a comprehensive list of empirical studies of front-end practices, as illustrated in Appendix 2.

Opportunity identification

Koen et al. (2001) describe opportunity identification as the phase when an organization identifies the opportunities that the organization desires to pursue and considers business and technological resources so that resources will be allocated to new avenues of market growth and operating efficiency. Opportunity identification is typically driven by business goals such as responses to competitive threat, breakthrough possibility for competitive advantage, or operations improvement (Koen et al. 2001). Poskela (2009) describes opportunity identification as a critical but often underestimated front-end activity where companies typically lack systematic and effective practices that would enable them to proactively identify emerging opportunities.

An organization may use formal opportunity identification with creativity tools and techniques (brainstorming, mind-mapping, lateral thinking), problem-solving techniques (such as causal analysis, fishbone diagrams, process mapping, theory of constraints), or alternatively informal opportunity identification activities (ad hoc sessions, cyberspace discussions, individual insights, or edicts from senior management) (Koen et al., 2001).

Opportunity analysis

During the opportunity analysis phase, additional information is needed to translate opportunity identification into specific business and technology opportunities and making early and often uncertain technology and market assessments. Hard quantifiable templates are typically not applied in front-end opportunity analysis; rather, more informal activities are engaged in, such as focus groups, market studies, scientific experiments, competitive intelligence, and trend analysis. (Koen et al., 2001)

Idea genesis

Idea genesis is the birth, development, and maturation of an opportunity into a concrete idea; it is an evolutionary and iterative process in which ideas are built, torn, combined, reshaped, modified, and upgraded. Idea genesis can be a formal process that includes brainstorming events and idea banks to inspire the organization to generate new ideas for the identified opportunity; however, a new idea can be generated outside of any formal process. Idea genesis can be enhanced by direct contact with customers or users, linkages with cross-functional teams, and collaboration with other companies and institutions (Koen et al., 2001).

Idea selection

In most businesses, there are numerous product or process ideas that the critical activity is to select which ones must actually be implemented. Idea selection is a critical activity that is necessary to choose which idea to be pursued in order to reach the most business value. Selection can be as straightforward as an individual's preference among alternatives or as formalized as a prescribed portfolio method. Extremely formalized project selection and resource allocation in the front-end is difficult due to the limited information and understanding at that phase and due to the uncertain definition of financial returns (Koen et al., 2001).

Concept and technology development

Concept and technology development is the final element in Koen's FEI machine. This stage involves the generation of a business case based on approximations of market potential, customer requirements, investment needs, competitor assessments, technology unknowns, and general project risk. The level of formality of the business case can vary according to the nature of the opportunity (new market, new technology, new platform, etc.), level of resources, organizational requirements, and the business culture (Koen et al., 2001).

Jarno Poskela (2009) has summarized front-end activities as opportunity identification, idea generation, idea screening and selection, concept development, concept testing, customer need assessment, technology verification, and business analysis; this is illustrated in greater detail in Table 4.

Table 4. FFE activities. Adapted from Poskela (2009).

Activity	Key aspects	References
Opportunity identification	Identification of new product opportunities driven by the organization's strategies and business goals.	Cagan and Vogel (2002), Nobelius and Trygg (2002), Koen et al. (2001), Khurana and Rosenthal (1997), Gorski and Heinekamp (2002), Afuah (1998), Von Hippel (1988), Cooper (1998), Koen and Kohli (1998)
Idea generation	Generating, developing, and expanding alternatives for the identified opportunity. Must be separated from idea evaluation.	Koen et al. (2001), McAdam and McClelland (2002), Gorski and Heinekamp (2002), Tidd et al. (2001), de Bono (1970)
Idea screening and selection	Identification and selection of the most potential ideas for further development with the help of screening criteria.	Cooper 1998, Ozer (1999), Bacon et al. (1994)
Concept development	Concretizing ideas into new product concepts.	Nobelius and Trygg (2002), Koen et al. (2001), Khurana and Rosenthal (1997), Tidd et al. (2001), Ulrich and Eppinger (2003), Cagan and Vogel (2002), Bacon et al. (1994)
Concept testing	Testing of concept viability internally and externally with potential customers.	Lees and Wright (2004), Ozer (1999), Tidd et al. (2001)
Customer need assessment	Acquiring timely and reliable information on customer needs and user requirements.	Bacon et al. (1994), Gruner and Homburg (2000), Lukas and Ferrell (2000), Atuahene-Gima (1995), Montoya-Weiss and Calantone (1994), Salomo et al. (2003), Vicari and Troilo (1998)
Technology verification	Detailed technical investigation of concepts that have been proposed to assure appropriate functionality.	Cooper (1998), Koen et al. (2001), Bacon et al. (1994)
Business analysis	Estimating market potential, investment requirements, competitors' reactions, and generic development risks.	Nobelius and Trygg (2002), Koen et al. (2001), Murphy and Kumar (1996)

There is a risk associated with focusing too much on one of the FFE activities (Cooper, 1993). Cooper highlighted the importance of proficiency in predevelopment activities and emphasized the danger of avoiding any vital activity (Cooper, 1993). Similarly, front-end activities must be considered as being interrelated and avoiding even one of them contributes to project failure (Khurana and Rosenthal, 1997).

The following subsection focuses on performance in the front-end phase and the associated performance evaluation metrics.

2.3.3 Front-end performance

According to Poskela (2009), holistic studies, empirical or theoretical, dealing with front-end innovation performance are rare due to the abstract nature of the front-end, where objective measurement of the performance is challenging. Scholars describe that project success is a multidimensional and complex subject, where management literature lacks a widely accepted definition of what shapes project success and frameworks for project success measurement are often inconsistent (Shenhar et al., 2001; Griffin and Page, 1993; Griffin and Page, 1996; Poskela, 2009). Much of the front-end performance discussion is adapted from the debate on project performance (Poskela, 2009; Herstatt et al. 2004; Kleinschmidt et al. 2005). Proficient implementation of front-end pre-project activities is considered a requirement for successful project execution, and the proficiency of preparation activities can be evaluated using a few traditional project success (performance) measures (Poskela, 2009).

Similarly, as organizational performance is derived from different viewpoints, comprehensive evaluation of project success must also reflect the different aspects of a project, which becomes easily complex as projects typically involve multiple stakeholders that all have their own objectives in terms of project success (Kaplan and Norton, 1992; Kaplan and Norton, 1996; Poskela, 2009).

Evaluation of project success also engages two distinct but connected dimensions: project management success and end result success, where project management success is a short-term measure for the efficiency of project execution and end result success reflects longer-term issues from the perspectives of the customer and the parent organization (Wit, 1988; Poskela, 2009). In certain cases, the end result can be successive, even though project management has failed; moreover, a project can be defined as being successful in the short run but the end result may turn out catastrophically different, for example, in terms of quality (Shenhar et al., 2001; Poskela, 2009).

Project success

Projects can be considered as strategic means targeting to pursue the short- and long-term goals of a company; moreover, discussion regarding product success overlaps with organizational performance (Poskela, 2009). Survival is considered the ultimate success of an organization (Dess and Robinson, 1984; Poskela, 2009).

Project management success consists of short-term efficiency measures, which are relatively easy to measure, such as the level of objective achievement in terms of schedule, budget, quality standards, and technical specifications (Atkinson, 1999; Baccarini, 1999; Turner, 1999; Kerzner, 1998; Poskela, 2009). Project completion is one performance metric for product success; however, project termination is also found to be valuable for organization performance, as it frees resources for other use (Kerzner, 1998; Poskela, 2009). Wit (1988) argued that project success cannot be measured objectively and unambiguously; however, management must nevertheless specify what criteria will be used to evaluate the success of the project in order to help the team focus on relevant issues and direction (Baccarini, 1999).

Product success

Product success relates to the performance of the final outcome of the project, a holistic and context-specific measure which considers quality, maintainability, reliability, price vs. performance, uniqueness, and the technical performance level of the product (Atkinson, 1999; Cooper, 1994; Griffin and Page, 1993; Freeman and Beale, 1992; Poskela, 2009). Evidently, product success is an important measure of success as it is the dimension that customers value the most, a concrete reference point against which customers compare the fulfillment of their needs and expectations (Poskela, 2009).

Poskela (2009) describes that product success is also a relevant performance measure of front-end success, as even though the final product does not yet exist, there is a product concept that describes the necessary features and a rough structure that can be studied to estimate a product's success level.

Product advantage is a major factor in product success, as it affects to the market adoption of a new product and it is found to strongly contribute new product performance. Moreover, product concept is the final target pursued during front-end execution (Rogers, 2003; Calantone et al., 2006; Poskela, 2009).

Product concept superiority is a short-term measure for front-end performance that can be evaluated based on a product concept defined in the front-end in terms of superior price/performance characteristics and unique features in relation to competing products in the market (Cooper, 1994; Poskela, 2009).

Stakeholder satisfaction

Stakeholders judge a project's success based on the state of fulfillment of their own requirements (Poskela, 2009). Customer, project creation team and the organization above are typically considered as the most relevant stakeholders (Shenhar et al, 2001; Wit, 1988; Freeman and Beale, 1992; Poskela, 2009). Organization includes different constituencies with dissimilar levels of fulfillment that influences their perceived performance of organizational action (Ford and Schallenberg, 1982; Thompson, 1967; Poskela, 2009).

Benefits to the organization

Griffin and Page describe that projects are initiated to create value for the organization that executes the project in return on investment (ROI), growth in sales, level of sales, profits, and profit margins. Measures such as the ROI and internal rate of return are appropriate, particularly in radical projects, since they take the time value of money into account (Ansoff, 1965; Griffin and Page, 1996; Poskela, 2009).

A large number of these criteria for measuring organizational advantages are challenging to use in the front-end of innovation, as anticipated sales levels, market shares, profit margins, and other business measures are difficult to estimate beforehand and include a remarkable amount of speculation, as the actual introduction of the product to the market may take place after a long period of time. The lack of precise objective measures in the front-end leads to emphasizing subjective, perception-based performance evaluation criteria, which requires the evaluative person to possess a holistic and balanced understanding of different success dimensions (Smith-Doerr et al., 2004; Poskela, 2009).

Strategic renewal, enabled by new knowledge, access to new markets, and the use of new technologies is typically measured in terms of two windows: created opportunity windows for new product categories and entrance into new markets (Herstatt et al., 2004; Griffin and Page, 1996; Poskela, 2009). Front-end performance is defined as the perceived superiority of product concepts and/or the contribution to strategic renewal and new product success in general (Kleinschmidt et al., 2005; Murphy and Kumar, 1996; Koen et al., 2001; Poskela, 2009).

2.4 The voice of the customer

This section aims to address the theory related to VoC, focusing to the essential marketing activities during the FFE and NPD. Chapters 2.2 and 2.3 discussed several key process models and activities of FFE and NPD providing the theoretical framework in which the voice of the customer can be used to enhance the performance of organizations. In order to succeed in today's marketplace, most corporations must engender cooperation between their marketing and R&D functions. In entrepreneurial firms, the producer-inventor frequently combines the knowledge of what is needed with how to develop it; however, when firms grow significantly, the marketing and R&D functions easily become specialized, and technical specialists and customer-oriented marketers grow apart and become less aware of each other's contribution. However, marketing and R&D share responsibilities, such as setting new product goals, identifying opportunities for the next generation of product improvement, resolving engineering design and customer-need tradeoffs, and understanding customer needs. The scientific evidence, which supports R&D and marketing interaction is strong, is illustrated in detail in Appendix 3 (Griffin and Hauser, 1996).

According to Cooper (1990), lack of market orientation and insufficient market assessment are consistently cited as major reasons for new product failure, particularly in industrial-product and high-technology firms. It must be noted that more important than the innovations that a firm is able to offer are innovations that customers are willing to adopt; therefore, winning high-tech firms must incorporate customers into their NPD processes (Mohr, Sengupta, and Slater, 2010). User's interests must drive critical decision-making (Cagan and Vogel, 2008).

Kleef et al. state that incorporating the VoC in the very early stages of the NPD process has been identified as a critical success factor for NPD. However, this very important activity is often poorly executed, perhaps due to lack of familiarity on methods available, use of disciplinary terminology, and difficulty in the accessibility of existing research on this topic (Kleef, Trijp, and Luning, 2005). NPD can originate from new technology inventions or new market opportunities, but irrespective of where opportunities originate, the customer is the ultimate judge for determining the success of new products (Eliashberg et al., 1997; Brown and Eisenhardt, 1995; Cooper and Kleinschmidt, 1987; Kleef, Trijp, and Luning, 2005). Therefore, in order to succeed in developing new products, companies must gain a deep understanding on VoC (Kleef, Trijp, and Luning, 2005).

Consumer research activities can be conducted during each of the basic NPD process stages: opportunity identification, development, testing, and launch; most commonly, it is applied during the development, testing, and launch stages (Suh, 1990; Urban and Hauser, 1993; Kleef, Trijp and Luning, 2005). In spite of the importance of the later stages, it has been increasingly recognized that successful NPD depends heavily on the quality of the opportunity identification stage (Cooper, 1985; Cooper, 1988; Cooper, 1998; McGuinness and Conway, 1989; Kleef, Trijp, and Luning, 2005).

Mohr et al. stated that customer-driven innovation brings together the collective wisdom in community for product improvements and innovations, requiring radical re-thinking of the innovation process by moving out from R&D-driven innovation in the lab to active co-creation of innovation with customers themselves, transforming from R&D to "R&We" (Mohr, Sengupta and Slater, 2010). Christensen (2003) added that markets that do not exist cannot be analyzed; therefore, strategies for confronting disruptive technological change must include plans for learning and discovery rather than plans for execution. Because of the turbulence in high-tech markets, today's innovative organizations must have a multidimensional focus on customers, flexibility, and speed by adopting market-focused organizational structure by shifting away from organizing around products (Mohr, Sengupta, and Slater, 2010).

Translating customer requirements into the right core technology, selecting the type and placement of features, and combining with an appropriate set of aesthetic choices cannot be done without a good understanding and combined dialogue with the people who will use the product (Cagan and Vogel, 2008). Keeping close to customers is an important management paradigm for handling sustaining innovations, but it does not work well with disruptive technological innovation, as it can provide misleading data and organizations must not expect customers to lead toward innovations that they do not need at the moment (Christensen, 2003).

Even modern high-technology companies are often not sufficiently market-driven and find it challenging to establish necessity in internal cross-functional collaboration between engineering and marketers (Mohr, Sengupta, and Slater, 2010). Although research evidence, collected by Griffin and Hauser (1996), strongly supports R&D and marketing cooperation correlating with new product success, numerous researchers have found a large number of barriers involving the communication and cooperation of these functions. Inherent personality differences have been found between marketing and R&D personnel in American corporations (Saxberg and Slocum, 1968). Cultural thought differences are inherent in different training and backgrounds (business vs. technical schools) (Dougherty, 1990; Dougherty, 1992; Douglas, 1987). Language barriers exist due to different terminology in technical or product positioning aspects (Griffin and Hauser, 1993). Moroever, organizational barriers can be born due to different task prioritization and responsibilities (Donnellon, 1993; Souder, 1975; Souder and Sherman, 1993), functional success measures unsupportive of integration (Souder and Sherman, 1993), lack of top-management support rewarding the integration (Hauser, Simester, and Wernerfelt, 1996), and the perceived illegitimacy of product development (Dougherty and Heller, 1994). Further, physical barriers commonly exist due to different locations of R&D and marketing campuses (Griffin and Hauser, 1996).

The factors that have turned themes as special discriminators for new product success or defect are the level of product superiority, the degree of technological and marketing synergy with firm's present capabilities, implementation and use of an NPD process within the innovating company, interface management between different functions and departments, the presence of product champions, and the level of top management support (Cooper and De Brentani, 1991; Cooper, 1986; de Brentani, 1989; Dwyer and Mellor, 1991; Lemaitre and Stenier, 1988; Maidique and Zirger, 1984; Maidique and Zirger, 1985; Rubenstein et al., 1976; Souder and Chakrabarti, 1979; Souder, 1987; Zirger and Maidique, 1990; Moenaert et al., 1995).

The research has consistently underlined the positive impact of the R&D and marketing interface on project success (Billings and Wroten, 1978; Cooper, 1979; Souder and Chakrabarti, 1978; Souder, 1987; Moenaert et al., 1995).

Day (1990) argued that market orientation shows skills in understanding and fulfilling customers, followed by its principal features as a set of beliefs that places the customer's interest first (Day, 1990; Day, 1994; Deshpande, Farley, and Webster, 1993), the ability of the firm to generate, spread, and use superior knowledge about customers and competitors (Day, 1990; Day, 1994; Kohli and Jaworski, 1990) and the coordinated application of inter-functional resources to the creation of superior customer value (Day, 1990; Day, 1994; Narver and Slater, 1990; Shapiro, 1988).

The following subsections address the marketing activities that are implemented as part of NPD in general and during the FFE phase in a more detailed manner.

Marketing communications are the means by which companies can establish a dialogue with customers regarding product attributes and offerings (Schoonmaker, Carayannis, and Rau, 2013; Hartley and Pickton, 1999; Schultz and Schultz, 1998). Mohr et al. describe marketing as a set of activities, processes, and decisions to create, communicate, and deliver products and services that offer value to customers, partners, and society—a philosophy of doing business so that it brings the VoC into the firm (Mohr et al., 2010). Mohr et al. (2010) continue that superior technology alone is not sufficient to achieve marketplace success but also requires careful analysis of the needs and capabilities of intended end users as essential to successful development of high-technology products.

Market orientation implies collecting, sharing, and using information on customers and trends to make decisions that lead to the creation of superior customer value (Mohr et al., 2010). Cooper describes that to succeed in collecting vital market information, the VoC process must pay special attention to identifying customers' real and unarticulated problems, working with highly innovative and not average users, utilizing market research to define the product, making the customer an integral part of the development process, and using market studios of buyer behavior to plan the market launch (Cooper, 2005).

A common reason why many companies do not succeed in being truly market-oriented is due to the strong cultural change that is often required in the organization to enable shared values and beliefs regarding the gathering, sharing, and compiling of market-based information (Mohr et al., 2010).

Lettl (2007) argues that for firms seeking radical innovations, it is important to involve the "right" users at the "right" time in the "right" form. In the early phases of a radical innovation R&D program, only a small number of exclusive users is sufficient for providing valuable inputs for a NPD project; in the later phases, when the project is nearing market introduction, the number of users must be increased to collect more representative information regarding the target market.

The interaction between R&D and marketing is most important during the early stages of a product development project (FFE), when marketing must have knowledge regarding customer preferences and competitive offerings that are crucial for resolving design and positioning issues (Mohr et al., 2010). According to Cagan and Vogel (2008), ethnographic methods bring benefits to the NPD process by defining the qualities that a product should possess by providing an in-depth understanding of a small representative sample of the intended market, a keyhole to understanding the everyday behavior of the customer—focusing on consumer's lifestyle, experiences, and patterns of use to gain insights to identify selling product features; studying how people use the product in different situations; and the ability to monitor dynamic markets to predict changes in the marketplace before they occur.

Marketing activities in the FFE

Kleef et al. described that consumer research in the early stages of the NPD—that is, opportunity identification—is often considered difficult because it is unclear what consumers must be asked at this point (Kleef, Trijp, and Luning, 2005). Ulwick stated the oft-heard argument that asking consumers what they want is useless, because they do not know what they want (Ulwick, 2002; Kleef, Trijp, and Luning, 2005). However, there are scientific findings that consumer research helps to raise the odds of NPD success in the market (Kleef, Trijp, and Luning, 2005). Even though consumers may not always be capable of expressing their wants, it is essential to know how they view products, how their needs are formed and effected, and how they carry out their product purchase choices based on their needs (Kleef, Trijp, and Luning, 2005). Moreover, it helps to avoid working on products that have the lowest probability of success in the first instance (Rochford, 1991; Kleef, Trijp, and Luning, 2005).

According to Kleef et al. (2005), conducting consumer research in the early stages (e.g., opportunity identification) is relatively inexpensive compared to the risk of product failure. Obtaining insight into consumers with the support of formal consumer research activities has the benefit that the outcome can without difficulty be distributed among all functions of an organization (Kohli and Jaworski, 1990; Kleef, Trijp, and Luning, 2005).

Despite the numerous available methods and principles to be used in the NPD process, the most of them are not implemented by firms or are only applied in an ad-hoc manner (Nijssen and Frambach, 2000; Nijssen and Lieshout, 1995; Wind and Mahajan, 1992; Kleef, Trijp ,and Luning, 2005). A large part of the research conducted in NPD involves focus groups, surveys, and the study of demographic data. The lack of a more versatile consumer research method is considered as one of the faults for the weak new product success rates. (Wind and Mahajan, 1992; Kleef, Trijp, and Luning, 2005)

Kleef et al. (2005) have listed and summarized the ten most common consumer research methods and techniques. 1) "Empathic design": A multi-functional team is created to observe the actual behavior and environment of consumers. 2) "Category appraisal": Respondents rank a given set of competing products of interest. 3) "Conjoint analysis": Respondents rank a given set of hypothetical product attribute profiles constructed along factorial design principles. 4) "Focus group": A group of participants discuss a product or a specific topic. 5) "Free elicitation": The researcher presents stimulus probes or cues to the participant who is asked to rapidly verbalize the concepts that come to mind as a perception of the stimulus. 6) "Information acceleration" (IA): The researcher constructs a virtual buying environment that stimulates the information available to consumers when they are supposed to make the purchase decision. 7) "Kelly repertory grid": Respondents are provided with a set of products presented in groups of three products and is asked to indicate the similarities between two of them and the difference between these two and the third one. 8) "Laddering": The respondent is provided with a set of products and asked to make distinctions between the products by sorting based on perceived meaningful differences. 9) "Lead-user technique": The researcher identifies lead users in a product category and derives data related to their experience with novel product attributes and product concepts. 10) "Zaltman metaphor elicitation technique" (ZMET): Respondents are given instructions about the research topic and are asked to take pictures (or cut magazine pictures) to indicate what the topic means to them. A holistic review of consumer research methods, adapted from Kleef et al. (2005), is represented in Appendix 4.

The objective of the various consumer research methods is to provide diagnostic consumer information relevant to the perception, preference, and value satisfaction resulting from the consumption of products. Although the different methods have the same overall objective, they differ in terms of the procedure that they follow but also in the resulting consumer needs, possibly leading into different "optimal" solutions to consumers' unmet needs (Kleef, Trijp, and Luning, 2005).

Figure 22 below illustrates the top ten consumer research methods in the NPD positioned against two dimensions: the newness of a product and actionability.

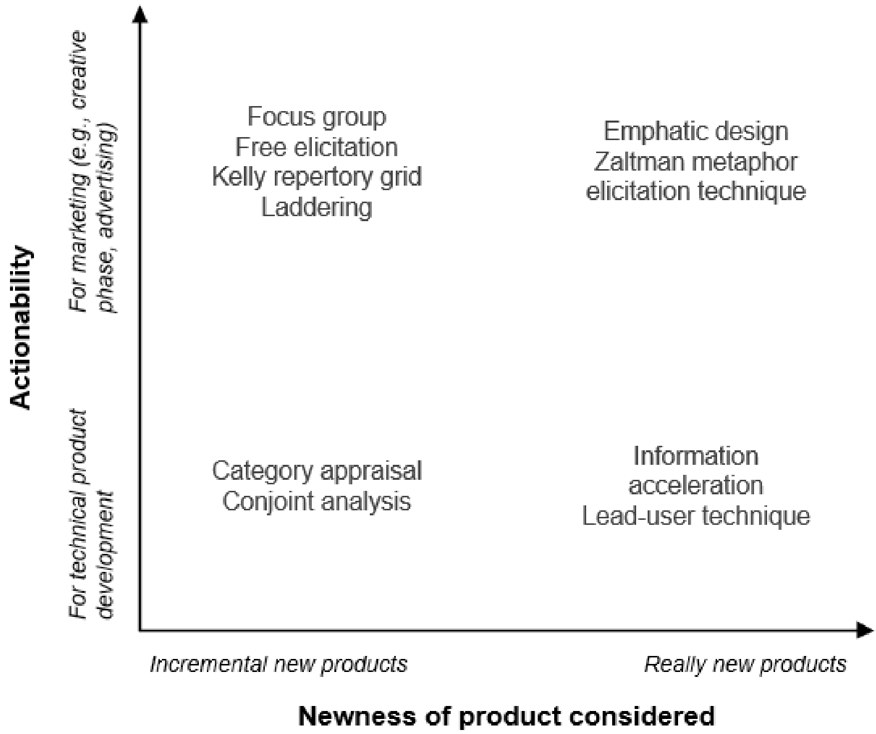


Figure 22. Consumer research methods in the opportunity identification phase. Adapted from Kleef et al. (2005).

Cagan and Vogel (2008) described that ethnographic methods are effective and valuable tools in the early phases of an R&D project marketing and function to help product teams develop the actionable insights they need to translate into the style and features that customers are looking for.

The methods listed on the left-hand side of Figure 20 are particularly appropriate for incremental new products, as these methods are product-driven and provide insights that are limited by the particular products included in the study. In general, consumers can provide reliable judgements regarding new products that are relatively similar to familiar products. The advantage of these methods is in their capacity to capture the current needs to optimize new products accordingly; the limitation of these methods lies in the fact that it is difficult to elicit unfulfilled needs by analyzing product preferences that currently exist in the market (Kleef, Trijp, and Luning, 2005).

The methods listed on the right-hand side of Figure 21 are more appropriate for radical new products and out-of-the-box thinking. Such products are extremely difficult to evaluate as they do not fall into any established current category and may combine several technologies that are not currently available together (Eliashberg et al., 1997; Kleef, Trijp, and Luning, 2005).

Just querying consumers what they want is not credible to obtain unfulfilled needs, as consumers tend to articulate needs that are yet present in the market. Meeting consumers with not known products that represent a radically new technology can lead to information that has lower predictive qualification. For new products, consumers have less knowledge to guide them and their expressions of liking are often shaped at the event that the respondent is requested to submit his/her judgement; therefore, there is a risk that customers will change their opinion by the time the product is developed and introduced (Kleef, Trijp, and Luning, 2005).

The lead-user technique and information acceleration technique attempts to access consumers' unspoken and latent needs with a clear link to physical solutions for those needs. By creating a simulated future environment, respondents are guided in understanding what the new product could do for them. The lead-user technique uses a few consumers whose present needs are expected to become more general needs of the mass market in the future. ZMET and the empathic design technique are also appropriate for radically new products, as they are both need-driven in that they focus on understanding consumer problems or motivations and focus on the more latent non-articulated needs, thereby providing detailed insight into what actually drives consumer behavior. As a downside, this conceptual insight demands complementing methods for turning into real physical product design (Kleef, Trijp, and Luning, 2005).

Consumer research methods in the early stages of the NPD process enable product developers to go farther and deeper in understanding consumer needs, often beyond what would be possible to be understood without utilizing such methods (Kleef, Trijp, and Luning, 2005). Creusen and Hultink investigated the choice of consumer research methods in both early and late phases of the FFE. The methods used during the early FFE in the opportunity identification phase and in the late FFE in the idea generation and concept development phases are illustrated in Appendix 5 (Creusen and Hultink, 2013).

Marketing activities with discontinuous innovation

Veryzer describes that the most discontinuous products involve significant new technologies and offer the user significantly enhanced benefits. When considering highly innovative products, it is important to consider the customer's view of the product, as quite often advanced technology incorporated in these products has been developed over a long period of time and may not seem that "discontinuous" or "radical" to the people involved in the development. If a customer's perspective is not considered during the NPD process, a simple technology-driven view of a discontinuous technology may result in a product that is at odds with the market's perception of it (Veryzer, 1998).

Further, Griffin and Page noted that the necessity of including customer orientation in the assessment of product innovativeness can be underscored by the importance placed on customer measures of product success and failure (Griffin and Page, 1993; Veryzer, 1998). Upfront activities such as building market knowledge and clear product and opportunity definition have been emphasized in numerous NPD models (Cooler and Kleinschmidt, 1986; Crawford, 1984; Griffin and Hauser, 1996; Hughes and Chafin, 1996; Veryzer, 1998). These activities are desirable for the development of most new products, but in the case of radical new products, it may be almost impossible and in certain cases undesirable to carry out such activities (Lynn, Paulson, and Morone, 1996; Morone, 1993; Veryzer, 1998).

Discontinuous innovation creates a unique challenge in opportunity identification and customer input as radically new products often require intensive technology development and long development periods (even 10–20 years); market opportunities for such products are often unspecified and unclear (Leonard-Barton, 1995; O'Connor and Rice, 1996; Zien and Buckler, 1997; Morone, 1993; Veryzer, 1998). Conventional market research techniques that rely on lead users early on in the process may not be helpful in the formulation and early development of these products if customers have nothing to compare the product to or if they do not have the ability to envision a product's potential (Griffin and Hauser, 1993; von Hippel, 1986; von Hippel, 1988; Veryzer, 1998).

Quality function deployment

Many U.S. and Japanese firms have adopted Quality Function Deployment (QFD), a total-quality-management process in which the VoC is deployed throughout the entire R&D, engineering, and manufacturing stages of product development to identify, structure, and prioritize customer needs (Griffin and Hauser, 1993). QFD improves communication among different organizational functions by linking the VoC to engineering, manufacturing, and R&D decisions (Griffin and Hauser, 1993). QFD was first developed in the Japanese car industry during the 1970s and brought to the U.S. due to claimed 60% reductions in design costs and 40% reductions in design time (Hauser and Clausing, 1988; Griffin and Hauser, 1993). QFD is interesting as it encourages other functions apart from marketing to use and perform market research and to bring their own uses and demands for the data on VoC (Griffin and Hauser, 1993).

Further, QFD uses four "houses" to present data, illustrated in Figure 23 below. In the first QFD house, customer needs and design attributes are linked, encouraging the combined judgement of marketing and engineering issues. In the second house, design attributes are linked to actions that the firm can take, and the third house connects actions to implementation decisions, and the fourth house connects the implementation to production planning (Griffin and Hauser, 1993).

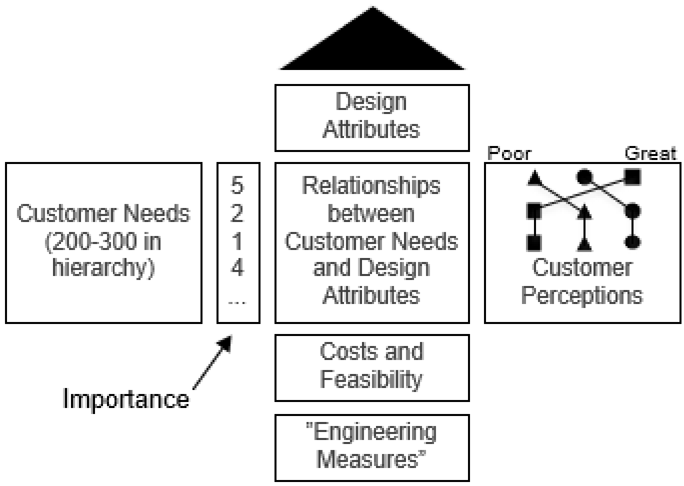


Figure 23. QFD house of quality. Adapted from Griffin and Hauser (1993).

Engineers require greater detail regarding customer needs than is provided by the typical marketing study to make specific tradeoffs in engineering design; however, too much detail in data can obscure strategic design decisions. If the product development team focuses too early on solutions, they might possibly miss creative opportunities. Discussions with customers typically identify approximately 200–300 customer needs that include basic needs, articulated needs, and exciting needs (Griffin and Hauser, 1993).

Griffin and Hauser (1993) describe that QFD structures customer needs into a hierarchy of primary needs: 5–10 top-level needs used to set strategic direction for the product or service; secondary needs: more specific indications pf what is needed to satisfy the primary needs; and tertiary needs: operational needs that provide details for R&D to develop engineering solutions to satisfy the secondary needs.

Connecting customers with engineers

Yoon and Jetter (2015) describe that in technology-driven firms marketing typically acts as a "go-between" that collects customer needs and experiences and translates them for R&D functions —information exchange happens via an indirect path. A high degree of consumer co-creation at the ideation (idea generation stage of FFE) and product concept development stages can contribute significantly to new product and firm performance (Gruner and Homburg, 2000). However, as a result of quickly changing and unpredictable environments and complicated products with silent requirements, companies increasingly emphasize a need for engineering functions to be more directly engaged with their customers (Yoon and Jetter, 2015).

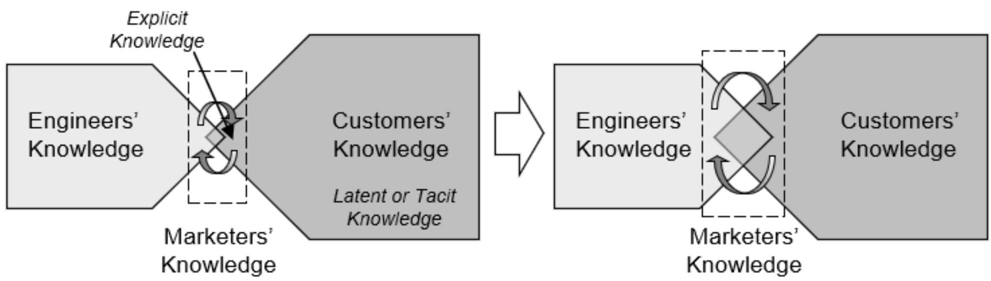


Figure 24. Knowledge interchange between engineering and customers. Adapted from Yoon and Jetter (2015).

According to Yoon and Jetter, in capturing customers' needs and creating customer values in the FFE, the success of NPD depends on how deeply engineers are able to comprehend customers' knowledge. Figure 24 above depicts the relationships among knowledge of engineers, marketers, and customers where FFE results can be improved through adequate consumer research methods and marketing knowledge is increased by a greater overlap between engineers and customers (Yoon and Jetter, 2015).

Enkel, Kaysch, and Gassman indicated that there are considerable inherent risks in integrating customers into product development, possibly resulting in loss of expertise, dependence on customers, limitation to simple incremental innovations, serving only niche markets, and misunderstanding between customers and employees (Enkel, Kaysch, and Gassman, 2005; Yoon and Jetter, 2015). In particular, deep customer interaction in product development has a risk that limits NPD to incremental innovation rather than radical innovation (Yoon and Jetter, 2015). In order to develop radical innovation for products, organizations must be able to involve the right customers at the right time in the right form (Brockhoff, 2003; Lettl, 2007; Yoon and Jetter, 2015).

The next section, 2.3, presents a literature review for theoretical models on the acceptance of new technology.

2.5 Theoretical models for the acceptance of new technology

Theoretical models for the acceptance of new technology aim to predict the end-users' attitude towards adoption of the new technology or product being developed in the NPD process. The earlier the FFE or NPD team is able to get information about possible end-users' opinion about the technology or product under development, the greater are the opportunities to make adjustments before the successful product launch. On the other hand, if voice of the customer is applied in too early phase, the project may still be in too immature state and the collected market information does not reflect well to the actual product that will be launched eventually. Marangunic and Granic state that with the ever-increasing technological evolution, especially information and communication technologies (ICT) and its integration into users' private and professional lives, the decision of its possible acceptance or rejection still remains unclear. A tremendous amount of research has been conducted on the TAM, originally introduced by Fred Davis, from its first appearance more than a quarter of a century ago, which is a strong indicator of a model's popularity in the field of technology acceptance.

TAM has become a governing model in investigating factors affecting users' acceptance of technology. The TAM assumes a mediating role of two variables called perceived ease of use and perceived usefulness in a complicated relationship between system characteristics (external variables) and potential use of the system. Further, TAM is derived from the psychology-based TRA and TPB (Marangunic and Granic, 2015). A comprehensive literature review of the TAM from 1986-2013 by Marangunic and Granic (2015) is illustrated in Appendix 6.

2.5.1 Origins of the Technology Acceptance Model

In the very beginning when technology began entering users' everyday life, a necessity began growing for comprehending reasons for why the technology was accepted or rejected (Marangunic and Granic, 2015). The first theories seeking to explain and predict these technology acceptance decisions were grounded in the field of psychology (Marangunic and Granic, 2015), as mentioned above (Ajzen, 1985; Ajzen and Fishbein, 1980; Marangunic and Granic, 2015).

Ajzen and Fishbein (1980) expected that individuals are typically rather rational and make systematic use of available information; they began to develop a theory for forecasting and understanding consumer behavior and attitudes. The TRA focuses on behavioral intentions (BI) rather than attitudes as the main predictors of behavior (Davis, 1986; Ajzen and Fishbein, 1980). The TPB is an extension of the TRA and includes a third element—perceived behavioral control—that Ajzen added to the theory with the aim of improving the model's ability to deal with behaviors over which individuals have incomplete volitional control (Ajzen, 1985). The TRA and TPB are illustrated in Figures 25 and 26 below.

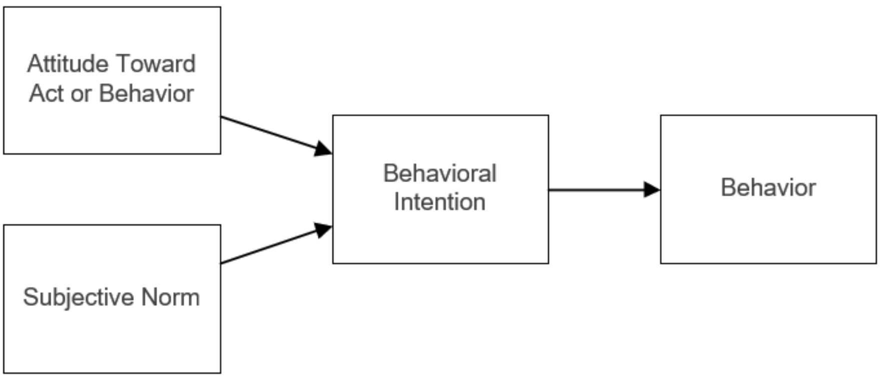


Figure 25. The theory of reasoned action (TRA). Adapted from Lai (2017).

The TPB has several limitations, as it assumes that human beings act rationally and make systematic decisions based on available information, excluding unconscious motives and not taking into consideration factors such as individuals' personality and demographic variables (Mathieson, 1991; Marangunic and Granic, 2015).

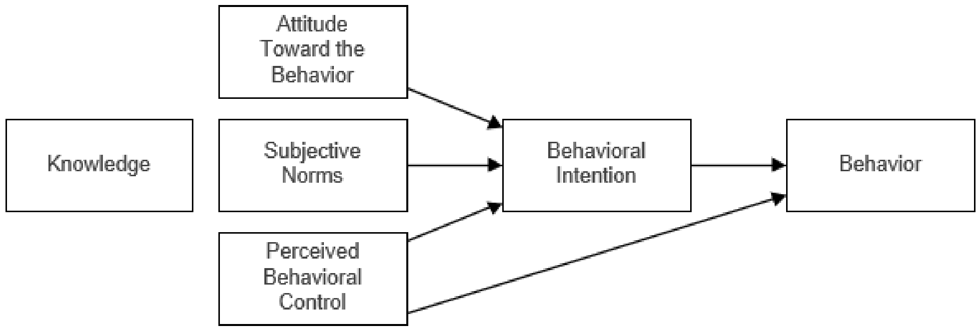


Figure 26. The theory of planned behavior (TPB). Adapted from Lai (2017).

Both the TRA and the TPB provided somewhat useful models to explain and predict the actual behavior of the individual; however, due to problems of adapting these models in various contexts like user acceptance of IT, Davis began further developing these models into TAM to develop a more reliable model that could predict the actual use of any specific technology (Davis, 1986; Marangunic and Granic, 2015).

2.5.2 The development of the technology acceptance model and its extensions

Three decades ago (Davis, 1986), a conceptual model for technology acceptance emerged from the research and theories based on psychology. In the following years, the original TAM model and its simplified parsimonious TAM models appeared. In the original TAM model, Davis suggested that the user's motivation can be explained by three factors: perceived ease of use (PEoU), perceived usefulness (PU), and attitude toward using the product. The original TAM model is illustrated in Figure 27 below (Davis, 1986; Marangunic and Granic, 2015).

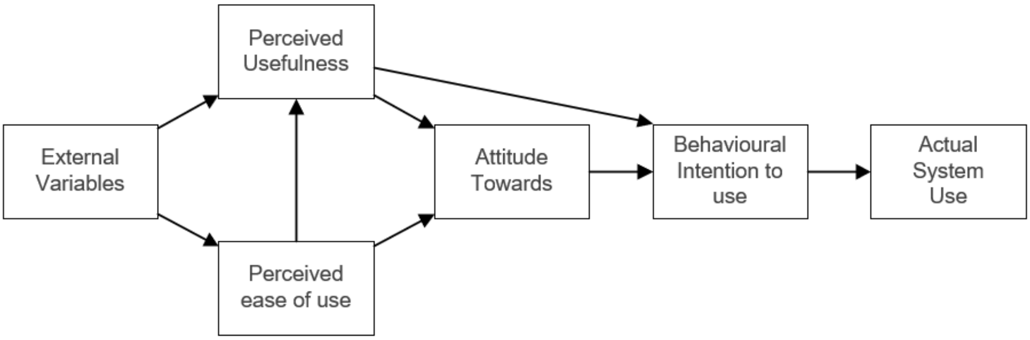


Figure 27. The original technology acceptance model (TAM). Adapted from Davis, Bagozzi and Warshaw (1989).

The model underwent continuous development over numerous years of research and led to the emergence of the TAM2 model (Figure 28 below), which was introduced by Venkatesh and Davis (2000) (Davis, 1986; Marangunic and Granic, 2015).

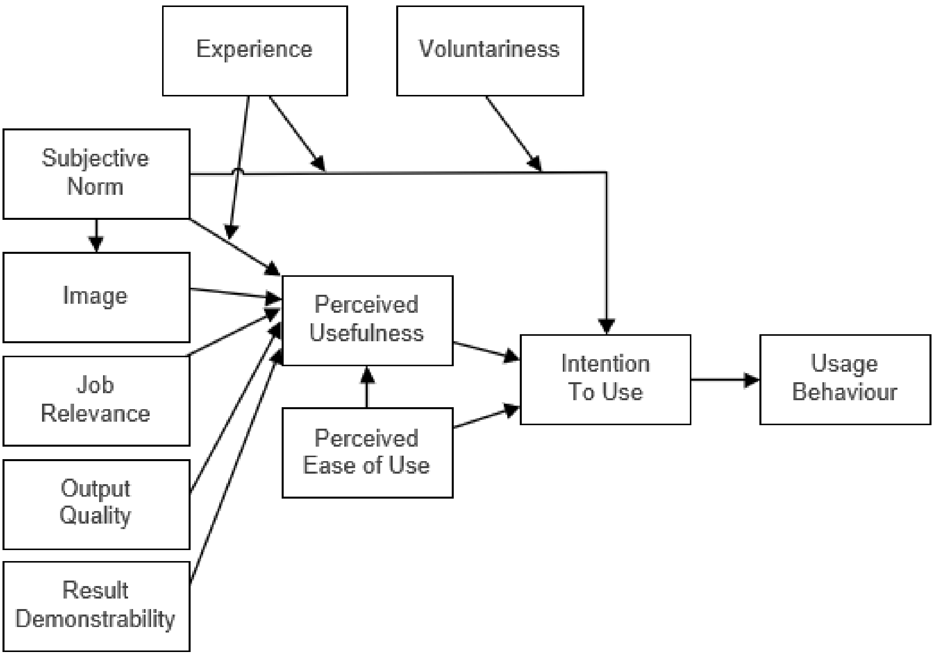


Figure 28. The technology acceptance model 2 (TAM2). Adapted from Venkatesh and Davis (2000).

Extensions were incorporated into the new TAM2 model. As the consistent findings of perceived usefulness are a substantial factor of the intention to use, Venkatesh and Davis suggested new variables that impact the perceived usefulness: "subjective norm" implies others' influence on users' decision to use or not to use the technology; "image" indicates a user's desire to maintain a favorable standing; "job relevance" implies the degree to which the technology is applicable; "output quality" is the extent to which the technology can adequately perform the required tasks; and "result demonstrability" that describes the production of tangible results (Davis, 1989; Davis, 1993; Venkatesh and Davis, 2000; Marangunic and Granic, 2015). In addition, experience and voluntariness were included as moderating factors of the subjective norm.

2.5.3 The unified theory of acceptance and use of technology

Next, a unified model called the unified theory of acceptance and use of technology (UTAUT) was formulated by Venkatesh et al. (2003). Four constructs considered to play a significant role as determinants of user acceptance and usage behavior are added to the UTAUT: performance expectancy, social influence, effort expectancy, and facilitating conditions (Venkatesh et al., 2003).

In addition, constructs such as attitude toward using technology, self-efficacy, and anxiety are not included in the UTAUT as direct determinants of intention (Venkatesh et al., 2003). The UTAUT also includes key moderators such as gender, age, voluntariness, and experience (Venkatesh et al., 2003). Figure 29 below presents the UTAUT model construct.

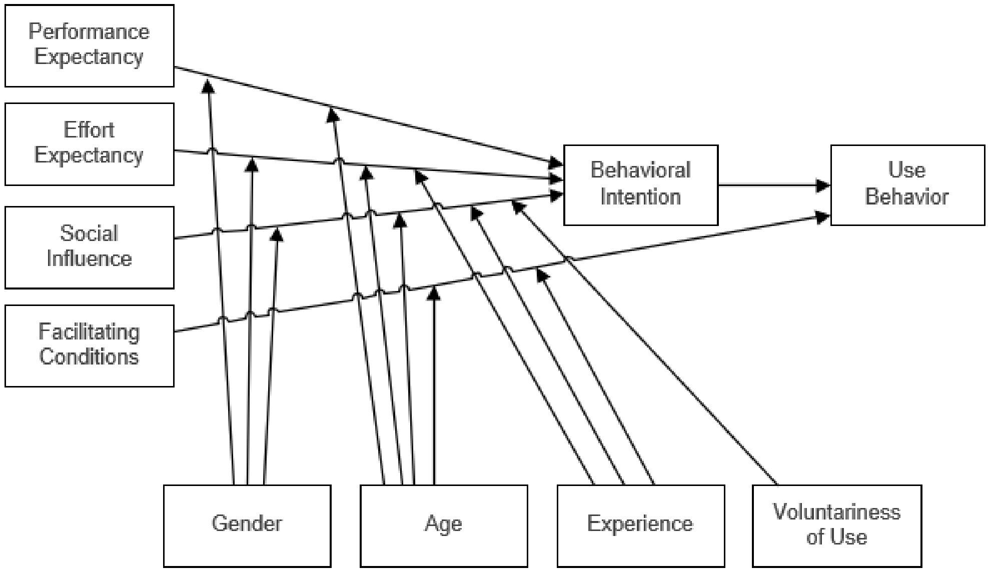


Figure 29. The unified theory of acceptance and use of technology (UTAUT). Adopted form Venkatesh et al. (2003).

2.5.4 The unified theory of acceptance and use of technology 2

As an extension of the original UTAUT, the model was updated to a newer version called the UTAUT2 with the objective of best explaining user's acceptance of technologies. The study by Venkatesh, Thong, and Xu extends the UTAUT to the acceptance and use of technology in a consumer context (Venkatesh et al., 2012). The UTAUT2 incorporates three new constructs: hedonic motivation, price value, and habit. Individual differences such as age, gender, and experience moderate the effects of these new constructs on behavioral intention and technology use (Venkatesh et al., 2012). Figure 30 below illustrates the UTAUT2 model.

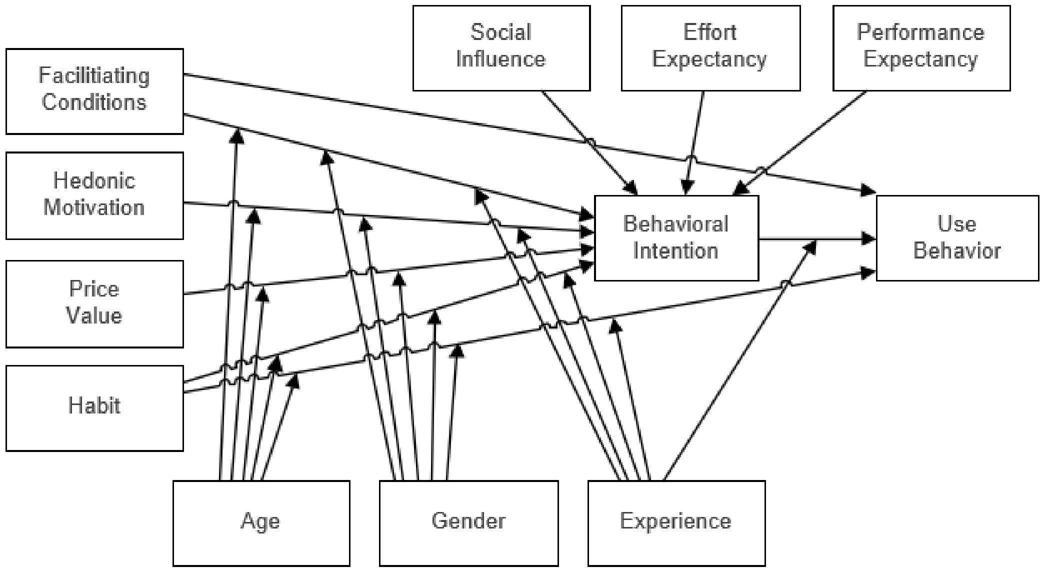


Figure 30. The unified theory of acceptance and use of technology 2 (UTAUT2). Adopted form Venkatesh et al. (2012).

In the UTAUT2, hedonic motivation is included as a key predictor in consumer technology use behavior. Performance expectancy is a strong predictor of behavioral intention. In the context of consumer technology, price is also an important factor. As an update to the original UTAUT construct, the voluntariness of use has been omitted from the updated model (Venkatesh et al., 2012).

2.5.5 The technology acceptance model 3

Venkatesh and Bala (2008) combined TAM2 and the model of the determinants of perceived ease of use (PEoU) and developed an integrated model of technology acceptance, the TAM3. The determinants of PEoU are illustrated in Table 5.

Table 5. Determinants of perceived ease of use (PEoU). Adapted from Venkatesh and Bala (2008).

Determinants	Definitions
Computer Self-Efficacy	The extent to which an individual supposes that he or she has the capability to carry out a certain task/job utilizing the computer (Compeau & Higgins, 1995a, 1995b).
Perception of External Control	The extent to which an individual supposes that organizational and technical resources favor the use of the system (Venkatesh et al., 2003).
Computer Anxiety	The extent of "an individual's apprehension, or even fear, when she/he is faced with the possibility of using computers" (Venkatesh, 2000).
Computer Playfulness	"…the degree of cognitive spontaneity in microcomputer interactions" (Webster & Martocchio, 1992).
Perceived Enjoyment	The degree to which "the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system use" (Venkatesh, 2000).
Objective Usability	A "comparison of systems based on the actual level (rather than perceptions) of effort required to completing specific tasks" (Venkatesh, 2000).

Venkatesh and Bala (2008) describe TAM3 as presenting a complete nomological network of the determinants of individuals' IT adoption and use. The TAM3 model is illustrated in Figure 31 below.

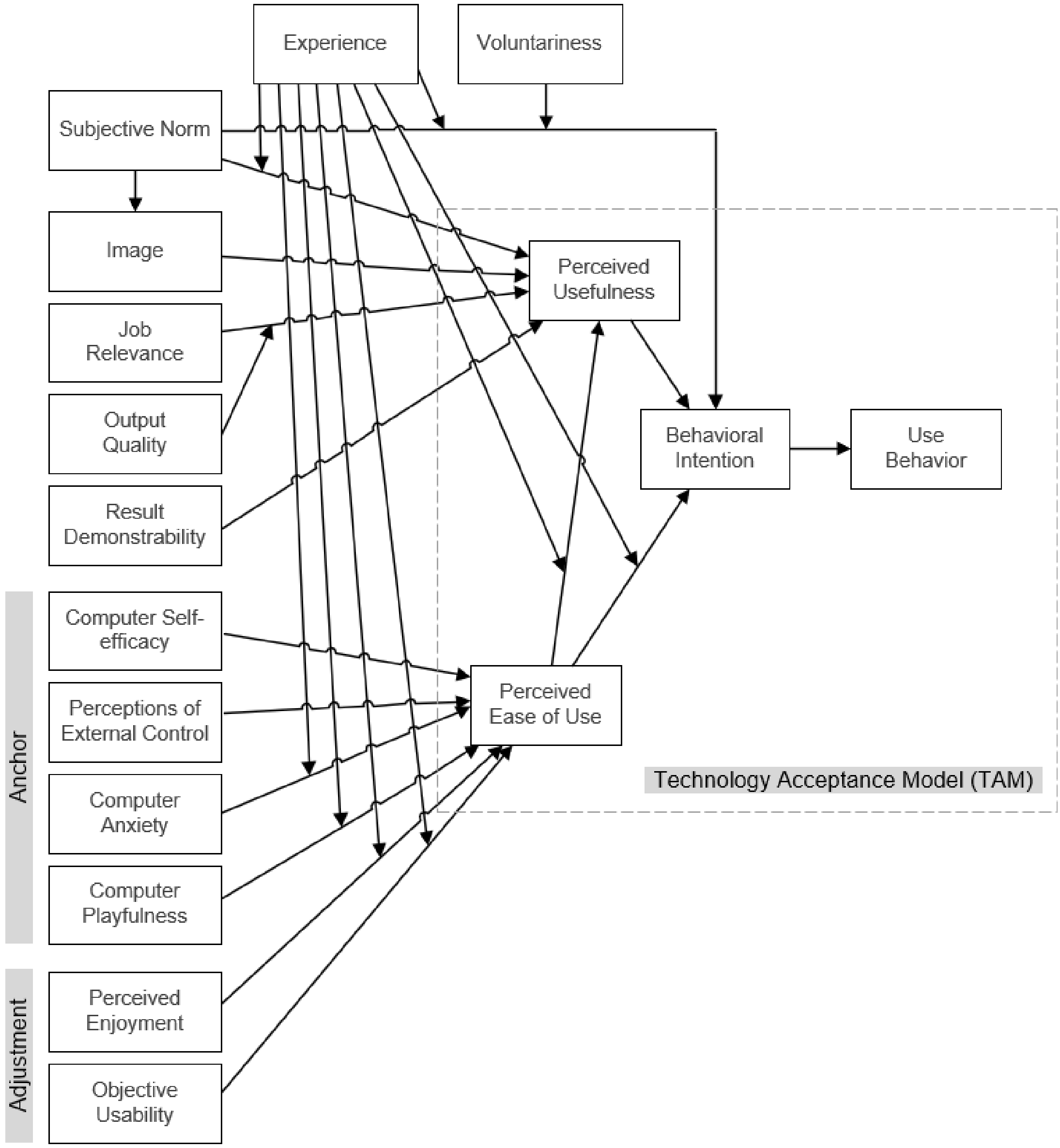


Figure 31. Technology Acceptance Model 3 (TAM3). Adapted from Venkatesh and Bala, 2008.

Venkatesh and Bala argue that two theoretical processes, social influence and cognitive instrumental processes, explicate the relationships between perceived usefulness and its determinants and the effects of several factors—subjective norm, image, job relevance, output quality, and result demonstrability—on perceived usefulness are bound to these two processes. TAM3 places three connections that were not empirically tested earlier in Venkatesh (2000) and Venkatesh and Davis (2000) and suggests that experience will moderate the relationships between PEoU and perceived usefulness, computer anxiety and PEoU, and PEoU and behavioral intention (Venkatesh and Bala, 2008).

Faqih and Jaradat (2015) describe that the original TAM model has been frequently criticized as it provides little actionable steering to organizations on how to develop appropriate interventions and mechanisms in order to encourage users to positively modify their behavior towards new technology adoption, acceptance, and use. The TAM3 model incorporates elements of context, content, process, and individual differences to address these concerns. Faqih and Jaradat (2015) continue that the TAM3 has not yet been widely explored in various areas of business and there are only a few published papers in literature that employ the TAM3 model as a theoretical framework. Therefore, the general applicability of the TAM3 model in the context of various types of IT in different settings is unknown to academics and practitioners; further research is called for to focus on investigating similar research in other contexts and domains (Venkatesh and Bala, 2008; Faqih and Jaradat, 2015).

The TAM3 (2008) has several advantages over the other options, for example, the newer (2012) UTAUT2 model and, therefore, is selected as the technical acceptance model under study in this research. The TAM3 includes several constructs that are particularly interesting in the context of this study on a service robot: job relevance, output quality, result demonstrability, self-efficacy, anxiety, playfulness, and enjoyment. Further, the UTAUT2 comprises constructs such as price value and the emphasized role of gender and age that do not make this model so interesting to study in the FFE context with the service robot technology prototype. Based on these arguments, the TAM3 model is selected as the TAM under study in this research.

3 RESEARCH DATA AND METHODS

This chapter explains the methods used during this research. In addition, it also explains data collection and preparation processes.

3.1 Research approach

The research is conducted utilizing a multi-method approach. Research Phase 1 involved quantitative research and Research Phase 2 involved work of a more qualitative nature.

Quantitative methods rely on experiments and surveys to collect measurable data that can be processed using statistical procedures (Creswell, 2003). A major advantage of quantitative methods is that results are typically generalizable to other populations. In this research, the quantitative portion is performed in the form of the Partial Least Squares Structural Equation Model (PLS SEM).

On the other hand, qualitative methods rely on descriptive narrative for data analysis (Berrios and Lucca, 2006). Qualitative methods enable the "richness of personal experience" by providing in-depth information in the natural language of the experience (Berrios and Lucca, 2006). In Phase 2 of this research, the FFE uncertainty reduction study was conducted as part of the qualitative research.

The multi-method research approach combines quantitative and qualitative approaches in the same study. A distinct tradition in the literature on social science research methods advocates the use of multiple methods—usually described as "convergent methodology," "multimethod/multi-trait," "convergent validation," or "triangulation,"—based on the concept that qualitative and quantitative methods are complementary rather that contrasting (Jick, 1979; Campbell and Fiske, 1959; Webb et al., 1966). The use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone (Creswell and Clark, 2007).

In the conducted research, Phase 1 had a high number of prototype end-user candidate participants (121), which enabled a wider use of statistical methods; in Phase 2, the data is collected from a typical R&D team of ten people. During Phase

2, the discussion held during the questionnaire event was recorded and quotations were captured.

The following sections, 3.2 and 3.3, provide a detailed explanation of the activities performed in Phases 1 and 2.

3.2 Research Phase 1: The FFE TAM3 study

Research Phase 1 was implemented as a quantitative study that collected TAM3-based user information on early and late markets for the robotics FFE phase of the NPD project. The original TAM3 model under testing is illustrated in the 31 and the construct questions are listed in the Appendix 8. The following subsections describe how the questionnaire was developed, how the material was collected, and how the data was handled.

3.2.1 Phase 1: material collection

Phase 1 included data collection for a robotics FFE project prototype among 121 end-user participants. A survey was conducted to collect user acceptance data on a new technology under development in an NPD project's FFE phase. This data was collected from a group of individuals, including participants representing two market segments: one formed by technology innovators and early adopters and other group including the remaining mass market.

The questionnaire included variables for three categories. "Demographics" targeted to capture the demographic sampling of participants. "Market segmentation" aimed to distinguish participants into early adopters of technology and mass market segment categories. "Technical" targeted capturing participants' attitude toward acceptance of the technology under evaluation.

All questionnaire variables had references to prior research. The "Market Segmentation" part was largely based on the diffusions of innovations theory by Rogers (1962) and the "Technical" was based on the TAM3 by Venkatesh and Bala (2008).

The questionnaire was answered by all participants at one time; however, the participants were divided into two categories for data analysis based on their attitude towards new technologies: "early adopters" (EA) of technology and "mass market"

(MM). The TAM3 model was tested for both groups and the differences between the groups were evaluated.

The material for the research was collected at the Tampere University of Technology (TUT) on 16 of March 2018. TUT was chosen as the location for the survey as it was assumed that the technical university will perform as an environment where it is possible to gather relatively many early adopters of technology. A service robot system, being further developed and evaluated at the Tampere University of Technology signal processing laboratory, was placed at the TUT facility hallway where students, staff and visitors pass when moving around the campus. Test location was chosen so that it would be able to collect a diverse group of participants. Test participants were given a task to use the robot application prototype to investigate the lunch menus at the campus cafeterias. Participants were given instructions to communicate with the robot either verbally or using the touch user interface (UI). To ensure the data validity, a robotics specialist observed the data collection process that participants understood the given task correctly and were able to operate with the robot to get the experience required in answering the questionnaire. Figure 32 below depicts the service robot, which was used to test the application prototype, at the Tampere University of Technology during March 2018.

Figure 32. The robot at the research setting

A questionnaire survey was conducted among the participating students, staff, and visitors. A total of 132 students participated in the research (Table 6 below).

Table 6. Questionnaire participants

Number	Survey participants
78	Completely filled forms
43	Some data missing
11	Papers eliminated from the research due to incorrect filling
132	Total participants who returned the questionnaire

Eleven questionnaire papers were eliminated from the study, as these had too many incorrect entries. A common mistake was leaving the back side of the questionnaire form blank, which resulted in participants missing half of the research questions. Consequently, a total of 121 questionnaire forms were included in the survey and data analysis. The missing values were handled during the analysis. The most common missing data (19 pcs) was related to a demographic question on participant's gender.

The Phase 1 questionnaire consists of three categories: demographics, market segmentation, and technical TAM3 constructs. Questions from the three different categories were all mixed in the questionnaire form in random order.

The demographic questions used in the survey are presented in Appendix 7. Demographic questions are mainly informative and are not the main focus in this research. However, it is interesting to know the extent of the demographic representation captured by the research setting. Including the demographics section in the questionnaire also enables building possible new future research work based on the collected data.

Most of the market segmentation questions arise from the work of Rogers (1962) on the diffusion of innovations. Rogers' work is further elaborated in the theory chapter 2.1.2 entitled "Innovation adoption and diffusion". Variables MS3 (My risk tolerance to adopt new technology is high) and MS4 (I must be certain that a new idea does not fail before I adopt) are based on the description given by Jahanmir and Lages (2016) about late adopters of technological innovations. MS6 (I adopt new technology / product in its introductory and growth stages) and MS7 (I adopt new technology / product in its maturity and decline stages) are derived from the work of Shun and Venkatesh (2014) regarding differences between early and late adopters of technology. The market segmentation questions used in the survey with relevant literature references in the theoretical background of the question are explained in Appendix 7. These ten market segmentation questions targeted to capture participants' attitude toward new technology and aim to provide a means to classify the participants between technology innovators/early adopters and the mass market. In this research market split was not done for one specific product category, such as service robots, but more broadly using several meters (10 market segmentation questions) that measure participants' attitude towards new technologies in general.

The technical part has a foundation in theoretical framework developed by Venkatesh and Bala (2008), presented as the TAM3 (TAM3), and follow their questionnaire items for the TAM3 constructs. The original TAM3 questionnaire is illustrated in Appendix 8 and the TAM3 setting in Figure 30 in Section 2.5.5 entitled "The technology acceptance model 3".

In this research, the TAM3 portion of the questionnaire is used to test participants' attitude toward the R&D project product prototype, introducing new robotics technology during the early FFE phase of the NPD project. Small modifications to the original TAM3 questionnaire were necessary due to the different circumstances that were part of the research settings. The service robot application tested at the Tampere University of Technology (TUT) has some similarities to IT adoption, but there are also fundamental differences (described in Section 1.3 "Scope of the research") that result in necessary modifications to the TAM3 questions. A few questions have been omitted from the study and a few have been modified to best fit the research setting. Further, the questionnaire has been translated to Finnish to enable targeting a wider demographic sampling at the TUT facility, including students, visitors, and staff. Changes to the original TAM3 questionnaire topics, before the English to Finnish translation, are described in Appendix 9.

The most obvious part of the deviation from the original TAM3 questions is rephrasing the tested feature as a "robot" instead of a "system" or a "software package." This is due to the original IT background of the TAM3 construct and the applied setting to robotics FFE. Another major change is describing the task given for the participant in a more detailed manner—for example, "investigating the lunch menus" instead of a broader "my job." In this setting, the service robot prototype is not used in a daily job function like common IT systems. The questions that were left out from the original TAM3 setting and the justifications for why this decision was made are listed in Appendix 10. Finally, the complete survey questionnaire translated in Finnish is found in Appendix 11.

3.2.2 Phase 1: methods and data handling

The following subsection describes how the questionnaire data from Phase 1 is handled. Missing data is handled and the EA/MM market is segmentation is categorized. Moreover, the basic statistics for the data are evaluated using IBM SPSS 25 and SmartPLS 3 tools.

Phase 1 of the research is targeting to replicate the original TAM3 research (Venkatesh and Bala 2008) in a new robotics FFE setting. Therefore, the basic methods and principles of data processing given by Venkatesh and Bala (article entitled "Technology Acceptance Model 3 and a Research Agenda on Interventions," 2008) are also followed in these steps of the user acceptance modeling portion of this thesis work. This enables to more precisely compare the results between the different applications of TAM3. The PLS-SEM processing is done following the principles of original TAM3 (Venkatesh and Bala 2008).

Multivariate analysis involves statistical methods that simultaneously analyze multiple variables, where PLS-SEM is classified as a second-generation primarily exploratory method (Hair et al., 2017; Hair et al. 2019). Chin et al note that the PLS-SEM method has minimal restrictions in terms of distributional assumptions and sample size (Chin, Marcolin, and Newsted, 2003; Venkatesh and Bala, 2008). According to the example of Venkatesh and Bala (2008), the basic principles specified by Chin et al. were also followed in this research when applicable. Following the principle of Venkatesh and Bala (2008), the constructs of this research were modeled using reflective indicators.

There are numerous possible reasons for missing data in academic surveys. Perhaps a participant accidentally skipped a question or maybe a participant was too much in a hurry to think through the question, or perhaps he/she did not want to answer a particular question, or perhaps the question was too challenging to understand and, thus, was necessary to leave blank. In this research, a few of the two-sided questionnaires were left blank on one entire side and these questionnaires were omitted from the research.

The missing data is presented in Appendix 12. There was a total number or 121 participants in this study and a total number of 65 missing data values. The variable MS4 (Participant gender), has the highest quantity of missing data values— a total of 19—which represents approximately 29% of the missing data values in the questionnaire data.

During this research, missing data is first handled in SPSS by coding the blank cells with variable value "-999". Subsequently, in the PLS-SEM processing phase using the SmartPLS 3.2.7 tool, the missing data values are handled with mean value replacement. This method is selected as the questionnaire data already has a somewhat low number of EA representatives and it was decided not to delete any additional data. The mean value replacement option replaces all missing data points with the mean value of all remaining data points per column, having the benefit of not altering the sample size (Ringle, Wende, and Becker, 2015).

The survey includes ten variables (described in Appendix 13) for participant market segmentation classification. Three of these variables MS4 (I must be certain that a new idea does not fail before I adopt), MS5 (I approach new innovations with a skeptical and cautious air), and MS7 (I adopt new technology / product in its maturity and decline stages) have an "inverse" nature and indicate the attitude toward late adoption of technology or a skeptical and cautious attitude toward new technologies, whereas the rest of the MS variables indicate the positive attitude toward new technology and early adoption of technologies. One variable—MS8 (I'm often first to adopt an innovative product)—is selected to best represent the participant's overall attitude toward early adoption of new innovations as a candidate for the "early adopter" vs. "mass market" categorization variable.

Further, a Linear regression test was run in SPSS to test how other nine MS variables explain the MS8. As presented in Appendix 13, the adjusted R^2 value is 0.513, which corresponds to the 51% variance explained by the model for the MS8 variable. Next, an ANOVA test is run in SPSS to study the p-value for the model. It is evident from Appendix 13 that the p-value (Sig.) has a value less than 0.05, which implies that the created model is reliable ($p < 0.05$). Appendix 13 also illustrates the coefficients for all individual MS variables relative to the selected MS8 under testing. In Appendix 13, it is evident that the p-values (Sig.) are all rather high in this listing. This is due to the fact that all these MS variables measure the same phenomenon: participant's attitude toward new technology.

Based on this information, all participants with MS8 variable score 5.00 or higher are classified in the category "Innovators and Early Adopters of Technology" and the remaining participants (MS8 < 5.00) are classified in the "Mass Market Representatives." The variable MS8 statement "I'm often first to adopt an innovative product" was rated on a 7-point Likert scale, on which 5 represents "Somewhat agree", 6 represents "Moderately agree," and 7 represents "Strongly agree."

In this research, three different data sets were created to be able to evaluate the TAM3 model separately among the different groups of technology adopters:

- The "Innovators and Early Adopters" market segment includes 39 survey participants who represent a 32.2% minority of the survey.
- "Mass Market representatives" include 82 individuals who constitute 67.8% of the survey participants.
- "All data" includes all the 121 persons who participated the survey.

Chapters below describe tests performed for the three different data sets to ensure the reliability and validity of the construct measures in the service robot TAM3 FFE study.

The data was already divided into three categories: "All data", "EA data", and "MM data". Next, the evaluation criteria for the PLS-SEM reflective measurement model was checked for the three data sets. This includes internal consistency, convergent validity, and discriminant validity tests. For reflective measurement models, SmartPLS suggests "Composite reliability" to evaluate internal consistency, "Average variance explained" (AVE) to evaluate convergent validity, and

“Heterotrait-monotrait ratio of correlations” (HTMT) to examine discriminant validity (Hair et al., 2017).

The traditional criterion for internal consistency reliability, Cronbach’s alpha, is sensitive to the number of items on the scale; due to the limitations of Cronbach’s alpha, it is technically more appropriate to apply the composite reliability method for testing internal consistency reliability (Hair et al., 2017).

The PLS-SEM guideline formulates that Composite Reliability values between 0.60–0.70 are acceptable and values between 0.70-0.90 are regarded as satisfactory. Values above 0.90 (and definitely above 0.95) are not aspired as they point that all the indicator variables measure the same phenomenon and are, therefore, not necessarily to be valid measures of the construct. Specifically, such composite reliability values occur if one uses semantically redundant items by slightly rephrasing the very same question (Hair et al., 2017).

For testing convergent validity, the extent to which a measure correlates positively with alternative measures of the same construct, SmartPLS suggests checking the outer loadings of the indicators and average variance explained (AVE) (Hair et al., 2017; Cheah et al., 2018).

Discriminant validity can be described as the extent to which a construct is truly distinct from other constructs by empirical standards (Hair et al., 2017). Traditionally, cross-loadings are the first approach to assess the discriminant validity of the indicators; however, authors of SmartPLS recommend using HTMT of the correlations (Hair et al., 2017).

For variance-based SEM, the traditional Fornell-Larcker criterion and examination of cross-loadings do not reliably detect the lack of discriminant validity; instead, HTMT is applied due to its superior performance (Henseler, Ringle, and Sarstedt, 2015).

For the HTMT test, a bootstrapping procedure is performed to create a distribution of the HTMT statistic by randomly drawing 5000 subsamples of the original data to derive a bootstrap confidence interval.

The choice of the HTMT criterion depends on the model set-up. For example, the TAM and its variations (Davis, 1989; Venkatesh et al., 2003) include the constructs “intention to use” and “actual use,” which are conceptually different but may be challenging to empirically distinguish fully. Therefore, authors describe a choice of a more liberal criterion term—that is, <0.85, <0.90, or <1.00 (Henseler, Ringle, and Sarstedt, 2015).

Collinearity check is done for investigating the VIF values. 5.000 rounds bootstrapping is run for all the data sets. A two-tailed test is performed to identify significance level and is evaluated by assessing the t and p values. In order to pass these tests, 5% significance (t value > 1.96 and p value < 0.05) is required.

Coefficient of determination (R^2) is a commonly used measure to evaluate the predictive power of a structural model (Hair et al., 2017). There are no hard rules for acceptable R^2 values, as it depends on model complexity and research discipline. For example, R^2 values of 0.20 are considered high in consumer behavior disciplines but, for example, marketing research considers 0.75 substantial (***), 0.50 moderate (**), and 0.25 weak (*) (Hair et al., 2017).

When a specified exogeneous construct is omitted from the model, the change in R^2 value, referred as f^2 effect size measure, can be used to evaluate whether the omitted construct has a substantive impact on the endogenous constructs (Hair et al., 2017).

In addition to evaluating the magnitude of R^2 values, as a criterion of predictive accuracy, researchers must also examine Stone-Geisser's Q^2 value as an indicator of the model's out-of-sample predictive power or predictive relevance (Hair et al., 2017). Q^2 values are obtained by using the blindfolding sample reuse procedure ($Q^2 = 1\text{-}SSE/SSO$). Q^2 values larger than zero suggest that the model has predictive relevance. Blindfolding was run at omission distance D = 7.

The final assessment addresses the q^2 effect size values, which are calculated using operation "$q^2 = (Q^2\_included - Q^2\_excluded)/(1 - Q^2\_included)$" (Hair et al., 2017).

Further evaluation of the results will be conducted in Chapter 4 "Results and Discussion."

3.3 Research Phase 2: Robotics R&D FFE Uncertainty Study

The following sections describe the research steps implemented for data collection and handling in Phase 2 of the research.

The responses of TAM3 questions, collected from EA and MM during the research phase 1, was presented to a ten-person R&D team working in the robotics technology area during the research phase 2. The data was tested for its capabilities to reduce technology and market-based uncertainty that often takes place during the challenging early FFE phase of an NPD project.

In Phase 2, the participant group size is determined by the size of the R&D organization and, therefore, data is collected from ten persons. Because of the somewhat limited size of the R&D team, the latter phase of the research is more qualitative than quantitative in nature. From a statistical perspective, the participant number is rather small, but in practice this very well represents a group size of a typical R&D team of specialists working in the FFE of NPD. In numerous organizations, teams can be also smaller (Moen, 2001; Kelly, 2001; ABC News, 1999; IDEO San Francisco, 2001).

The following subsection, 3.3.1, describes how the data collected in Phase 1 was used to develop the questionnaire for the Phase 2.

3.3.1 Phase 2: questionnaire development

Following Phase 1, the "MS8" is used as the categorization variable for early and late market segments as well during Phase 2. A one-way ANOVA test was run in SPSS 25 using MS8 (I'm often first to adopt an innovative product) market segmentation control variable to separate the EA and MM groups. Further, a test for homogeneity of variance was run to investigate the statistically significant differences between the EA and MM market segment groups (sig. < 0.05). Data skewness is taken into account when preparing the results for the FFE R&D team presentation. The TAM3 market information data provided to the R&D team is presented in Table 18 in subsection 4.1.3.

Table 7 below describes the market and technology-based uncertainty items measured by the R&D team. The literature references associated with the uncertainty items are explained in greater detail in subsection 2.1.3 entitled "Market and technology uncertainty."

Table 7. Market and technology uncertainty items

Uncertainty item	Classification	Reference
Target market definition	Market	Cooper, 2005
Product positioning	Market	Cooper, 2005
Needs that technology will address	Market	Mohr, Sengupta and Slater (2010)
Product concept definition	Technology	Cooper (2005)
Product functionalities	Technology	Poskela (2009)
Choice of technology	Technology	Chen et al. (2005)

There are six FFE uncertainty item measurements (described in Table 7 above) and seven pieces of TAM3-based information that were presented to the R&D team for the study of FFE uncertainty reduction. This results in a matrix of a total of 42 uncertainty measures. An example graphical representation of TAM3 market segmentation data that was presented to the R&D team as input for the discussion and questionnaire data collection is illustrated in Appendix 14.

The questionnaire used to collect feedback from the R&D team for the reduction of market- and technology-based uncertainties in FFE utilizes visual analogue scale (VAS). VAS is a continuous ("analogue") scale which differentiates it from discrete scales ("steps"), such as the common Likert scale. VAS is argued to have superior metric characteristics over discrete scales, and a wider range of statistical methods can be applied with VAS (Reips and Funke, 2008).

The following chapter illustrates how the collected R&D feedback data was handled.

3.3.2 Phase 2: methods and data handling

The data was collected from the R&D team as a questionnaire survey. A presentation consisting of seven TAM3 construct items was shown to the team and discussed as a group. The discussion with the R&D team was recorded to capture quotations. Each of the six slides presented one essential finding regarding the EA vs. MM category differences based on the research findings conducted in Phase 1. The seventh slide showed the entire TAM3 construct for the tested market as a whole ("all data").

After presentation of each of the seven slides, a discussion was held among the ten R&D specialists; thereafter, the discussion participants answered the questionnaire individually. The purpose of the discussion was both to engage the team to brainstorm the given information and to function as a team. Further, verbal feedback regarding the findings was collected by recording the discussion. Participants were asked to use the questionnaire VAS scale after each EA and MM finding to answer the following question on a scale ranging from "Not at all" to "Remarkably": "How much does this information reduce the uncertainty?"

The questionnaire's VAS scale was converted into a percentage scale ranging from 0–100% where 0% represents uncertainty reduction being "Not at all" and 100% implies the uncertainty reduction being reduced "Remarkably." The tick mark on the visual scale line is made by the questionnaire participant, and the other markings ("MM" and "%" scales) in Appendix 14 are measurements and calculations made by the researcher when classifying the data. The researcher measured the given answers in the VAS scale first in millimeters (range: min = 0mm, max = 73mm) and then converted the answer into percentage form (range: min = 0%, max = 100%). After conversions, the data was handled using SPSS.

Missing data was coded in SPSS with variable “-999”. Moreover, the extra variables for creating “average” operations was calculated from the questionnaire data in SPSS. Mean values were calculated for the market and technology uncertainty items for each MM and EA finding for TAM3 constructs. The data collected from the R&D team representing the uncertainty reduction that occurs in the robotics FFE of NPD is illustrated in detail in Appendix 25.

The results are further elaborated in Chapter 4 below.

4 RESULTS AND DISCUSSION

The following sections and subsections discuss the research results. Subsection 4.1.1 presents the variable general distribution of the basic questionnaire data obtained from Phase 1 of the research. Subsection 4.1.2 deals with Phase 1 data reliability and validity test results. Subsection 4.1.3 continues to the evaluation of the TAM3 structural models for EA, MM, and entire market data. Subsections 4.1.4 and 4.1.5 answer research questions 1 and 2. Subsection 4.2.1 guides through the Phase 2 qualitative R&D study results as necessary background before answering research question 3 in subsection 4.2.2. Finally, the results are discussed in section 4.3.

4.1 Results of Research Phase 1

4.1.1 Phase 1: questionnaire demographics

First, the variables from the "Demographic" section of the questionnaire of research Phase 1 are illustrated. Tables 8–11 below highlight the data distribution for demographic variables DEM1 (Participant's age), DEM2 (Participant's gender), DEM3 (Participant's degree of education), and DEM4 (Participant's occupation).

Table 8. Participants' gender (DEM1)

	Frequency	Percentage
Male	55	45.5
Female	47	38.8
Missing data	19	15.7

Gender is closely equally distributed among the participants, as 46% of participants are male, 39% female, while the remaining 16% did not answer this question.

Table 9. Participants' educational degree (DEM2)

	Frequency	Percentage
Below	44	36.4
B.Sc.	44	36.4
M.Sc.	24	19.8
Ph.D.	7	5.8
Missing data	2	1.7

As is evident from the above table, 36% of the participants have a degree lower than B.Sc., 36% have a B.Sc. degree, 20% have a master's degree, and 6% have a doctoral degree.

Table 10. Participants' occupation (DEM3)

	Frequency	Percentage
Student	52	43.0
Working	54	44.6
Both Student and working	14	11.6
Missing data	1	0.8

Among the survey participants, 43% classify themselves as students, 45% are working, and 12% are both working and studying.

The research was conducted at the Tampere University of Technology, which explains the high relative representation of students (43% students and 12% studying and working). For a wider demographic sampling, it is good that almost half the participant population (45%) are workers, presumably staff at the University campus, and visitors.

Table 11. Participants' age (DEM4)

	Frequency	Percentage
<20 years	6	5.0
20–29 years	65	53.7
30–39 years	26	21.5
40–49 years	18	14.9
50–59 years	6	5.0

Approximately half of the participants are in age group of 20–29 years. Only 10% of the participants are either younger than 20 years of age or older than 49 years of age.

The means of the "Market segmentation" variable from the Phase 1 questionnaire are presented in Appendix 26. Participants appear to have a rather neutral attitude toward the questions targeting social status (MS1: I have high social status) and leadership (MS2: I have opinion leadership in my social context). Questions regarding participants' risk tolerance when adopting new technology (MS3: My risk tolerance to adopt new technology is high, MS4: I must be certain that a new idea does not fail before I adopt, and MS5: I approach new innovations with a skeptical and cautious air) show moderate agreement toward the acceptance of risk related to new technology. Further, among the first movers (MS6: I adopt new technology / product in its introductory and growth stages, MS7: I adopt new technology / product in its maturity and decline stages, and MS8: I'm often first to adopt an innovative product), participants appear to have a rather neutral or even a slightly negative attitude toward adopting new technology or an innovative product. Participants are somewhat knowledgeable about new technology and strongly enjoy learning about new technology (MS9: I am knowledgeable about new technology, and MS10: I enjoy learning about new technology). These variables (MS1–10) are used to classify participants into two groups.

"Technical" variable means for the Phase 1 questionnaire are presented in Appendix 27. Subjective norm variables SN1 (People who influence my behavior think that I should experiment with the robot) and SN2 (People who are important to me think that I should try out the robot) indicate a neutral attitude toward the influence of other people toward participants' testing of the service robot. Image variables IMG1 (People in my organization who use the robot have more prestige than those who do not), IMG2 (People in my organization who use the robot have a high profile), and IMG3 (Testing the robot is a status symbol in my organization) show a neutral or slightly negative attitude toward testing the robot, thereby revealing a higher status or profile in the social context. A majority of the participants somewhat agree with the output quality of the robot being high or excellent (OUT1: The quality of the output I get using the robot is high, OUT2: I have no problem with the quality of the robot's output, and OUT3: I rate the results from the robot to be excellent). The result variables RES1 (I have no difficulty telling others about the results of using the robot), RES2 (I believe I could communicate to others the consequences of using the robot), and RES3 (The results of using the robot are apparent to me) show that a majority of the participants moderately or somewhat agree that the results of using the robot are obvious and apparent. Further, self-efficacy variables CSE1 (I could investigate the lunch menus using the robot . . . if there was no one around to tell me what to do as I use the robot), CSE2 (. . . if I had just the robot's built-in help facility for assistance), CSE3 (. . . if someone showed me how to do it first), and CSE4 (. . . if I had used similar robots before this one to do the same task) show that a majority of the participants moderately agree that the robot use does not require external support other than the in-built help of the system. A majority of the participants moderately or strongly agree that robots do not scare, cause anxiety, or make participants uncomfortable or nervous (CANX1: Robots do not scare me at all, CANX2: Working with a robot makes me nervous, CANX3: Robots make me feel uncomfortable, and CANX4: Robots make me feel uneasy). However, a majority of the participants moderately disagree with the robot being useful or helpful in improving user's performance in completing the task of investigating the campus cafeterias' lunch menus (PU1: Using the robot improves my performance in my task investigating the lunch menus, PU3: Using the robot enhances my effectiveness in my task investigating the lunch menus, and PU4: I find the robot to be useful in my task investigating the lunch menus). A majority of the participants moderately or strongly agree with the use of robot being fun, pleasant, and enjoyable (ENJ1: I find using the robot to be enjoyable, ENJ2: The actual process of using the robot is pleasant, and ENJ3: I have fun using the robot). Participants somewhat or moderately agree with service robot's playfulness (CPLAY1: The following questions ask you how you would characterize yourself when you use robots: . . . spontaneous, CPLAY2: . . . creative, CPLAY3: . . . playful, and CPLAY4: . . . unoriginal) in terms of spontaneity, creativity, playfulness, and unoriginal characterization. A majority of the participants somewhat or moderately agree with the Pepper service robot's perceived ease of use (PEOU1: My interaction with the robot is clear and understandable, PEOU2: Interacting with the robot does not require a lot of my mental effort, PEOU3: I find the robot to be easy to use, and PEOU4: I find it easy to get the robot to do what I want it to do). In addition, behavioral intention variables BI1 (Assuming the robot would be permanently at the setup under testing . . . I would use the robot if it would be accessible), BI2 (. . . I might use the robot if it would be accessible), and BI3 (. . . I would plan to use the robot in the future) show that a majority of the participants somewhat and moderately agree with the possible use of the robot in the future if Pepper would be available for use at the test setup at TUT.

4.1.2 Phase 1: data reliability and validity test results

The test results for data reliability and validity tests are discussed according to the PLS-SEM technique, addressed earlier in subsection 3.2.2.

Data was divided into three categories: "All data", "EA data", and "MM data" and is tested first for evaluation criteria for the reflective measurement model. Appendixes 15–17 illustrate the outer loading, AVE, composite reliability and HTMT test results in more detail for the All, EA, and MM data sets.

There is clearly some level of rephrasing of the questions in the original TAM3 model (Venkatesh and Bala, 2008). As TAM3 model is applied in this robotics FFE study, also same rephrasing in the questions takes place. There are a few exceptions in the data set that exceed the 0.90 value for the internal consistency reliability composite reliability test, but none of the values exceed the 0.95 limit. The results for the internal consistency reliability composite reliability test are presented in Appendix 16.

For the reflective variables RES4 (I would have difficulty explaining why using the robot may or may not be beneficial), CSE3 (I could investigate the lunch menus using the robot . . . if someone showed me how to do it first), CSE4 (. . . if I had used similar robots before this one to do the same task), and CPLAY4 (The following questions ask you how you would characterize yourself when you use robots: . . . unoriginal), the outer loadings (Appendix 15) were too small (<0.400); in such a case, PLS-SEM convergent validity guidelines recommended omitting these variables from the model, provided such variables are not significant for the model. It is evident in Appendix 9, that even though the variables RES4, CSE3, CSE4, and CPLAY4 are omitted from the TAM3 construct, the variables "Result demonstrability", "Robot self-efficacy," and "Robot playfulness" continue being very well explained by the remaining RES, CSE, and CPLAY variables. After eliminating the RES4, CSE3, CSE4, and CPLAY4 variables, all other loadings measure above 0.400 for all data sets (All, EA, and MM).

In addition, variable CANX1 (Robots do not scare me at all) was interfering the EA data, thereby causing AVE and composite reliability tests to perform below recommended values. After the elimination of the CANX1 variable, the TAM3 model construct performed reliably in the EA data set as well as with All and MM data sets. The composite reliability AVE test results are presented in Appendix 16.

In order to determine discriminant validity, the HTMT test was run for all three data sets under evaluation. All data passed the set criteria, except one sample "PEOU→BI" in the EA data set with a value of 1.017, which is only slightly above the <1.00 criteria. Discriminant validity HTMT test results are presented in Appendix 17.

Table 12 below summarizes the test criteria and results for the three different TAM3 data sets in the PLS-SEM reflective measurement model.

Table 12. Summary of the reflective measurement model

	Convergent Validity		**Internal Consistency**	**Discriminant Validity**
	Loadings	AVE	Composite Reliability	HTMT confidence interval
	>0.4	>0.5	0.60–0.90 preferred, not >0.95	<1.00
All data	OK	OK	OK, exceptions: CANX = 0.901, BI = 0.927	OK
EA data	OK	OK	OK, exceptions: BI = 0.917, PE = 0.948	OK, exception: PEOU→BI = 1.017
MM data	OK	OK, exception: RES = 0.492	OK, exceptions: BI = 0.927, CANX = 0.908	OK

AVE = Average Variance Explained, HTMT = Heterotrait-monotrait ratio, CANX = Robot Anxiety, BI = Behavioral Intention, PE = Perceived Enjoyment, PEOU = Perceived Ease of Use, RES = Result Demonstrability.

All outer loadings are above the 0.40 recommended limit. All AVE values are above the 0.50 recommended limit, except the "Result demonstrability" construct in the MM data set that has a value of 0.49, which is very close to the recommended limit. For the composite reliability test, all data is below the strongly recommended 0.95 limit value. A vast majority of the data values are between the preferred range of 0.60–0.90, with only a few exceptions. In the HTMT test, all data meets the <1.00 criteria, except one sample ("Perceived Ease of Use" → "Behavioral Intention") that has a value of 1.017, which is just slightly above the given limit. Thus, it can be stated that the data fits the model.

Now that the data has been tested for the reflective measurement model evaluation criteria, the next step is to evaluate the TAM3 structural models. This includes studying the explained variance, predictive relevance, size, and significance of path coefficients and effect sizes.

The collinearity check was performed by investigating the VIF values. Detailed outer model and inner model VIF values are listed in Appendixes 18 and 19. All VIF values clearly pass the <5.00 criteria. Further, 5.000 rounds bootstrapping was run for all the data sets. The significance level was tested using the two-tailed test by assessing the t and p values. All the values that crossed the 5% significance criteria (t value > 1.96 and p value < 0.05) are highlighted in Appendixes 20–22 among path coefficients, outer loadings, and coefficients of determination (R^2).

Table 13 below summarizes the values of the coefficients of determination (R^2) for all data sets to describe the predictive power of the structural model.

Table 13. Coefficients of determination (R^2)

Construct	All data	EA data	MM data
Behavioral Intention	0.437 (*)	0.5 (**)	0.415 (*)
Image	0.16	0.167	0.158
Perceived Ease of Use	0.45 (*)	0.551 (**)	0.424 (*)
Perceived Usefulness	0.43 (*)	0.619 (**)	0.352 (*)

There are no hard rules for acceptable R^2 values, as these depend on model complexity and research discipline. Marketing research considers 0.75 substantial (***), 0.50 moderate (**), and 0.25 weak (*) (Hair et al., 2017).

According to the data illustrated in Table 13, there are some differences between the coefficients of determination (R^2) values among All, EA, and MM data. The perceived usefulness has the largest difference in its R^2 value, varying between the MM 0.35 and EA 0.62 values. Overall, all the other constructs than the Image are rather well (>0.4) explained for all data sets. The coefficients of determination are further discussed in subsection 4.1.3.

Table 14 below illustrates the effect size f^2 values for all data sets.

Table 14. f^2 effect size

	All data	EA data	MM data
Image -> Perceived Usefulness	0.099 (*)	0.171 (**)	0.068 (*)
Output Quality -> Perceived Usefulness	0.138 (*)	0.175 (**)	0.164 (**)
Perceived Ease of Use -> Behavioral Intention	0.021 (*)	0.116 (*)	0.004 (†)
Perceived Ease of Use -> Perceived Usefulness	0.002 (†)	0.068 (*)	0.000 (†)
Perceived Enjoyment -> Perceived Ease of Use	0.411 (***)	0.553 (***)	0.215 (**)
Perceived Usefulness -> Behavioral Intention	0.448 (***)	0.210 (**)	0.539 (***)
Result Demonstrability -> Perceived Usefulness	0.075 (*)	0.324 (**)	0.031 (*)
Robot Anxiety -> Perceived Ease of Use	0.057 (*)	0.023 (*)	0.116 (*)
Robot Playfulness -> Perceived Ease of Use	0.049 (*)	0.017 (†)	0.003 (†)
Robot Self-Efficacy -> Perceived Ease of Use	0.035 (*)	0.059 (*)	0.021 (*)
Subjective Norm -> Behavioral Intention	0.019 (†)	0.059 (*)	0.009 (†)
Subjective Norm -> Image	0.191 (**)	0.201 (**)	0.188 (**)
Subjective Norm -> Perceived Usefulness	0.000 (†)	0.000 (†)	0.002 (†)

† = no effect, * = small effect, ** = medium effect, and *** = large effect

The f^2 effect sizes lower than 0.02 indicate that there is no effect (†), 0.02 indicates a small effect (*), 0.15 indicates a medium effect (**), and 0.35 indicates a large effect (***). All the f^2 values are in line with previous findings related to t and p values (Appendixes 20–22). Subsequently, in subsection 4.1.3, f^2 values are assessed when comparing the TAM3 construct differences between EA and MM category representatives.

Table 15 below presents the predictive accuracy as construct cross-validated redundancy for all three data sets.

Table 15. Q^2 values

	All data	EA data	MM data
Behavioral Intention	0.321	0.328	0.296
Image	0.087	0.096	0.068
Perceived Ease of Use	0.220	0.288	0.170
Perceived Usefulness	0.288	0.392	0.226

As evident from Table 15 above, all four endogenous constructs have Q^2 values clearly above zero, which supports the model's predictive relevance regarding the endogenous latent variables.

Table 16 below summarizes the q^2 effect sizes for all three data sets. Appendix 23 presents the effect size q^2 for all three data sets. All values below 0.02 threshold are marked with a "†" symbol.

Table 16. q^2 effect size values

	BI			IMG			PEOU			PU		
	All	EA	MM	All	EA	MM	All	EA	MM	All	EA	MM
BI												
IMG										0.06	0.07	0.04
OUT										0.07	0.07	0.09
PEOU	0.01†	0.05	0.00†							-0.01†	0.02	-0.01†
ENJ							0.15	0.21	0,07			
PU	0.28	0.12	0.33									
RES										0.04	0.12	0.02†
CANX							0.02	0.00†	0.04			
CPLAY							0.02†	0.00†	0.00†			
CSE							0.01†	0.01†	0.00†			
SN	0.01†	0.02†	-0.01†	0.10	0.11	0.07				0.00†	-0.01†	0.00†

† = fails the test threshold criteria. BI = Behavioral Intention, IMG = Image, PEOU = Perceived Ease of Use, PU = Perceived Usefulness, OUT = Output Quality, ENJ = Perceived Enjoyment, RES = Result Demonstrability, CANX = Robot Anxiety, CPLAY = Robot Playfulness, CSE = Robot Self-Efficacy, SN = Subjective Norm.

A summary of the q^2, f^2, t, and p values is presented in Appendix 24.

When comparing the "failing" q^2 effect sizes (Table 16 above) to the corresponding path coefficients (Appendixes 20–22), it is evident that the links with the q^2 effect size below the 0.02 threshold are the same links that have low path coefficient values, typically <0.20.

Now that all the data reliability and validity checks have been performed, the data results are presented and the three research questions answered in the following subsections.

4.1.3 Phase 1: Analysis of PLS-SEM results of the TAM3 model

A summary of the statistically significant TAM3 construct paths is presented for all three data sets. A visualization of those construct links that are considered effective and statistically significant is illustrated in Figure 33 below. The user data groups (EA, MM, and All) that have meaningful significance test results are marked in the figure on top of the path.

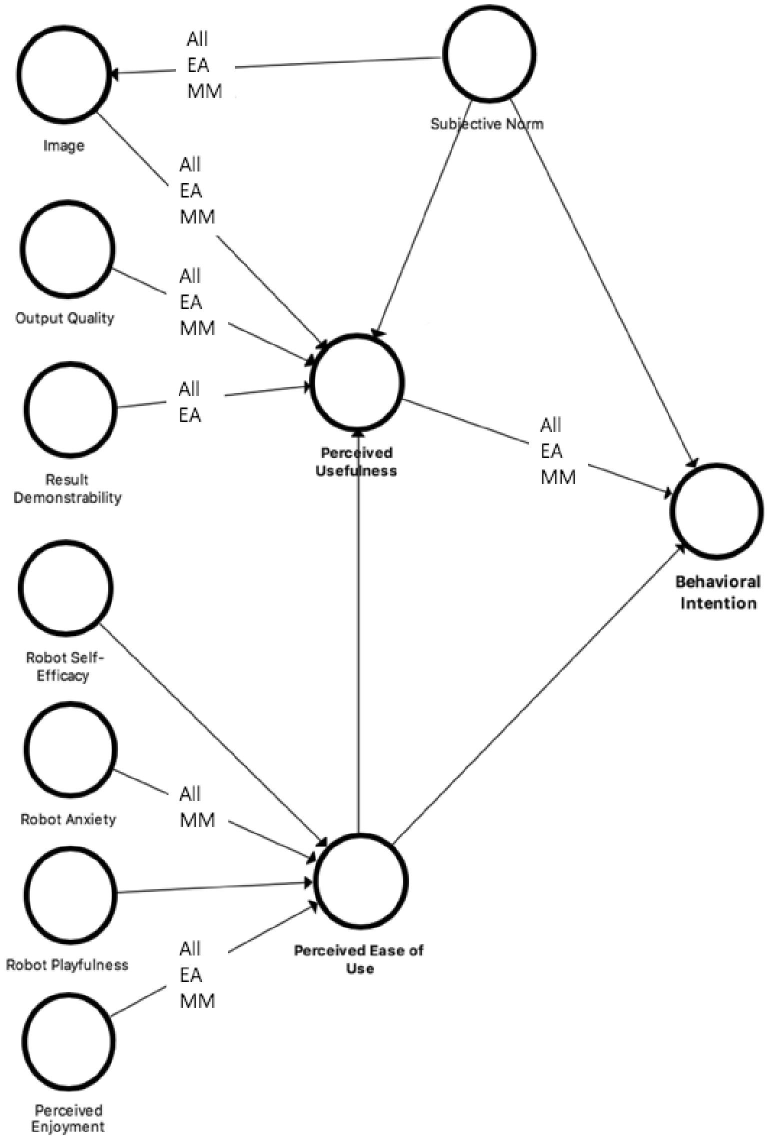


Figure 33. Effective and statistically significant TAM3 construct links

The endogenous constructs and path coefficients of the PLS-SEM model are discussed in the following subsections.

Variance of the endogenous constructs explained (R^2)

It is remarkable that the Behavioral Intention to Use is explained strongly in this TAM3 construct by all three data sets (BI: All 44%, EA 50%, and MM 42%). Behavioral Intention is the main construct in TAM3, which leads solely to the use of a technology and which is explained by all the other reflective variables and endogenous constructs of the TAM3 model.

Perceived usefulness is explained particularly strongly among the EA over the MM representatives (PU: All 43%, EA 62%, and MM 35%). Perceived usefulness is a construct that links other endogenous constructs (Subjective Norm, Image, Perceived Ease of Use and Behavioral Intention) together. Perceived usefulness is more consistent among the early adopters and the TAM3 model performs better among the early adopters in this area. Among mass market representatives, the explaining power comes apart due to the greater heterogeneity of the data group.

Similarly, Perceived Ease of Use is explained strongly in all market categories; however, it is slightly more strongly explained among the EA (PEoU: All 45%, EA 55%, and MM 42%). In TAM3, Perceived Ease of Use comprises constructs formed by reflective indicators, such as Robot Self-Efficacy, Robot Anxiety, Robot Playfulness, and Perceived Enjoyment.

It must be noted that Image is somewhat poorly explained among all the market categories in this TAM3 construct study (IMG: All 16%, EA 17%, and MM 16%). Image is a result of reflective indicators and one endogenous construct, Subjective Norm.

Structural model relationships (Path coefficients)

It is obvious that Perceived Usefulness has the strongest effect on Behavioral Intention compared to either Perceived Ease of Use or Subjective Norm in all three datasets (PU→BI: All 0.56, EA 0.40, and MM 0.61). More interestingly, there is no significant link between Perceived Ease of Use or Subjective Norm and Behavioral Intention when TAM3 is applied to this FFE study among the potential EA and MM users of the service robot prototype.

In this study, Perceived Ease of Use does not have a significant effect on either Perceived Usefulness or Behavioral Intention. Among EA, there is a negative relationship between Perceived Ease of Use and Perceived Usefulness (-0.33), but this does not have statistical significance based on the t and p tests.

Among both EA and MM representatives, the Output Quality has a stronger positive effect on Perceived Usefulness than Image (OUT→PU: All 0.41, EA 0.51, and MM 0.44; IMG→PU: All 0.26, EA 0.30, and MM 0.23).

Among EA, Result Demonstrability has a strong effect on Perceived Usefulness (RES→PU: EA 0.50, and All 0.26); however, among the representatives of MM, this relationship does not have statistical significance.

Subjective Norm has a statistically significant effect only on Image and not on Perceived Usefulness or Behavioral Intention. The effect of Subjective Norm on Image remains very constant among all market segments (SN→IMG: All 0.40, EA 0.41, and MM 0.41).

The effect of Image on Perceived Usefulness is somewhat strong and very constant among all market segments (IMG→PU: All 0.26, EA 0.30, and MM 0.23).

Among the representatives of MM category, Robot Anxiety has a somewhat strong negative effect on Perceived Ease of Use (CANX→PEoU: MM -0.31, All -0.20), but among EA of technology this relationship does not have a statistically significant impact.

In this study, Robot Self-Efficacy and Robot Playfulness do not demonstrate a statistically significant effect on Perceived Ease of Use.

Further, Perceived Enjoyment has a strong positive effect on Perceived Ease of Use among all participant categories, where the effect is particularly strong among the early adopters of technology (ENJ→PEoU: All 0.57, EA 0.66, and MM 0.41).

Summary of PLS-SEM results

The endogenous constructs and path coefficients of the TAM model are calculated using the PLS-SEM technique for all three data sets (EA, MM, and All). This chapter summarizes the key findings of the data analysis.

Table 17 below presents the high-level findings for the TAM3 robotics FFE study among EA and MM representatives.

Table 17. TAM3 FFE service robot findings

1	Perceived Usefulness has a strong positive effect on Behavioral Intention to Use.
2	Perceived Ease of Use and Subjective Norm do not have a significant effect on Behavioral Intention to Use.
3	Output Quality has a stronger positive effect on Perceived Usefulness than Image or Result Demonstrability have.
4	Among Early Adopters, the Result Demonstrability has a strong positive effect on Perceived Usefulness, but among Mass Market representatives this effect is not significant.
5	Subjective Norm has a strong positive effect on Image, but there is no significant effect on Perceived Usefulness of Behavioral Intention to Use.
6	Image has a somewhat strong positive effect on Perceived Usefulness among both EA and MM representatives.
7	Robot Anxiety has a somewhat strong negative effect on Perceived Ease Use among MM representatives, but no significant effect on Early Adopters.
8	Robot Self-Efficacy does not demonstrate a significant effect on Perceived Ease of Use.
9	Robot Playfulness does not demonstrate a significant influence on Perceived Ease of Use.
10	Perceived Enjoyment has a strong positive effect on Perceived Ease of Use.
11	The positive effect of Perceived Enjoyment on the Perceived Ease of Use is stronger among EA than among MM representatives.

All the statistically significant EA and MM differences based on the TAM3 market information that was collected during Phase 1 and presented to the FFE R&D team during Phase 2 are illustrated in Table 18 below. In Table 18 below, the items with an arrow ("→") refer to the PLS path coefficients and the items with a numeric value in parentheses refer to the variable mean for the data set (EA or MM) under investigation.

Table 18. Summary of findings from the TAM3 FFE service robot study

Influence of Perceived Usefulness (PU) on Behavioral Intention to Use (BI)
- PU3: EA "Neutral" (4), MM "Somewhat disagree" (3)
- PU→BI PLS Path coefficient: EA Moderate positive effect (0.4), MM Strong positive effect (0.6)
- BI3: EA "Somewhat agree" (5), MM "Neutral" (4)
Influence of Result Demonstrability (RES) on Perceived Usefulness (PU)
- RES1: EA "Moderately agree" (6), MM "Somewhat agree" (5)
- RES→PU PLS Path coefficient: EA Strong positive effect, MM no statistically significant effect
- BI3: EA "Somewhat agree" (5), MM "Neutral" (4)
Influence of Robot Anxiety (CANX) on Perceived Ease of Use (PEOU)
- CANX→PEOU PLS Path coefficient has a moderate negative effect (-0.3) among MM, but does not have any statistically significant effect among EA
Influence of Perceived Enjoyment (ENJ) on Perceived Ease of Use (PEOU)
- ENJ→PEOU PLS Path coefficient has stronger positive effect among EA (0.7) than the MM (0.4)
- ENJ1: EA "Moderately agree" (6) and MM "Somewhat agree" (5)
Influence of Image (IMG) on Perceived Usefulness (PU)
- IMG→PU PLS Path coefficient has a similarly moderately positive effect among EA (0.3) and MM (0.2)
Influence of Subjective Norm (SN) on Image (IMG)
- SN1: EA "Somewhat agree" (5), MM "Neutral" (4)
- SN→IMG PLS Path coefficient has equally strong positive effect among EA (0.4) and MM (0.4)
TAM3 construct as a whole
- ENJ→PEOU PLS Path coefficient has a strong positive effect
- OUT→PU PLS Path coefficient has a strong positive effect
- PU→BI PLS Path coefficient has a strong positive effect
- PEOU→PU or PEOU→BI PLS Path coefficients are not statistically significant
- CPLAY→PEOU PLS Path coefficient is not statistically significant
- SN→PU or SN→BI PLS Path coefficients are not statistically significant

These findings summarize the data for Phase 1 of the research. In Phase 2, these collected findings were tested by an R&D team involved with robotics technologies.

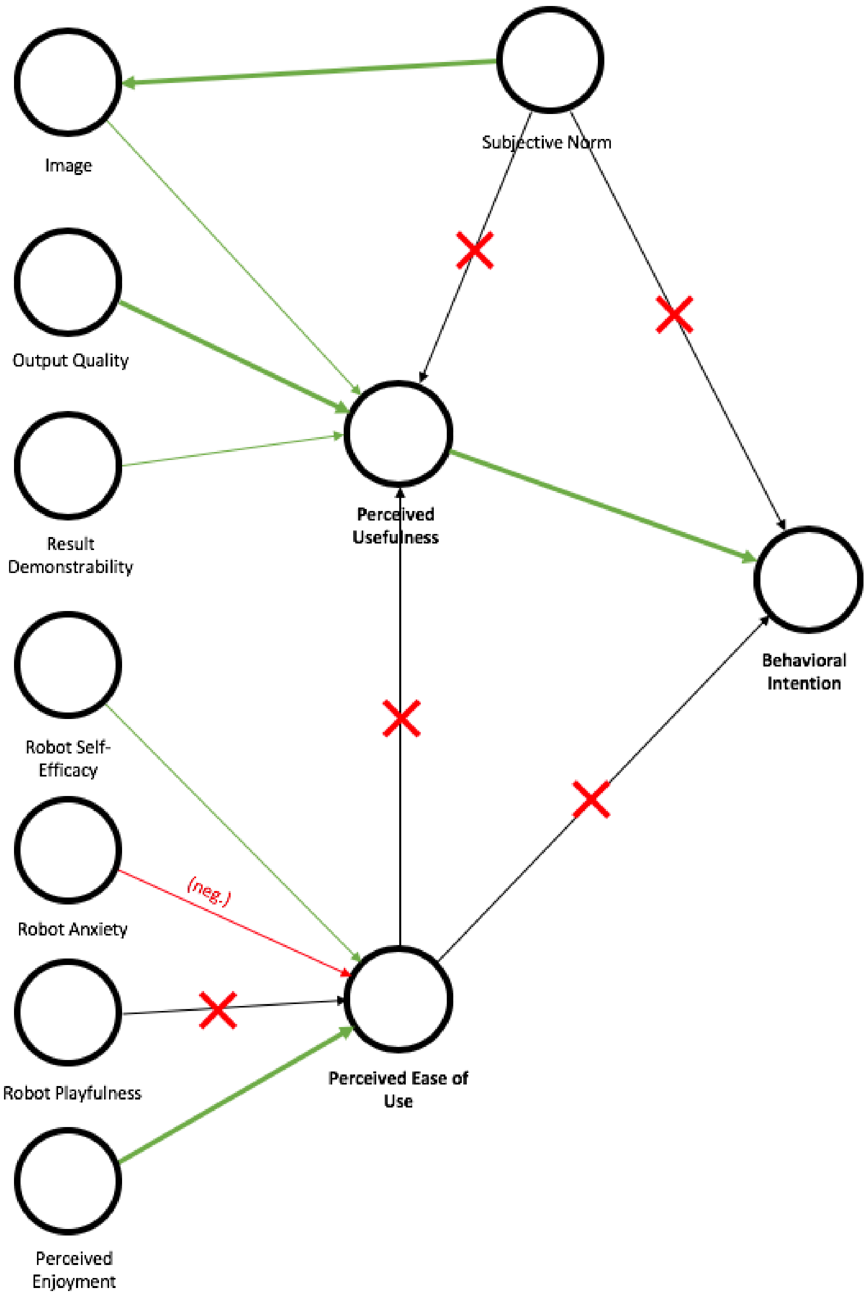
Now, all PLS-SEM data is tested and presented, and the actual research questions are answered in the following sections 4.1.4, 4.1.5, and 4.2.2. Research questions 1 and 2 are answered by the work done in the Phase 1, and research question 3 is answered based on the contributions of Phase 2.

4.1.4 Answering research question 1: TAM3 functionality in the FFE

The first research question investigates how the original TAM3 constructs perform when the model is applied to the early FFE phase of the NPD process and the technological context is robotics. The path coefficient values are studied to investigate the links between various TAM3 constructs.

- **Research question 1**: How does the TAM3 model perform in robotics FFE compared to the IT PD phase?

In the original TAM3 model (Venkatesh and Bala, 2008) there are three major inner constructs: Perceived Usefulness, Perceived Ease of Use, and the Behavioral Intention to Use. In the original TAM3 model, Perceived Usefulness and Perceived Ease of Use lead to Behavioral Intention. Figure 34 below illustrates the TAM3 model applied to the robotics NPD FFE phase.



Lines in the figure represent path coefficients from outer to inner constructs. Paths marked "neg." represent a negative effect toward the inner construct. Lines with an X-mark are symbols for a path that does not have statistical significance in the setting. The width of the line represents the strength of the link.

Figure 34. TAM3 All data in the robotics FFE

In the application of the TAM3 model to the FFE phase of robotics NPD, it must be noted that the relationship between Perceived Ease of Use and Behavioral Intention is broken, as there is no statistically significant effect here. This is different from the original TAM3 model, where this link is active. Similarly, the relationship between Perceived Ease of Use to Perceived Usefulness is broken due to no statistically significant effect. However, Perceived Usefulness has a strong positive effect on Behavioral Intention, as expected. The PLS results for TAM3 All data can be found in detail in Appendix 20.

In the original TAM3 model, the Perceived Usefulness inner construct is explained by four outer constructs—Result Demonstrability, Output Quality, Image, and Subjective Norm. These constructs have positive effects on Perceived Usefulness, as expected. However, the Subjective Norm does not have a statistically significant effect on Perceived Usefulness in the FFE phase of robotics NPD. Moreover, the relationship between Subjective Norm and Behavioral Intention does not have statistical significance.

In the TAM3 model, Perceived Ease of Use is explained by four elements: Computer Self-Efficacy, Computer Anxiety, Computer Playfulness, and Perceived Enjoyment. When the TAM3 model is applied to the FFE phase of robotics NPD, it is noted that according to the original model, there are positive effects from Computer (Robot) Self-Efficacy and Perceived Enjoyment on Perceived Ease of Use. Moreover, there is a negative effect from Computer (Robot) Anxiety on Perceived Ease of Use. However, in contrast with the original TAM3 model, it is evident that the Computer (Robot) Playfulness effect on Perceived Ease of Use does not have statistical significance. In order to fully understand the reasons underlying these broken links in the TAM3 model, future research in this direction is suggested in section 5.4.

A majority of the links between the constructs (8/13 pcs) have effects on the other constructs, as expected, based on the original TAM3 model; however, a significant portion of the links (5/13 pcs) differ from the original construct in the sense that the links do not have statistical significance. Therefore, it must be noted that there are fundamental differences between how the TAM3 model functions in its original setting at IT PD compared to the robotics FFE.

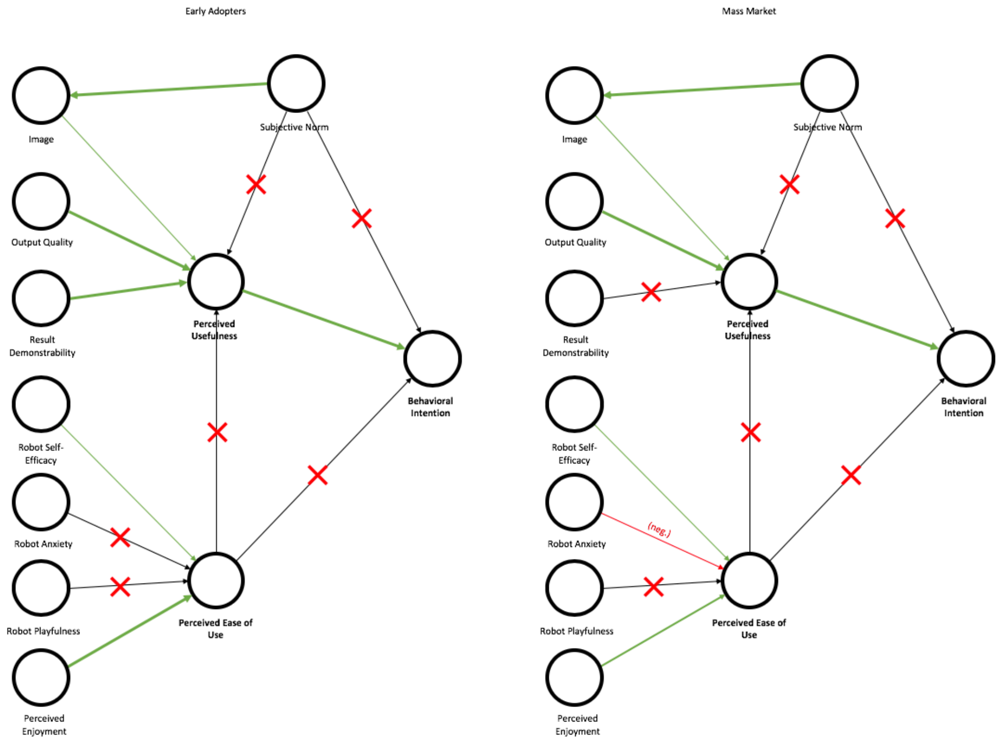
When applying the TAM3 model in FFE of robotics NPD, some of the constructs' path coefficients are higher than others. The links such as Subjective Norm → Image, Output Quality → Perceived Usefulness, Perceived Usefulness → Behavioral Intention, and Perceived Enjoyment → Perceived Ease of Use have stronger positive effects (higher path coefficient values) than the other significant links (Results Demonstrability → Perceived Usefulness, Image → Perceived Usefulness, Computer (Robot) Self-Efficacy → Perceived Ease of Use, Computer (Robot) Anxiety → Perceived Ease of Use, and Computer (Robot) Anxiety → Perceived Ease of Use). The Computer (Robot) Anxiety has a negative effect on Perceived Ease of Use, as expected.

4.1.5 Answering research question 2: Applicability of the TAM3 model to the early and late markets during the FFE

The second research question investigates the EA and MM representatives as two separate market segments. Both market segments have separate TAM3 models illustrated, and the significant differences between the two models are analyzed.

- **Research question 2:** How does the TAM3 model differ in the early and late market segments of robotics FFE?

Figure 35 below illustrates the EA and MM TAM3 models for the FFE of robotics NPD. The PLS data for EA and MM TAM3 models are described in detail in Appendixes 21 and 22.



Lines in the figure represent path coefficients from outer to inner constructs. Paths marked "neg." represent a negative effect toward the inner construct. Lines with an X-mark are symbols for a path that does not have statistical significance in the setting. The width of the line represents the strength of the link.

Figure 35. EA and MM TAM3 models in robotics FFE

The Perceived Usefulness link to Behavioral Intention has a strong positive effect (0.6) among the MM representatives but the link effect is only moderate (0.4) among EA. The link of the Result Demonstrability to Perceived Usefulness has a strong positive effect (0.5) among EA but the link does not have statistical significance among MM representatives. The Computer (Robot) Anxiety link to Perceived Ease of Use has a moderate negative effect (-0.3) among MM representatives, but there is no statistical significance among EA. The Perceived Enjoyment link to Perceived Ease of Use has a strong positive effect (0.7) among EA, but the link with MM representatives is only moderate (0.4). These findings open new research avenues that are explained later in section 5.4 entitled "Suggestions for future research."

In addition to the path coefficients (links), MM and EA TAM3 PLS-SEM models also have differences in the R^2 values of their inner constructs. Table 19 below summarizes the inner constructs of EA and MM and their differences.

Table 19. R^2 Values of Inner Constructs

TAM3 Inner construct	MM model value	EA model value
Perceived Usefulness	0.352	0.619
Perceived Ease of Use	0.424	0.551
Image	0.158	0.167
Behavioral Intention	0.415	0.500

In all of the inner construct items, the R^2 values are higher for the EA TAM3 model. This information implies that the variance in the inner constructs is explained more by the EA data. The greatest difference is in Perceived Usefulness, where the R^2 value of the MM model is 0.35 and that of the EA model is 0.62. The other differences are smaller. One possible explanation for the great difference in Perceived Usefulness is the fact that Result Demonstrability does not have a significant effect on Perceived Usefulness among MM representatives.

During the robotics FFE phase, the TAM3 model functions better (constructs are explained better, higher R^2 values) with EA than MM representatives.

4.2 Results of Phase 2 of the Research

4.2.1 Phase 2: FFE qualitative R&D study results

The third research question addresses the capability of the TAM3-based information to reduce the market and technology -based uncertainty in the challenging but important FFE phase of the NPD process.

In Phase 2, the TAM3-based EA and MM market segment data was presented to the robotics R&D team. The capability of model constructs to reduce the FFE market and technology uncertainty was measured individually using the VAS scale. The participants in the R&D team answered the uncertainty reduction questions on the VAS scale using the range 0% = "not at all" to 100% = "remarkably."

TAM3 constructs and their impact on the R&D uncertainty reduction measurement items are discussed below. The R&D uncertainty item data matrix is illustrated in detail in Appendix 25.

As discussed in the method chapter, the TAM3 information related to EA and MM market segments was presented to the R&D team in seven pieces. After each information item, a short discussion was held on the topic and each participant answered individually. Next, the capability of these seven TAM3 constructs and their market segment information in the context of reducing FFE uncertainty are discussed.

Differences between EA and MM in terms of Perceived Usefulness and Behavioral Intention to Use

When data on the impact of Perceived Usefulness on Behavioral Intention was presented to the R&D group, the information resulted as high uncertainty reduction on "Product concept definition" (53%, SD 22) and "Choice of technology" (52%, SD 16) technology uncertainty items. On the other hand, the R&D team described the effect on "Target market definition" uncertainty reduction as only 22% (SD 13). The uncertainty reduction of other items ("Product positioning" 39%, SD 22, and "What needs will new technology address" 44%, SD 22) are close to the survey average of 40%.

In a discussion among the R&D team members, it was stated that "I have a problem in a sense that Usefulness is something that someone is willing to pay. I don't see the earning logic so that who will make money. There are parallel applications providing same functionalities. I don't see that service robot will deliver any other added value except that for a short time it is a new cool thing that people will like to come see and use it." This statement very well describes the challenge related to "Target market definition" uncertainty. The R&D team continued: "However, this could be cool application in a bar where are hundreds of drinks and cocktails available. This thing can work as people in bar do not like to read that much." Further, the R&D team also argues the test setup during the early FFE stage, "Robot is tested in this application to do something simple that could be done other way as well," possibly affecting Perceived Usefulness.

Data related to Perceived Usefulness and its impact on Behavioral Intention among EA and MM creates a polarized response in the R&D team, as two uncertainty items are reduced remarkably and one uncertainty item almost not at all.

Differences between EA and MM in terms of Result Demonstrability and Perceived Usefulness

When data from EA and MM pertaining to the effect of Result Demonstrability on Perceived Usefulness was presented to the R&D team, the group responded that this information has stable but not a very strong effect on the FFE technology and market -based uncertainty reduction. All uncertainty reduction items have responses that range between 33%–44%. The highest rating is for "Target market definition" (44%, SD 23) and the lowest for "Choice of technology" (33%, SD 22). Other uncertainty reduction items are "Product positioning" (42%, SD 24), "What needs new technology will address" (40%, SD 24), "Product functionalities" (37%, SD 21), and "Product concept definition" (34%, SD 20).

The R&D argues that "if they (participants) have no difficulty in revealing the results, it implies the probably that the participant is capable of accomplishing the task"; moreover, they indicate with regard to market segment categorization that "if early adopters believe in the technology they would like it to work, and mass market thinks it don't work anyways." R&D specialists also argue the relation of Result Demonstrability and Perceived Usefulness as "I have a problem because I think that the usefulness of this kind of service robot application is that it is fun, and all the other functionalities are secondary. If participants feel positive about the results, can it be only because it is fun, not useful." When the discussion continued to the current market situation, it was said, "similar service robots currently in commercial settings are purely about the fun and enjoyment, and that is pretty much the only benefit of Pepper." The R&D team also touched upon the demographic setting of the FFE study: "It varies within countries as well, for example Japan vs Finland (are very different)."

Differences between EA and MM in terms of Robot anxiety and Perceived Ease of Use

Data from EA and MM related to the effect of Computer (Robot) Anxiety on Perceived Ease of Use results in only a mediocre effect on uncertainty reduction. The R&D team rated all technology and market-based FFE uncertainty reduction items with responses ranging between 36%–49%. The highest uncertainty reduction ratings are given for "Product positioning" (49%, SD 24), "Choice of technology" (47%, SD 23), and "Target market definition" (46%, SD 25). The lowest rating is for "Product functionalities" (36%, SD 26), "Clarifies what needs new technology will address" received a reduction percentage of (38%, SD 27), and "Helps product concept definition" (46%, SD 20).

The R&D team describes the Robot Anxiety in relation to the demographic setting in the FFE phase study by saying" "Robot Anxiety is measured among people with almost same age group" and suggest that "Robot Anxiety is probably higher when going out from the technical university," possibly because "higher age group people may have higher anxiety levels". On the other hand, an R&D specialist indicated that "the anxiety is not only about the age, as some 70-year-old people can be very friendly with service robots" and reminded that "therefore, in addition to the age, technical background also has an effect"

Differences between EA and MM in terms of Perceived Enjoyment and Perceived Ease of Use

When the EA and MM data related to the effect of Perceived Enjoyment on the Perceived Ease of Use was presented to the R&D team, it was revealed that the given information has a strong effect on the FFE technology and market uncertainty reduction. The uncertainty reduction of the robotics R&D team is particularly high on "Target market definition" (63%, SD 29), "Product positioning" (57%, SD 24), and "Product concept definition" (50%, SD 19) uncertainty items. Other constructs obtain ratings for "Clarifies what needs new technology will address" (42%, SD 25) and "Helps choice of technology" (45%, SD 31).

The R&D team discussed the challenges of the original TAM3 model in this robotics FFE setting: "I think the Perceived Enjoyment should not be linked to the Perceived Ease of Use but rather to the Perceived Usefulness construct. This is related to who pays the bill. In a cafeteria, they would invest in a service robot because it attracts people and brings usefulness in that way. It is not actually doing anything but being fun." The high level of uncertainty reduction associated with Target market definition is explained verbally in the following manner: "It definitely does clarify target market. Target market is Early Adopters—they may not buy it but will rent it for a short period of time. When it loses its flash, they will cancel the subscription. Those are the target markets." From a theoretical perspective, this is helpful, as Kotler and Keller (2012) note that a company must identify which market segments it is able to serve effectively as opportunity for its target market.

Clearly, Perceived Enjoyment and its relationship to the Perceived Ease of Use is one of the top-performing TAM3-based items of market information in terms of its capability to reduce uncertainty related to the FFE market and technology.

Differences between EA and MM in terms of Image and Perceived Usefulness

The data from EA and MM on Perceived Usefulness indicates a somewhat weak effect on the FFE uncertainty reduction. This construct is perceived as slightly challenging in the R&D team and results only in weak and mediocre ratings on uncertainty reduction (19%–38%). The highest rating is at "Product positioning" (38%, SD 21) and the weakest constructs are "What needs new technology will address" (19%, SD 18), "Choice of technology" (20%, SD 20), "Product functionalities" (22%, SD 17), and "Product concept definition" (24%, SD 17).

According to the R&D team, "It (Image) depends on country to country. Every country has different social status and conceptions of that. Scandinavia would be different to other areas." The robotics FFE TAM3 research was conducted in the Finnish language because it was assumed that this would enable capturing more MM representatives in the technical university setting, where mainly the university staff—including cleaning, household, and kitchen workers—represent the non-academic staff. However, the language selection had an impact on the homogeneity of the participants' nationality. The R&D team argues the relationship between Image and Perceived Usefulness, depending on "Whether people like being seen using the robot and how it impacts usefulness."

The EA and MM data related to the effect of Image on Perceived Usefulness does not contribute much to the reduction of market and technology uncertainty in the robotics FFE.

Differences between EA and MM in terms of Subjective Norm and Image

The EA and MM data with regard to the effect of Subjective Norm on Image also has a somewhat weak effect on uncertainty reduction in the FFE.

The information results only in weak and mediocre ratings on the uncertainty reduction (22-36%). The highest rating is given to "Product positioning" (36%, SD 24) and weakest to "Product functionalities" (22%, SD 16), "What needs new technology will address" (22%, SD 19), and "Product concept definition" (28%, SD 23). "Helps choice of technology" received an average rating of 30% (SD 28).

The R&D team described the Subjective Norm TAM3 construct in the robotics FFE setting in the following manner: "People that influence my behavior… that could mean friends that person came with to the setting."

Clearly, the EA and MM data pertaining to the SN effect on IMG does not have a strong effect on uncertainty reduction in the FFE.

The TAM3 model for All data

The last piece of TAM3-based information provided to the R&D team included the entire TAM3 model (all constructs at the same time) and all the market data (EA and MM not separated but included in the whole). The effect on uncertainty reduction was measuring somewhat high on the constructs "Product positioning" (56%, SD

18), “Product concept definition” (53%, SD 17), and “Target market definition” (51%, SD 21) and mediocre on the constructs “Product functionalities” (42%, SD 15), “What needs new technology will address” (44%, SD 23), and “Choice of technology” (47%, SD 24).

It is noted that the entire TAM3 model with all the market data clearly provides the R&D team with meaningful information that can be used to reduce the uncertainty during the FFE phase. This may be somewhat obvious as compared to the previous information items, as here the entire TAM3-model delivers a lot of information at once, as compared to the prior EA and MM TAM3 constructs dealt with individually.

Further, the R&D team questions the applicability of the TAM3 to the robotics FFE setting: “Does enjoyment or some other boxes matter—it is leading to something that is a dead end (not leading to future use)”. The team also discussed that “Would this model look different for Industrial robots, versus this study with service robot.” Participants suggested that “Ease of use not leading to the Future use—maybe that is because participants can use other methods than the robot to perform the task given in this example (find the lunch menus in cafeterias).” It must be noted that TAM3 setting in the robotics FFE is different from the typical TAM IT PD settings: “People using the robot for the first time may not have a concept of reference. Versus testing a new printer has a reference of a previous model etc.” The discussion within the R&D team indicates possible future topics for TAM3 robotics research: “I think the robot market will not be for consumers but for businesses—you may want to do similar study in the future for businesses” and “Japan is different market segments due to the original religion that everything has a soul—rock and computers as well.”

4.2.2 Answering research question 3: the TAM3 model’s ability to reduce uncertainty in the FFE

Here, the third research question is answered, as all the results for Phase 2 qualitative FFE R&D study have been thoroughly dealt with in the previous section, 4.2.1.

- **Research question 3:** How can TAM3-based market information be used to reduce the market and technology uncertainty in the FFE phase?

Market segment information based on the TAM3 model can clearly be helpful to the R&D team during the challenging but important FFE phase to reduce uncertainties related to market and technology. The average market uncertainty reduction in the R&D survey is 43% (SD 11) and that for technology-based uncertainties 41% (SD 9) on a VAS scale, where 0% represents uncertainty being "not at all" reduced and 100% represents uncertainty being "remarkably" reduced. Basically, there is no noticeable difference between technology and market -based uncertainty reductions on average. However, uncertainty reduction does vary substantially for different uncertainty items and TAM3 construct information combinations. These differences may arise due to the nature of the often chaotic FFE phase or because of special circumstances of robotics technology. It is noted that, on average, the TAM3 model-based market information data in the robotics FFE has a rather similar impact on the uncertainties related to both market and technology.

The overall uncertainty reduction in R&D is rather strong for TAM3 constructs. It is certain that the information items that the TAM3 model brings to R&D as well as the uncertainty metrics are relevant to FFE-based robotics development. The next items that are considered to possess less capability to reduce uncertainty and the items that have the highest impact on uncertainty reduction are summarized. Tables 20 and 21 below summarize the highest and lowest performing constructs in this research.

Table 20. TAM3 constructs with the highest uncertainty reduction

Construct	Market	Uncertainty item	Percentage
Robot Anxiety → Perceived Ease of Use	EA & MM	Target market definition	63%
Robot Anxiety → Perceived Ease of Use	EA & MM	Product positioning	57%
Whole TAM3	All	Product positioning	56%
Whole TAM3	All	Product concept definition	53%
Perceived Usefulness → Behavioral Intention (to use)	EA & MM	Product concept definition	53%

Table 21. TAM3 constructs with the lowest uncertainty reduction

Construct	Market	Uncertainty item	Percentage
Image → Perceived Usefulnes	EA & MM	What needs new technology will address	19%
Image → Perceived Usefulnes	EA & MM	Choice of technology	20%
Image → Perceived Usefulnes	EA & MM	Product functionalities	22%
Subjective Norm → Image	EA & MM	Product functionalities	22%
Perceived Usefulness → Behavioral Intention (to use)	EA & MM	Target market definition	22%

It must be noted that uncertainty items such as "Product Positioning" and "Product Concept Definition" are repeated at the Top Five list, and the "Product Functionalities" item is repeated in the Low Five list. It is also an important finding that the highest ratings for uncertainty reduction come from the data that introduced the information related to the difference between EA and MM (EA and MM data sets) and not from the entire market (All data set).

The TAM3-based approach can be recommended to be used to particularly reduce the uncertainties related to the definitions of Target market, Product positioning, and Product concept during the FFE phase of robotics NPD.

4.3 Discussion

This chapter discusses the research results in the context of the theoretical background of this thesis. The results are addressed below in three parts, following the structure of the research questions.

The service robot FFE phase project under study is an empirical example of the literature-backed view of how organizations dealing with radical innovations often face challenging tasks to translate new customer needs to technical features (Lynn and Akgun, 1998; Poskela, 2009). New-to-World Products (Figure 3), such as the service robot application, are described as those that are new to the market and also new to the company developing them (Booz, Allen, and Hamilton, 1982). From customers' perspective, product newness can be regarded as innovation attributes and adoption risks (Danneels and Kleinschmidt, 2001). The TAM3 constructs Subjective Norm, Perceived Usefulness, and Perceived Ease of Use indicate the main Behavioral Intention to Use construct, which targets to provide developing organizations an indication of technology adoption in the future.

4.3.1 The applicability of the TAM3 to robotics FFE (RQ1)

The TAM has become a dominant model in investigating the factors affecting users' acceptance of technology (Marangunic and Granic, 2015). This research focuses only on the applicability of TAM3 model, which is the latest version of TAM. Research Phase 1 reveals several findings related to how the TAM3 model functions differently during the robotics FFE phase as compared to its original setting in the PD phase IT environment (Venkatesh and Bala, 2008). A majority of the TAM3 constructs perform as expected based on the original model, but five out of the thirteen paths do differ. The key task during the FFE phase from the perspective of the technology development organization is to reduce uncertainty (Moenaert et al., 1995). The FFE phase differs substantially from the PD stage due to its experimental and often chaotic nature, with high uncertainty and an unpredictable nature (Koen et al., 2001).

In the original TAM3 model, there are three major inner constructs formed by Perceived Usefulness and Perceived Ease of Use, which are connected to the Behavioral Intention to Use with positive effects (Venkatesh and Bala, 2008). The TAM presumes a mediating role of these variables in a complex relationship between external variables and potential use of the system (Marangunic and Granic, 2015). The results reveal that when TAM3 is applied to the robotics FFE phase, Perceived Usefulness has a strong positive effect on Behavioral Intention to Use, but Perceived Ease of Use is not connected to either Perceived Usefulness or Behavioral Intention to Use. This finding makes the TAM3 model in robotics FFE partially limp, as a major part of the variables lose their connection to the Behavioral Intention to Use due to the broken link from Perceived Ease of Use toward Behavioral Intention. The concept of usefulness may be different for the users of service robots than traditional IT equipment. During the Research Phase 2, robotics R&D staff specialists pointed out that perhaps the advantage of service robots is that the use of those is fun and perhaps other functionalities are secondary. This is clearly a topic for future research—why does Perceived Ease of Use not contribute to Behavioral Intention when TAM3 is applied to the robotics FFE. Perhaps the early stage and low maturity of the application prototype under testing has its limitations, which result in no connection between ease of use and future use of the device. The service robot prototype has challenges in terms of hearing in noisy environments and occasionally end-users need to repeat their instructions several times when communicating with the application. However, this may not solely explain the situation of Perceived Ease of Use, as the other fundamental construct of Perceived Usefulness remains connected to the Behavioral Intention to Use.

The recent TAM research within the field of robotics technology (Bröhl et al., 2011; Lotz et al., 2019; Chu et al, 2019; Yagoda, 2013) has not highlighted these aspects. The reason is probably related to the fact that recent research has been mainly conducted either with industrial robots, hospital robots or UGVs. A common aspect of these segments is that a robot performing a job and people operating the robot can be considered to be functional in an organization where the technology is planned to be used. Such a setting is more typical for the original TAM models compared to the service robot setting of the current research, where use of the robot is voluntary, and the robot is not related to performing a job in an organization. Moreover, recent research has been conducted with more mature robot applications, which indicates a setting in a more mature PD phase of an NPD project than that in the current research, which took place during the early FFE phase.

Further, the construct of Subjective Norm has a strong positive effect on Image, but in a different manner than that in the original TAM3 model, where there is no effect on Perceived Usefulness or Behavioral Intention to Use. Individuals' motivation to adopt an innovation can come from the meaning that an innovation holds, a symbolic value (Eveland, 1986). When adopting a new technology, social risk can lead to loss of social status by making an adoption mistake (Gatignon and Robertson, 1991).

In the robotics FFE phase, Computer (Robot) Playfulness does not have a positive influence on Perceived Ease of Use, as expected on the basis of the original TAM3 model. Computer (Robot) Playfulness refers to "the degree of cognitive spontaneity in microcomputer interactions" (Webster and Martocchio, 1992). Based on the conducted research, participants' playfulness with the service robot prototype application does not affect the Perceived Ease of Use of the device. This is different from the original TAM3 model and can be one reason behind the unexpected broken link with Behavioral Intention. Perhaps, the bad hearing of the robot prototype impacts the robot's playfulness and its relation to the Perceived Ease of Use.

Output Quality has a stronger positive effect on Perceived Usefulness than Image or Result Demonstrability. Output Quality implies the extent to which the technology can adequately perform the required tasks, Image refers to a user's desire to maintain a favorable standing, and Result demonstrability describes the production of tangible results (Davis, 1989; Davis, 1993; Venkatesh and Davis, 2000). Based on the conducted research, the quality of task performance has a greater impact on Perceived Usefulness over the production of tangible results or maintaining a favorable standing. In this prototype application under testing, participants are investigating the campus lunch menus by communicating with the service robot; therefore, the quality of this task performance positively affects the Perceived Usefulness of the device in this setting.

Perceived Enjoyment has a strong positive effect on Perceived Ease of Use. Perceived Enjoyment refers to the extent to which the activity of using the system is perceived as being an enjoyable one apart from any performance consequences (Venkatesh, 2000). Perceived Enjoyment is strongly linked with Perceived Ease of Use, and this is similar to the original TAM3 research.

Further, among industrial robots, improved output quality and enhanced enjoyment have been recently recognized as two factors that foster the acceptance of HRC (Lotz et al., 2019).

Computer (Robot) Anxiety has a negative effect on Perceived Ease of Use, as expected based on the original TAM3 model. Computer (Robot) Anxiety indicates the degree of an individual's apprehension or even fear when faced with the possibility of using computers (robots) (Venkatesh, 2000). The original TAM3 research supports the finding that anxiety in using the device under testing has a negative impact on the perceived ease of use of the device. Within industrial robotics (Lotz et al., 2019), "robot anxiety" is among the top-three key anxieties from an employee's viewpoint.

4.3.2 TAM3 FFE: Early and late market differences (RQ2)

The findings of the conducted research in Phase 1 suggest that there are several differences in how TAM3 applies to the EA and MM segments during the robotics FFE phase. This is not surprising then, when examining the entire market from the perspective of innovation adoption and its diffusion (DOI) theory. In the DOI process, a few members of a social system first adopt an innovation based on their level of risk-taking when adopting a new innovation (Rogers, 1962).

Among EA, Result Demonstrability has a strong positive effect on Perceived Usefulness, but this link does not exist in MM. During the first steps of the innovation adoption process, an individual is exposed to the existence of the innovation and gains some understanding of how it functions (Rogers, 1962; Rogers, 2002). From the theoretical viewpoint of the DOI, it could be argued that the EA have already gained some understanding of how the technology functions and formed a favorable attitude towards the innovation based on the results they are able to get using the robot application prototype. Perhaps the MM representatives were not able to obtain satisfactory results using the technology prototype in a manner that would have impact on the perceived usefulness due to their lower level of willingness to take risks in innovation adoption (Valente, 1996). The innovation-decision process is a mental five-step process that an individual moves through, first from knowledge of an innovation to forming an attitude toward the innovation, and then to a decision to adopt it and confirm the decision (Rogers, 2002).

Robot Anxiety has a moderate negative effect on Perceived Ease of Use among MM representatives, but this effect does not exist among EA. The lack of robot anxiety among EA may be explained by their high willingness of risk-taking, constant interest in new ideas, and ability and motivation toward new innovations (Rogers, 2002; Ferlie et al., 2001). Perhaps EA are already familiar or so open-minded toward service robots, that Robot Anxiety does not impact their view on Perceived Ease of Use of the application.

The positive effect of Perceived Enjoyment on the Perceived Ease of Use is stronger among EA (strong) than MM (moderate). In the theoretical background, the early market segment (innovators) are described as venturesome and eager to try new ideas compared to the late market segment, which approaches innovations with a skeptical and cautious air and, rather, follows more than leads the DOI process (Rogers, 1962; Rogers, 2003). It is possible that the venturesome minds of the early adopters vs. the skepticism of late adopters impact how the Perceived Enjoyment affects the Perceived Ease of Use of the service robot application prototype.

Further, the positive impact of Perceived Usefulness on Behavioral Intention is stronger among the MM representatives than the EA. This finding regarding the TAM3 model in the robotics FFE phase is rather surprising and cannot be fully explained from the perspective of the DOI theory. This opens great new possibilities for future research. It can be argued that EA find the service robot application rather usable as a cool new innovation irrespective of how useful it is perceived to be based on their test usage. Perhaps the MM representatives are not so much into the use of the new innovation itself that they feel they need the experience of perceived usefulness to justify the future use of the service robot application.

The variance of the TAM3's inner constructs is explained more (higher R^2 values) with EA than with MM representatives. Therefore, it can be stated that in the robotics FFE phase, the TAM3 performs better with EA data compared to MM data. As EA has higher R^2 values than MM it reflects that early adopters are more consistent and coherent as a subgroup than the mass market which consists of many kinds of individuals.

The way how EA and MM subgroups are split naturally has an effect on the results of the research. This research used eight market segment categorization parameters to estimate the participants' attitude towards new technologies, described in-detail in the Chapter 3. Other type of participant split for EA/MM might have resulted in different results. This opens new research avenues for future studies on service robots.

4.3.3 TAM3 FFE uncertainty reduction (RQ3)

High market uncertainty results in stepping into new markets with lack of information about customers' needs and market characteristics, whereas high technology uncertainty can be explained by which product structures and functionalities are not understood (Poskela, 2009). Successfully operating NPD teams need to be able to perform uncertainty reduction during the FFE phase of the innovation process (Moenaert et al., 1995). Kim and Wilemon (2002) found that it is critical to reduce uncertainty by decreasing complexity in idea development. Different methods to reduce uncertainty, like conducting ethnographic studies, have been suggested by Rosenthal and Capper (2006). According to research by Verworn, Herstatt, and Nagahira (2008), intelligent planning and the reduction of technical and market uncertainty explain subsequent success. The recent research from Akbar and Tzokas (2013) describes that the early involvement of all departments and reduction of market and technical uncertainty positively affects product development success.

The findings from Phase 2 of the research reveal that market and technology-based uncertainty can be reduced during the very important and challenging FFE phase by bringing the R&D team information based on the TAM3 model in the early and late market segments. The findings of the conducted research reveal that uncertainty reduction is not equal among all the centric market and technology uncertainty items. Moreover, the information related to the different TAM3 construct items perform differently in the uncertainty reduction items. This is not surprising as the TAM3 model includes constructs that are different in nature, which can influence the different uncertainty aspects.

The early and late market segment information of the effect of Computer (Robot) Anxiety on Perceived Ease of Use reduces the uncertainty of "Target market definition" by 63% (on scale 0% = "not at all" – 100% = "remarkably"). Similarly, the early and late market segment information of the effect of Computer (Robot)

Anxiety on Perceived Ease of Use reduces the uncertainty of "Product positioning" by 57%. Robot Anxiety negatively affects the Perceived Ease of Use only in the MM segment, which gives the R&D team means to work on the device target market and positioning. It is obvious that this finding helps reduce the FFE uncertainty, particularly related to "Target market definition" and "Product positioning."

Market segmentation process breaks up the entire consumer market into sub-markets or segments that have similar consumer profiles, homogeneous needs or wants, and similar buyer characteristics (Pendleton et al., 1995). From a marketing perspective, market segmentation is necessary to identify target customers, and new products must be positioned for target customers (Chen and Chen, 2014). "Target market definition" and "Product positioning" are closely related to the positioning of new products for target customers; therefore, it is remarkably important that the uncertainty arising from these sources of uncertainty in the FFE-stage can be reduced by TAM3 data.

The results show that the early and late market segment information of the effect of Perceived Usefulness on Behavioral Intention to Use reduces the "Product concept definition" uncertainty by 53%. The findings suggest that market uncertainty item "Product positioning" and technology uncertainty item "Product concept definition" show up repeatedly in the list of most reduced uncertainty items. The entire TAM3 model for All data (no market segmentation) is also perceived as very helpful to reduce the FFE uncertainties related to "Product positioning" (56%) and "Product concept definition" (53%).

4.3.4 Integrating VoC in the FFE phase

Predevelopment activities are important, as they qualify and define the project by providing answers to key aspects such as the economic attractiveness of the project, target customer definition, product positioning, features and attributes, and product differentiation (Cooper, 1990). The service prototype application was tested during its early FFE stage to obtain early customer feedback about its technical acceptance and the capability of the TAM3 to reduce technology and market uncertainty. Moenaert et al. (1995) suggested that the key task during the FFE is to reduce uncertainty and that this can be the best achieved by close cooperation between R&D and marketing.

In the stage-gate system, the project under study can be placed at "Concept" phase (Figure 10), including "Idea" and "Initial Screen" (Figure 11) activities. Cooper

(1990) highlights that the most important steps of the new product process, that usually separate winners from losers, lie in the early stages that precede actual product development. However, the challenge when testing a technology in its very early phase is the maturity of the built prototype—how well does it represent the actual product after an upcoming NPD phase?

The discontinuous product innovation process (Figure 13) integrates the "Formative Prototype" and "Lead User Testing" later in the design phase (Veryzer, 1998). This is convenient when considering the disruptive nature of the product under development and the immature early stages for such "New to the world" technologies. However, a disadvantage of collecting the user feedback in the later phase is the longer lead-time for the feedback and the need to justify R&D investments without proof or data to back up the decision. The Formative prototype phase in the discontinuous product innovation process enables the implementation of subsequent activities like opportunity analysis and target market selection (Veryzer, 1998).

Another challenge of the early technology acceptance testing is the maturity of the technology and prototype as well as the expectations of the management. When a project is getting to the next gate in the development process, its funding is estimated again (Cooper, 1998). Occasionally, projects need a "champion" or "sponsor" type of visionary (Figure 15) within the organization to survive through the "Valley of Death" (Figure 14), where a project meets the challenging gap between the research resources and the actual PD resources (Schoonmaker et al., 2013).

In the current research, Phase 2 validated the collected technology acceptance data from an actual R&D team to obtain confirmation for the applicability of the collected data of the early FFE prototype. In technology-driven companies, marketing typically captures the consumer's needs and interprets them for engineering functions (Figure 24); however, it is rather recommended that engineering functions must be more directly engaged with their customers (Yoon and Jetter, 2015). In the conducted research, the setting was simulated in a way that the technology acceptance data collected in Phase 1 was prepared by the marketing function (the researcher) and communicated to the engineering function (robotics R&D team) in Phase 2. During the research process, the R&D function was not in direct contact with the customers. The original TAM model has been criticized to provide only little actionable guidance to practitioners (Faqih and Jaradat, 2015). Connecting R&D with the customer would open new research avenues for future studies.

5 CONCLUSION

The current research applied the TAM3 to the early FFE phase of a robotics NPD project. TAM3-based VoC was collected from over a hundred end users who tested the service robot application under development. The test group was divided into two market segments, one formed by innovators and early adopters of new technology and the other group comprising mass market and late adopters of technology.

The research sought answers to determine the extent to which TAM3 can be applied to the often chaotic FFE phase of the NPD project. To this end, this study employed the TAM3 model to a new setting both in terms of the timing from PD to FFE and in terms of technology from IT to robotics.

5.1 Key findings and contributions

The findings of this study suggest that there are fundamental differences in the TAM3 functionality in the robotics FFE compared to its original IT setting (Venkatesh and Bala, 2008). In particular, some of the inner and outer constructs of the TAM3 model perform differently in the new setting. This information is useful for practitioners planning to apply the TAM3 model in a different context than the IT environment. When the TAM3 model was applied in the robotics FFE setting, the model's inner construct of Perceived Ease of Use (PEoU) was found to not have a significant effect on Perceived Usefulness (PU) and Behavioral Intention (BI), as expected in the original context. Further, Subjective Norm (SN) does not have a significant effect on either PU or BI. These findings may have background in the fundamental differences between the early and fuzzy FFE phase compared to more stabilized PD phase, the differences between service robot technology versus IT technology, or properties of consumer type of test participants compared to workers of an organization. Also, it is possible that sample size of the research, the chosen test application, or the technical properties of the early technology prototype have effect on the results. These cause research limitations, discussed in chapter 5.3, and also open new research avenues, described in chapter 5.4.

More interestingly, the study results also indicate that there are fundamental differences between the EA and MM segments when it comes to certain outer constructs of the model. This is useful to consider when applying the TAM3 model in a context where both the EA and MM group representatives are present. Further, Result Demonstrability (RES) has a strong positive effect on PU within the EA segment, but the effect is not significant among the MM representatives. Robot Anxiety (CANX) has a moderate negative effect on PEoU among the MM representatives, but the effect is not significant among the EA. Among the EA, the TAM3's inner constructs are better explained than within the MM segment, with the biggest difference being in PU (MM 35% and EA 62%).

In management theory of uncertainty and equivocality, high uncertainty results leads to R&D in numerous problems that require defined questions that managers must seek answers to and provide data for (Daft and Lengel, 1986). The capacity of TAM3-based market information to reduce the commonly present uncertainty of the FFE phase was measured by a ten-person robotics research and development team. The study findings suggest that the TAM3-based information from EA and MM segments can reduce the often-experienced uncertainties related to the market and technology. This information is useful for the practitioners working in the FFE phase of an NPD project (in the R&D team) who are seeking methods to reduce market- and technology-based uncertainty. In general, a remarkable cause of new product failures and delays is not being able to define the product concept, target market, benefits, positioning, requirements, and features well before beginning product development (Cooper, 2005). A company must identify which market segments it is able to serve effectively, and which segments offer the greatest opportunities as its target markets (Kotler and Keller, 2012). The research results reveal that the market information derived from different TAM3 constructs perform differently on different technology and market uncertainty items. The uncertainty reduction capability of the "Perceived Enjoyability" and "Perceived Ease of Use" constructs was particularly high on the "Product positioning" uncertainty item. Moreover, the information related to the "Perceived Usefulness" and "Behavioral Intention" constructs has a substantial effect on uncertainty reduction on "Product concept definition" and "Choice of technology" items. The weak capability of uncertainty reduction is evident in the effect of TAM3 constructs "Image" and "Perceived Usefulness" on "What needs technology will address" and "Choice of technology". Further, the "Subjective Norm" and "Image" aspects are challenging in terms of uncertainty reduction, particularly on the "Product functionalities" and "What needs technology will address" items.

Successfully operating NPD teams must perform uncertainty reduction during the FFE phase with regard to user needs, technology, competition, and the resources required to create a commercially successful product (Moenaert et al., 1995). The conducted research gains understanding that the TAM3-based market segment information can be useful in FFE uncertainty reduction. The results offer insights that some of the TAM3 constructs have a higher capability of uncertainty reduction than others. These differences from the original TAM3 setting can be related generally to the FFE phase (compared to the typical TAM PD setting) or particularly to the robotics technology field (vs. a typical TAM IT setting) and open interesting new research avenues for future studies.

5.2 Reliability and validity

The reliability and validity constructs are discussed for the research steps conducted in Phases 1 and 2 to evaluate the results and analyses of the dissertation. Reliability is the extent to which an experiment or measurement is able to yield the same results on repeated trials, implying consistency of the results over repeated observations (Carmines and Woods, 2005b; Bollen, 1989, Drost, 2011). Validity indicates whether a construct is actually able to measure the concept that it is being used to represent in a research (Rosenthal and Rosnow, 1991; Carmines and Woods, 2005b). Several types of validity are appropriate in social science research (content validity, criterion-related validity, and construct validity) and are discussed here in the context of the conducted research (Carmines and Woods, 2005b).

Content validity

Content validity focuses on how an indicator adequately and comprehensively represents what it is supposed to measure (Rosenthal and Rosnow, 1991; Carmines and Woods, 2005b). At the center of the assessment of content validity is consulting the literature on the subject in order to select the research indicators that reflect the meaning of particular aspects of the phenomena under evaluation (Carmines and Woods, 2005b).

In order to ensure the deep theoretical background in questionnaire development, a comprehensive literature survey was conducted. This includes chapters related to the adoption and diffusion of innovation, market and technology uncertainty, NPD, FFE, VoC, and theoretical models for the acceptance of new technology. Carefully studying the theoretical concepts enabled the formation of a direct theory of references to the indicators of the questionnaire.

Criterion-related validity

Criterion-related validity touches the correlation between a measure and the criterion variable of attention (Rosenthal and Rosnow, 1991; Carmines and Woods, 2005b). If the correlation is high, the measure is valid for the criterion and useful for the particular purpose (Carmines and Woods, 2005b).

In order to ensure that the criterion-related validity in this research was as high as possible, the indicators (illustrated in Appendices 7 and 8) used during Phases 1 and 2 were selected so that those have deep ties to the existing theory under discussion. The theory utilized in the development of the Phase 1 questionnaire indicators is explained in section 2.1.2 entitled "Innovation adoption and diffusion" and section 2.5.5 entitled "The technology acceptance model 3."

The technical part of the Phase 1 survey closely follows the principles of the TAM3 original framework (Venkatesh and Bala, 2008). In Phase 2, the grounds of the questionnaire items in theory are explained in Table 7 in section 3.3.1 entitled "Phase 2 questionnaire development."

Construct validity

Construct validity targets that empirically observed outcomes are consistent with theoretical predictions, thereby resulting in the degree of how well a measure fits within existing hypothesized relationships with other measures (McDonald, 2005; Carmines and Woods, 2005b; Rosenthal and Rosnow, 1991). The fundamental feature of construct validation is theory and there must be a theoretical framework that enables the validation of the concept (Carmines and Woods, 2005b).

Three steps must be performed to ensure construct validity in the research: describing the theoretical relationships between concepts, studying the relationships, and interpreting the empirical evidence for how the research clarifies the construct validity of the question measure (Carmines and Woods, 2005b).

In this research, the theoretical relationships are derived based on the theory documented in Chapter 2. The selected constructs closely follow prior research on the TAM3. The derived results have been reflected using prior research and discussed in section 4.1.4 entitled "Answering research question 1," section 4.1.5

entitled "Answering research question 2," section 4.2.2 entitled "Answering research question 3," and section 4.3 entitled "Discussion."

Reliability

The concept of reliability within the psychometric tradition refers to the random (non-systematic) error in the measurement (Rosenthal and Rosnow, 1991; Alwin, 2005). In order to deal with measurement reliability, researchers often either replicate multiple measurements or employ similar, although not identical, questions or indicators and then examine the correlation or covariance properties of the data collected (Alwin, 2005).

Random error is stated to be present in any measure, whereas reliability focuses on the assessment of random error and estimating its consequences (Carmines and Woods, 2005a). The internal consistency method is a commonly used basic method for estimating the reliability of empirical measurements, and the most popular measure of internal consistency is Cronbach's alpha (Carmines and Woods, 2005a).

To a certain extent, random errors are always present in measurements when conducting a quantitative research. In this research, these errors are minimized by performing data collection with extreme care and ensuring that a large group of participants (130 pcs) are included in the survey. During Phase 1, the data was collected by several research assistants to minimize the possible systematic errors related to that research step.

A comprehensive set of tests for data reliability was implemented during Phase 1 following the PLS-SEM guidelines given by Hair et al. (2017). The test criteria for internal consistency reliability, convergent reliability, discriminant validity, collinearity, the predictive power of the structural model, and effect size are described in section 4.1.2 entitled "Phase 1: data reliability and validity test results."

5.3 Limitations of the research

This dissertation studied the feasibility of applying the TAM3 to the FFE phase in robotics. The research setting and method set limitations that must be considered in the interpretation of the results. The multi-method research is conducted in two phases and the limitations of both phases are discussed separately.

Phase 1 of the quantitative research consisted of a collection of information pertaining to EA and MM segments from 121 end-user participants of an FFE phase service robot application. There were certain limitations in this research setting. The data collection took place at Tampere University of Technology during March 2018. Data was collected during only on one day and, thus, it is possible that there could be some sort of bias in the demographics when data is collected during such short period of time. Further, the age distribution of the test group sets a certain bias of a younger population. The age group of 20–29 years constitutes 54% of the participants. This research is an experiment of the population at Tampere University of Technology, including students, researchers, staff and visitors. The research targeted to collect data from a diverse group of people, also including tech savvy individuals who are tech sophisticated more than the average population. One limitation of the research is that there cannot be guarantee how well this sample will represent the actual population of service robot end users after all the future research and development activities leading to successful product launch. In this research, the EA group had 39 participants and the MM representative segment had 82 participants. The EA group (32%) formed by the early adopters and innovators of technology is remarkably higher than that typically described in literature (16%), double in its relative size (Rogers, 1962), which is largely explained by the research setting at the technical university. The EA group has only 39 participants which sets some limitations for the analysis method. SmartPLS (PLS-SEM) used in this research is proven to work well with relatively small data sets (Sarstedt et al., 2014; Reinartz et al., 2009). Also, the method for categorization of early adopte and mass market segments may have effect on the research results. This opens also avenues for future research to study different categorization parameters for robotics early adopters. The Phase 1 questionnaire was in Finnish, thereby enabling to also capture late adopters and laggards, as it was expected that the participants who work at the university cafeteria, cleaning staff, etc., were expected to give a different opinion than the tech-savvy students and researchers. However, the selection of Finnish language set some limitations to the demographics in the sense of it not being international. During the Research Phase 2, in the robotics R&D specialist feedback, it was also noted that the regional setting may have an effect on the research results as markets are different and cultural properties may affect the adoption of robotics technology. Further, the "lunch menu" use case, which was tested as the service robot application, utilizes the typical features of service robots under development, such as speech recognition, artificial speech, touch user-interface, and body movements. Nevertheless, the tested use case represents only a narrow scope of all the future capabilities of robotics; therefore, it must be understood that there are certain limitations when applying the results of the research in action. Although test participants were given a very concrete and topical task, “to use the robot to investigate the lunch menus of the cafeterias at the university campus”, it cannot be overruled that some participants took part because of their curiosity towards the robot. The motives of participants were not measured; what is the actual role of the need to solve the lunch menu question or the curiosity towards the technology under testing. Non-response bias is also one topic that may affect academic research. During the research, team tried to prevent the curiosity effect from dominating the research participation by “collecting” test participants that were not natively drawn to the research setting. Research assistants offered participants small incentive in a form of a restaurant voucher to draw wider demographics to the research sample. Many non-responding individuals were in a hurry or needed to follow their friends who decided not to take part in the research. There is only a limited window at University hallway in-between classes and not everyone had time to stop to the research setting.

Phase 2 of the qualitative research included testing the collected TAM3 EA and MM FFE data by a robotics R&D team. The team size of 10 persons is typical in FFE projects; in this sense, a typical FFE NPD R&D setting was well represented in this research. However, from a statistical viewpoint, the 10 people do not offer such a significant means for numerical analysis. Therefore, Phase 2 was more qualitative in nature. The questionnaire in Phase 2 was in English, which enabled the participation of the international members of the robotics R&D team.

The robot was not permanently placed in its test setting at the Tampere University of Technology; therefore, the relationship of the TAM3 Behavioral Intention to Use and the actual use of the robot was not possible to measure. This sets limitations to the interpretation of the TAM3 results in the sense that the link of BI and actual use cannot be evaluated.

5.4 Suggestions for future research

Conducting the current research led to the discovery of a few new possible research avenues. In particular, it was found that the TAM3 model as is does not perfectly match the investigated robotics technology project in the FFE phase. Some of the centric TAM3 construct links such as “Perceived Ease of Use → Behavioral Intention to Use” and “Perceived Ease of Use → Perceived Usefulness” are not active in the robotics FFE phase. Future research must be conducted to investigate these issues. Perhaps it is common to all FFE phase projects that the Perceived Ease of Use does not affect Behavioral Intention, or perhaps it is more of a robotics technology area phenomenon. A possible interesting new research direction would be forming a new "FFE-TAM" model that fits the best to the fuzzy and unclear characteristics of the early FFE phase of the NPD project. More precisely, it would be beneficial to study the reasons underlying the non-significant inner construct links and to investigate if constructs such as Computer (Robot) Playfulness and Perceived Enjoyment alternatively have a direct effect on Behavioral Intention when TAM3 is applied to the FFE phase, in which the technology demonstrator prototype is not yet a fully developed mature product and the target market is not yet fully established, as in most of the cases where TAM models are applied (such as IT HW or SW applications).

Another explanation for the TAM3 model not fitting perfectly in the conducted research setting could be the unique characteristics of robotics technology. This opens new interesting research directions in forming a new "Robotics TAM" that the best fits explaining robotics adoption. It should be further studied, if the Playfulness (CPLAY) construct is related directly to Behavioral Intention (BI) or other constructs, not via Perceived Ease of Use (PEOU), when TAM3 is applied to robotics and particularly in the early front-end of innovation phase. The evaluation of the TAM3 model can be continued with other type of robots. In the conducted research, the device under testing was a service robot—how would TAM3 apply to the context of an industrial robot that might be closer to the origins of the TAM in commercial IT systems?

Research also revealed differences in TAM3 behavior in the robotics FFE phase between the data groups of early adopters of technology and the mass market representatives. Studying the root causes behind these research findings related to the TAM3 model FFE differences for EA and MM opens interesting future research possibilities. Is the Computer (Robot) Anxiety effect related to the Perceived Ease of Use non-significant among EA because these market representatives do not experience Robot Anxiety? Or is the Robot Anxiety in FFE connected to, for example, Behavioral Intention rather than Perceived Ease of Use? Moreover, why does Result Demonstrability not have a significant positive effect on Perceived Usefulness among the MM representatives? Is this due to the capability of MM representatives to experience the results or usefulness of the early robot technology prototype?

In addition to the TAM3 approach, also its predecessors or for example UTAUT model constructs could also be tested at the FFE. For example, the "Hedonic motivation" construct in UTAUT2 would be interesting to include in future research in FFE studies for novel new technologies. The UTAUT3 model presents a new construct of "Personal Innovativeness", which could also offer a new perspective in explaining technology adoption during the early FFE phase.

This research opens also avenues for further research on innovators and early adopters. The market segmentation variables can be further evaluated for the robotics technology area and for the early FFE phase where the actual product is not yet in mass market and segmentation may rely more on individuals' personal properties and attitudes towards technology.

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APPENDIX 1. OVERVIEW OF PRIOR EMPIRICAL PRODUCT INNOVATIVENESS RESEARCH

Adapted from Danneels and Kleinschmidt (2001).

Table 1
Comparative overview of prior empirical product innovativeness research[1]

Study	Measure of product innovativeness used	Technological and marketing dimensions explicitly distinguished?	Innovativeness from whose perspective	Dependent variables	Causal role of product innovativeness
Ali [1]	Modified Booz, Allen, and Hamilton typology	No	Not explicitly distinguished	Market performance	As moderator
Ali, Krapfel, and LaBahn [2]	Newness to customers	N/A	Customers	Cycle time	As independent variable
Atuahene-Gima [4]	Newness to customers (radical vs. incremental dichotomy) Newness to firm (radical vs. incremental dichotomy)	No	Firm and Customers	Market performance and Project performance	As moderator
Atuahene-Gima and Evangelista [5]	Modified Booz, Allen, and Hamilton typology (dichotomy)	No	Not explicitly distinguished	New product performance	As independent variable
Cooper[14]	Seven dimensions that reflect innovativeness	Yes	Firm and Customers	Product success rate	As independent variable
Cooper and de Brentani [15]	Synergy, newness to the firm, and newness to customers	No	Firm and Customers	Product success rate	As independent variable
Cooper and Kleinschmidt [18]	Individual items (dimensionality not assessed)	N/A	Firm	Go/No Go decision	As independent variable
Cooper and Kleinschmidt [19]	Modified Booz, Allen, and Hamilton typology and individual items relating to familiarity and synergy (dimensionality not assessed)	No	Not distinguished in typology measure and firm perspective in items	Product success rate	As independent variable
Danneels [20]	Two-dimensional typology based on customer and technological firm competences	Yes	Firm	N/A (interpretive study)	N/A (interpretive study)
Gatignon and Xuereb [23]	Newness of technology incorporated in product	No	Not explicitly distinguished	New product performance	As dependent and independent variable
Green, Gavin, and Aiman-Smith [25]	Four dimensions based on technology and business uncertainty	Yes	Not explicitly distinguished	Go/No Go decision Project lifespan	As dependent and independent variable
Kleinschmidt and Cooper [29]	One-dimensional classification (low, moderate, high)	No	Not explicitly distinguished	Product financial performance	As independent variable
Meyer and Utterback [35]	Individual items (dimensionality not assessed)	Yes	Firm and Customers	Cycle time	As independent variable
More [38]	Individual items (dimensionality not assessed)	N/A	Firm	Go/No Go decision	As independent variable
Olson, Walker, and Ruekert [42]	Dichotomy (really new vs. incremental)	No	Not explicitly distinguished	Project and and process outcomes	As moderator
Schmidt and Calantone [46]	Dichotomy (two experimental conditions)	No	Not explicitly distinguished	Go/No Go decision	As independent variable
Sivadas and Dwyer [48]	Dichotomy (incremental vs. radical)	No	Not explicitly distinguished	New product success	As independent variable
Song and Montoya-Weiss [49]	Dichotomy (really new vs. incremental)	No	Not explicitly distinguished	Product financial performance	As moderator
Song and Parry [50, 51]	Marketing and technological synergy	Yes	Firm	Product financial performance	As independent variable
Souder and Jenssen [52]	Market familiarity	Yes	Firm	Commercial success	As moderator
Souder and Song [53]	Market familiarity	Yes	Firm	Commercial success	As moderator
Swink [55]	Technological innovativeness	Yes	Firm	Development time, design quality, financial performance	As moderator
Yoon and Lilien [62]	Dichotomy (original vs. reformulated)	No	Not explicitly distinguished	Market share	As moderator
Zirger and Maidique [63]	One-dimensional synergy with firm competences	No	Firm	Product success rate	As independent variable

[1] This overview only includes empirical studies that have treated innovativeness at the product level. It does not include research conducted at the aggregate new product program (i.e, SBU or firm) level. This overview of past research is extensive, but inevitably not exhaustive.

APPENDIX 2. EMPIRICAL STUDIES OF BEST FRONT-END PRACTICES

Adapted from Koen, Bertels and Kleinschmidt (2014).

Authors	Sample	Type	Method	Dependent Construct	Major Conclusions
Bacon et al. (1994)	6 Fortune 100 companies in U.S.	Case	Asked managers to compare success/ failure insights across 7 successful and 5 unsuccessful incremental projects.	Success and failure	Quality of product definition entering the subsequent development process was linked to overall product success.
Moenaert et al. (1995)	40 Belgian companies w/ median sales of $62 million	Survey	Analyzed 40 successful and 38 failed incremental projects.	Paired comparison between successful and failed projects in the same company	Successful front-end project teams minimized project uncertainty by enhancing exchange between marketing and R&D.
Khurana and Rosenthal (1998)	12 multinational companies, 8 from US and 4 from Japan	Case	Studied 10 incremental and 2 radical projects and the business unit practices.	Activities that preceded the Stage-Gate decision and the types of problems the companies faced	Successful organizations follow a holistic approach that integrates product strategy, portfolio, concept development, business justification, resource planning, and executive decision making.
Langerak, Hultink, and Robben (2004)	126 Dutch firms with mean sales of $31 million	Survey	Analyzed front-end organizational practices of firms that had introduced new products in the last 12 months.	17-item construct based on overall new product performance	Strong correlation was found between product performance and both strategic planning and idea generation, but no correlation was seen between idea screening and business analysis. Market orientation was positively related to proficiency of strategic planning and idea generation, but not to product performance.
Verworn, Herstatt, and Nagahira (2008)	475 Japanese companies with 5–70,000 employees	Survey	Analyzed development process for the last product brought to market, including both incremental and radical projects in combined analysis.	2-item construct that measured degree of agreement between planned and actual financial and personnel resources and 5-item effectiveness construct that evaluated how well project met profit and customer targets	Correlation was found between reduction of market and technical uncertainty and effectiveness. Reduction of technical uncertainty was correlated with efficiency, but not with reduction of market uncertainty.
Verworn (2009)	175 German companies with 5–6,700 employees	Survey	Analyzed development process for the last product brought to market, including both incremental and radical projects in combined analysis.	2-item construct that measured degree of agreement between planned and actual financial and personnel resources and 3-item construct to measure satisfaction with process, results, and team	All of the front-end constructs were correlated with fewer project changes and better team communication. Reduction of technical uncertainty was correlated with efficiency, but not with reduction of market uncertainty.
Poskela and Martinsuo (2009)	133 Finnish companies with >50 employees	Survey	Evaluated the role of management control in the front end.	4-item strategic construct that measured degree to which a new product opens up new opportunities or markets	Input control (selecting people to run the project, defining goals for the project) and market and technology novelty were correlated with success. No correlation was found between success and either strategic vision or informal communication.
Martinsuo and Poskela (2011)	107 Finnish companies with median 350 employees (author estimate)	Survey	Evaluated the Stage-Gate decision criteria for most recently completed front-end project.	4-item construct based on competitive potential and 4-item construct based on future business potential	Technical and strategic, but not market, criteria correlated with future business potential of projects with high complexity and novelty.

APPENDIX 3. SOME OF THE SCIENTIFIC EVIDENCE RELATED TO COOPERATION BETWEEN MARKETING AND R&D

Adapted from Griffin and Hauser (1996).

Researcher(s)	Sample	Type of Firm	Evidence (Partial List)
Cooper [19]	58 projects	Industrial	Projects that balance marketing and R&D inputs have a higher rate of success.
Cooper [20]	122 firms	Electronic, heavy equipment, chemicals, materials	Management strategies that balance marketing and R&D have a greater percentage of new product successes and greater percentage of their sales coming from new products.
Cooper and de Brentani [23]	106 projects	Financial services	Synergy (e.g., fit with the firm's expertise, management skills, and market research resources) was the number one correlate of success. (Correlation = 0.45.)
Cooper and Kleinschmidt [24]	125 firms 203 projects	Manufacturing	Market synergy and technological synergy are both significantly related to success.
de Brentani [26]	115 firms 276 projects	Financial and mgmt services, transportation, communication	Sales, communication between functions. (Correlation with sales and market share = 0.38, correlation with reduced cost = 0.29.)
Dougherty [28]	5 firms 18 projects	Industrial, consumer, and services	More communication and communication on *all* relevant topics separated successful projects from unsuccessful projects.
Gupta, Raj, and Wilemon [46]	167 firms 107 R&D managers 109 marketing managers	High-technology	Lack of communication was listed as the number one barrier to achieving integration among marketing and R&D.
Hise, O'Neal, Parasuraman, and McNeal [57]	252 Marketing Vice Presidents	Large manufacturing firms	High level of joint effort in new product design is a significant factor in determining success. This is true for both industrial and consumer good companies.
Moenaert and Souder [73]	Literature review	Products and services	Function integration positively relates to innovation success.
Moenaert, Souder, DeMeyer, and Deschoolmeester [74]	40 Belgian firms	Technology innovative firms	Significant correlation between commercial success and (1) interfunctional climate, (2) information received by R&D.
Pelz and Andrews [85]	1311 scientists and engineers	Scientists and engineers	Positive relationships between the amount of interaction and performance.
Pinto and Pinto [86]	72 hospital teams 262 team members	Health services	Strong relationship between cross-functional cooperation and the success (perceived task outcomes and psychosocial outcomes) of the project. (Correlation = 0.71.)
Souder [106]	56 firms 289 projects	Consumer and industrial	The greater the harmony between marketing and R&D, the greater the likelihood of success.
Souder and Chakrabarti [108]	18 firms 117 projects	Consumer and industrial	Interaction, integration, and information exchange significantly differentiate between technical and commercial success and failure.
Takeuchi and Nonaka [111]	6 projects U.S. and Japan	Consumer and industrial	Cross-fertilization and self-organizing teams led to success.

APPENDIX 4. REVIEW OF CONSUMER RESEARCH METHODS USED IN NPD

Adapted from Kleef et al. (2005).

Theoretical basis, operating procedure and key references of 10 consumer research methods and techniques for opportunity identification in new product development (in alphabetic order)

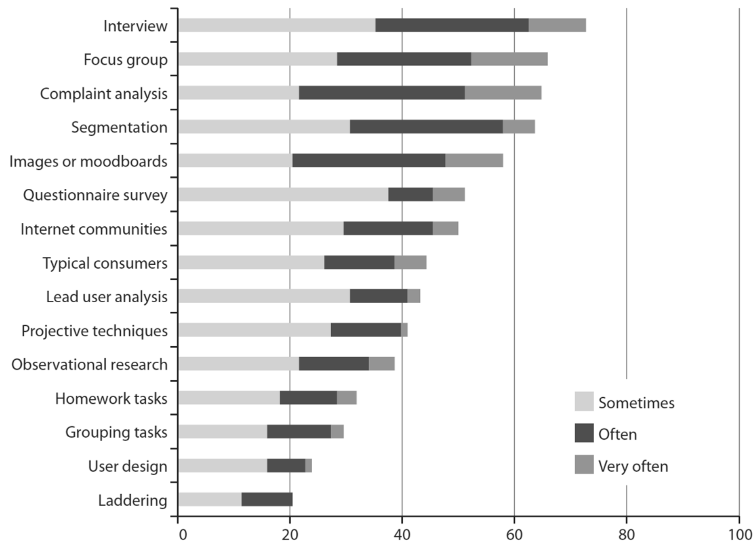
Method	Theoretical basis	Operating procedure	Key references
Category appraisal	No specific	1. The researcher selects a set of competing products of interest (possibly including a product concept) 2. The products are presented to the respondent 3. The respondent directly ranks, rates or sorts the products on sensory, preference or perceptual attributes or on their perceived (dis)similarity 4. One of the widely available statistical procedures (e.g. factor analysis, multidimensional scaling) is used to graphically portray stimuli, respondent's individual preferences and/or attributes in a geometrical space 5. The resulting map captures many significant factors defining the competitive structure of the product category. Depending on the applied technique, the map: • shows intensity of competition between products—the closer two product are together, the more similar they are perceived or preferred • summarises how consumers perceive products on each attribute • shows relationships between attributes and how well these attributes differentiate between products • indicates areas of the map which are desirable to certain segments of consumers	Internal preference analysis • Coombs (1964) • Tucker (1960) External preference analysis • Carroll (1972) • Green and Carmone (1969) • Greenhoff and MacFie (1994) • Moskowitz (1985, 1994) NPD applications • Richardson-Harman et al. (2000) • Guinard et al. (2001)
Conjoint analysis	Experimental design	1. The researcher selects attributes relevant to the product category (e.g. by means of a focus group with target consumers) 2. The researcher selects the levels of each attribute to be used in study. Typically studies use between two and five levels for each attribute. Hypothetical products are defined as combinations of attribute levels 3. The respondent is given a set of these hypothetical profiles (constructed along factorial design principles in the full profile case) 4. The respondent ranks or rates the stimuli according to some overall criterion, such as preference, acceptability, or likelihood of purchase 5. In the analysis of the data, part-worths are identified for the attribute levels such that each specific combination of part-worths equals the total utility of any given profile. A set of part-worths are derived for each respondent	• Green and Srinivasan (1978) • Green et al. (2001) NPD applications • Frewer et al. (1997) • Lilien and Rangaswamy (1998) • Krieger et al. (2003)
Empathic design	Theories of anthropological investigation and tacit knowledge	1. A multi-functional team is created to observe the actual behaviour and environment of consumers. The goal is to see what consumers do and do not do, how to make their tasks easier or more pleasant, and see those needs that consumers do not expect can be met. It is decided who should be observed, who should do the observation (e.g. an expert in a certain discipline) and what the observer should be watching (e.g. normal routines of people) 2. A visual record is made of consumers interacting with their environment. Photographs, videotape, sketches and notes are tools, which make a record of behaviour. Data can as well be gathered through responses to questions like 'why are you doing that?' 3. Team members have a brainstorming session to transform observations into graphic, visual representations of possible solutions. At this step, the team should include some individuals who were not on the original team of observers 4. A non-functional, two or three-dimensional model of a product concept provides a vehicle for further testing among potential consumers	• Polanyi (1966) • Leonard (1995) • Leonard and Sensiper (1998) NPD applications • Leonard and Rayport (1997) • Ulwick (2002)
Focus group	No specific	1. A group of participants, usually 8–10, sits together for a more or less open-ended discussion about a product or a specific topic 2. The discussion moderator let participants introduce themselves and feel comfortable and makes sure that the topics of significance are brought up. To help participants verbalise their needs, interaction between group members is encouraged 3. The report summarises what was said, and perhaps draws inferences from what was said and left unsaid in the discussion	• Calder (1977) • McQuarrie and McIntyre (1986) • Bruseberg and McDonagh-Philp (2002) NPD applications • McNeill et al. (2000)
Free elicitation	Theories of spreading activation	1. The researcher presents stimulus probes or cues (usually words) to the participant 2. The participant is asked to rapidly verbalise the concepts that come to mind and that he/she considers relevant in the perception of the stimulus. For example, when the stimulus is a product name, the objective is to activate all nodes associated with this product name in respondent's memory. It is assumed that first mentioned statements are most important 3. The interview is generally recorded and transcribed before analysis 4. Results can be analyzed in a variety of ways, depending on the goal of the research, for example by displaying associative knowledge networks or classifying statements in meaningful categories	• Collins and Loftus (1975) • Anderson (1983)
Information acceleration	Diffusion of innovations and decision-flow models	1. The researcher constructs a virtual buying environment that simulates the information that is available to consumers at the time that they make a purchase decision 2. Respondents are 'accelerated' into the future by providing them alternative future environments that are favorable, neutral, or unfavorable towards the new product. In this virtual buying environment, they are allowed to search for information or shop 3. Measures are taken of respondents' likelihood of purchase, perceptions, and preferences 4. Based on these measures, a model is developed to forecast sales and simulate strategy alternatives	• Urban et al. (1996) • Urban et al. (1997)
Kelly repertory grid	Personal construct theory	1. The participant is provided with a set of products presented in groups of three products 2. For each triple combination, the participant is asked to think carefully about the products, and decide in what way two of them are similar, and at the same time, different from the third one 3. Having identified the reasons to discriminate between the products, the participant is then asked what they would consider the opposite to be. This procedure is repeated until all products are evaluated in combinations of three 4. The attributes (called constructs) are all written down on a grid sheet. A repertory grid is a matrix representation of products and constructs. In addition, all products can be scored against each construct to find out its importance 5. Grids can be clustered by content analysis, frequency counts, or principal component analysis to analyse what is relevant, similar and different in the eyes of the consumer	• Kelly (1955) • Sampson (1972) NPD applications • Thomson and McEwan (1988) • Bech-Larsen and Nielsen (1999)
Laddering	Means-end chain theory	1. The participant is provided with a set of products 2. The participant is asked to make distinctions between the products (by means of triadic sorting on perceived meaningful differences or by means of preference differences or by means of perceived differences by occasion) 3. Each mentioned distinction is the starting point for a series of 'why'-probes by the researcher, to determine sets of linkages between attributes, consequences and values 4. Once all interviews are completed, key elements of the interview are summarised by standard content-analysis, taking into account the different levels of abstraction 5. A summary table is constructed representing the number of connections between elements 6. From the summary table dominant connections are graphically represented in a tree diagram, called a hierarchical value map (HVM). Hierarchical value maps consist of a number of ladders (or association networks), and represent the combinations of attributes, benefits, and values that consumers use as a basis for distinguishing between products in a given product class	• Gutman (1982) • Reynolds and Gutman (1988) NPD applications • Walker and Olson (1991) • Claeys et al. (1995) • Nielsen et al. (1998)

Appendix 4 continues.

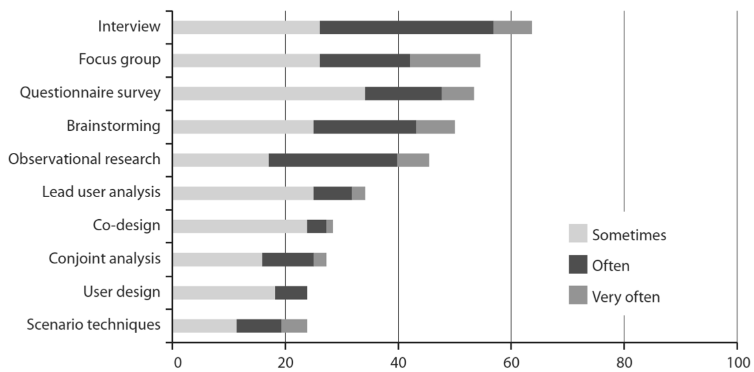
Method	Theoretical basis	Operating procedure	Key references
Lead user technique	Diffusion of innovations	1. To identify lead users in a product category of interest, the researcher first identifies underlying trends on which these lead users will have a leading position (e.g. by means of expert method 'Delphi', trend extrapolation techniques or econometric models) 2. Lead user indicators are specified by: (1) finding a market or technological trend and related measures, and (2) defining measures of potential benefit (e.g. user dissatisfaction with current products, evidence of active modification of product by user themselves) 3. The potential market is screened based on measures specified in previous step (e.g. by means of a questionnaire) to identify a lead user group 4. Data from lead users is derived concerning their experience with novel product attributes and product concepts. Creative group sessions are often used to pool user solution content and develop new product concepts. In some cases, a fully implemented product is developed in co-operation with the lead users 5. The products developed by lead users are evaluated by more typical users in target market by conducting traditional product tests after segmenting lead and non-lead users	• Von Hippel (1986, 1988) • Urban and Von Hippel (1988) NPD applications • Herstatt and Von Hippel (1992) • Von Hippel et al. (1999) • Olson and Bakke (2001) • Lilien et al. (2002) • Von Hippel and Katz (2002)
Zaltman metaphor elicitation technique (ZMET)	Theories of non-verbal communication, metaphors as representations of thoughts, mental models	1. Participants are given instructions about research topic (e.g. a brand name, a corporate identity, a product design) and the task to take photographs and/or collect pictures (e.g. from magazines/books) that indicate what the topic means for them. Seven to 10 days later a personal interview is planned 2. Participants bring in their pictures and photographs and tell their stories about the topic (storytelling) 3. Participants are asked to make distinctions between products (e.g. by means of triadic sorting). Each mentioned distinction is starting point for a series of 'why'-probes by the researcher, to determine sets of linkages between attributes, consequences and values (laddering technique) 4. Participants are asked to indicate picture that (1) most represents their feelings, and (2) might describe the opposite of the task that they were given. In addition, they are asked to use other senses to convey what does and does not represent the topic being explored 5. The interviewer reviews all the constructs discussed and participant creates a map to illustrate connections among important constructs (mental map) 6. Next, a summary image or montage is constructed by participant or a graphic technician to express important issues (e.g. by digital imaging techniques) 7. A consensus map is created by analyzing number of constructs and frequency of related constructs. The consensus map is a diagram showing linkages among constructs. Constructs are related to each, in that some constructs are originating points in a reasoning process and others are ending points. Connectors constructs serve as linkages between constructs. In addition, an interactive CD can be composed which includes the visual, sensory and digital images and vocal descriptions along with vignettes to illustrate how consumers experience constructs	• Zaltman and Coulter (1995) • Zaltman (1997) NPD applications • Coulter et al. (2001) • Christensen and Olson (2002)

APPENDIX 5. CONSUMER RESEARCH METHODS USED IN THE EARLY FFE

Adapted from Creusen and Hultink (2013).



Percentage of consumer research method use in the early FFE.



Percentage of consumer research method use in the late FFE.

APPENDIX 6. REFERENCES TO TAM-RELATED LITERATURE: DEVELOPMENT, MODIFICATIONS AND APPLICATIONS

Adapted from Marangunic and Granic (2015).

Author(s)	Category	Main topic
Davis [20]	Development	Development of technology acceptance model (TAM)
Davis [21]	Development	Development of parsimonious TAM
Davis et al. [23]	Development	Introduction of *behavioral intention* as a new variable of the model
Mathieson [58]	Development	Comparison of TAM and TPB models
Davis [22]	Development	Realization of field study of TAM
Barki and Hartwick [8]	Extension	Introduction of the factor *subjective norm* to the model
Igbaria et al. [45]	Extension	Definition of two aspects of *motivation*: *extrinsic* and *intrinsic*
Taylor and Todd [79]	Extension	Introduction of the factor *self-efficacy* to the model
Chau [14]	Extension	Integration of TAM and personal computer utilization models
Venkatesh and Davis [84]	Development	Consideration of possible introduction of other factors referred to as *external variables*
Agarwal and Prasad [1]	Extension	Introduction of additional belief factor *trialability* to the model
Gefen and Straub [32]	Extension	Introduction of *personality traits* as external variables to the model
Jackson et al. [46]	Extension	Extension of the model to include *situational involvement*, *intrinsic involvement*, and *argument for change*
Straub et al. [75]	Development	Comparison of the TAM model across different cultures
Dishaw and Strong [27]	Extension	Integration of TAM and task-technology fit (TTF) models
Karahanna et al. [47]	Extension	Introduction of additional belief factor *visibility* to the model
Lucas and Spitler [57]	Extension	Extension of the model to include *social norms*, *user performance*, and two *control variables*
Venkatesh [82]	Extension	Consideration of role of *intrinsic motivation* as a lever to create favorable user perceptions
Venkatesh [83]	Extension	Identification of the *antecedents* to the *perceived ease of use* variable in the TAM model
Venkatesh and Davis [84]	Development	Development of TAM 2
Venkatesh and Morris [86]	Extension	Introduction of *demographic characteristics* as external variables to the model
Mathieson et al. [59]	Extension	Introduction of the factor *perceived behavioral control* to the model
Plouffe et al. [68]	Extension	Introduction of additional belief factor *result demonstrability* to the model
Brown et al. [9]	Development	Examination of TAM in a mandated use environment
Venkatesh et al. [87]	Development	Formulation and empirical validation of unified model, which integrates elements across eight models of technology acceptance
Lin and Wu [55]	Extension	Introduction of *intra-* and *extra-organizational* factors as causal factors of end user computing perception
Van der Heijden [81]	Development	Identification of differences in user acceptance models for productivity-oriented (or utilitarian) and pleasure-oriented (or hedonic) information systems
Arning and Ziefle [7]	Extension	Introduction of *subjective technical confidence* as moderating variable to the model
Gumussoy et al. [34]	Extension	Introduction of *subjective norms* and *educational level* factors to the model
Schepers and Wetzels [70]	Extension	Moderation of effects of one individual-related factor (*type of respondents*), one technology-related factor (*type of technology*), and one contingent factor (*culture*)
Chow et al. [18]	Extension	Introduction of *computer self-efficacy* construct as external variable to the model
Lee and Lehto [49]	Extension	Introduction of additional belief factor *content richness* to the model

Appendix 6 continues.

Author(s)	Category	Main topic
Davis et al. [23]	Modification	Incorporation of usage measure *attitude toward technology*
Davis and Venkatesh [25]	Modification	Incorporation of external predictor *self-efficiency*
Szajna [77]	Modification	Incorporation of usage measure *usage perception*
Straub et al. [75]	Modification	Incorporation of contextual factor *cultural diversity*
Hu et al. [40]	Application	Applicability of TAM in explaining physicians' decisions to accept telemedicine technology in the health care context
Venkatesh and Morris [86]	Application	Applicability of TAM in the context of individual adoption and sustained usage of technology in the workplace
Horton et al. [37]	Modification	Incorporation of usage measure *usage perception*
Moon and Kim [61]	Modification	Incorporation of usage measure *usage perception*
Plouffe et al. [68]	Modification	Incorporation of contextual factor *technology characteristics*
Chau and Hu [15]	Application	Applicability of TAM on Internet-supported medical procedures
Hong et al. [36]	Application	Applicability of TAM on digital library system
Featherman and Pavlou [29]	Modification	Incorporation of factor *risk* for increasing predictive validity of TAM
Gefen et al. [31]	Modification	Incorporation of factor *trust* for increasing predictive validity of TAM
Hardgrave et al. [35]	Modification	Incorporation of factor *subjective norm* for increasing predictive validity of TAM
Huang et al. [44]	Modification	Incorporation of contextual factor *gender*
Liaw and Huang [54]	Application	Applicability of TAM on search engine systems for seeking information on Web
Lu et al. [56]	Application	Applicability of TAM on mobile Internet
Oh et al. [63]	Modification	Incorporation of external predictor *prior usage*
Pavlou [67]	Modification	Incorporation of factor *risk* for increasing predictive validity of TAM
Venkatesh et al. [87]	Modification	Incorporation of factor *expectations* for increasing predictive validity of TAM
Yu et al. [94]	Application	Applicability of TAM on wireless Internet
Amoako-Gyampah and Salam [6]	Modification	Incorporation of external predictor *confidence in technology*
Chan and Lu [12]	Application	Applicability of TAM on Internet banking system
Davis and Venkatesh [26]	Modification	Incorporation of measure *actual usage* of technology
Gefen [30]	Modification	Incorporation of factor *trust* for increasing predictive validity of TAM
Gong et al. [33]	Application	Applicability of extended TAM in the context of e-learning
Shih [73]	Application	Applicability of extended TAM to reveal factors influencing acceptance and usage of Internet
Yi and Hwang [93]	Application	Applicability of TAM on Internet-based information systems
Hu et al. [41]	Application	Applicability of TAM on information systems
Huang [42]	Application	Applicability of TAM in exploring Internet acceptance considering the gender of users
Burton-Jones and Hubona [10]	Modification	Incorporation of external predictor *experience*
Saadé and Kira [69]	Modification	Incorporation of external predictor *technology anxiety*
Amoako-Gyampah [5]	Modification	Incorporation of factor *user participation* for increasing predictive validity of TAM
Castaneda et al. [11]	Application	Applicability of TAM on specific Web sites
Huang et al. [43]	Application	Applicability of TAM for m-learning
Park et al. [66]	Application	Applicability of original TAM in the context of e-learning

Appendix 6 continues.

Serenko [71]	Application	Applicability of TAM on electronic mail system
Zhang et al. [95]	Application	Applicability of extended TAM in the context of e-learning
Lee and Kim [50]	Application	Applicability of extended TAM to reveal factors influencing acceptance and usage of Internet
Tao et al. [78]	Application	Applicability of TAM on business simulation games
Melas et al. [60]	Application	Applicability of extended TAM to predict acceptance of clinical information systems
Pai and Huang [65]	Application	Applicability of TAM on health care information systems
Wu et al. [91]	Application	Applicability of TAM on wireless Internet
Wu et al. [92]	Modification	Incorporation of factor *trust* for increasing predictive validity of TAM
Farahat [28]	Application	Applicability of original TAM in the context of e-learning
Lee et al. [51]	Application	Applicability of extended TAM to reveal factors influencing acceptance and usage of Internet
Nasri and Charfeddine [62]	Application	Applicability of TAM on Internet banking system
Son et al. [74]	Application	Applicability of TAM on mobile Internet
Cheung and Vogel [16]	Application	Applicability of extended TAM in the context of e-learning
Padilla-Meléndez et al. [64]	Modification	Incorporation of contextual factor *gender*

APPENDIX 7. RESEARCH PHASE 1 QUESTIONNAIRE DEVELOPMENT

Demographic questions

ID	Question
DEM1	Participant’s age
DEM2	Participant’s gender
DEM3	Participant's degree of education
DEM4	Participant's occupation

Market segmentation questions and their references

ID	Question	Reference
MS1	I have high social status	Rogers, 1962
MS2	I have opinion leadership in my social context	Rogers, 1962
MS3	My risk tolerance to adopt new technology is high	Rogers, 1962
MS4	I must be certain that a new idea does not fail before I adopt	Jahanmir and Lages, 2016
MS5	I approach new innovations with a skeptical and cautious air	Jahanmir and Lages, 2016
MS6	I adopt new technology / product in its introductory and growth stages	Shun and Venkatesh, 2014
MS7	I adopt new technology / product in its maturity and decline stages	Shun and Venkatesh, 2014
MS8	I'm often first to adopt an innovative product	Noppers et al., 2015; Rogers, 1962; Rogers, 2003
MS9	I am knowledgeable about new technology	Shun and Venkatesh, 2014; Dickerson and Gentry 1983; Parasuraman and Colby, 2001
MS10	I enjoy learning about new technology	Shun and Venkatesh, 2014; Dickerson and Gentry 1983; Parasuraman and Colby, 2001

APPENDIX 8. ORIGINAL TAM3 CONSTRUCT ITEMS

Adapted from Venkatesh and Bala (2008).

Variable	Description
Perceived Usefulness (PU)	
PU1	Using the system improves my performance in my job.
PU2	Using the system in my job increases my productivity.
PU3	Using the system enhances my effectiveness in my job.
PU4	I find the system to be useful in my job.
Perceived Ease of Use (PEOU)	
PEOU1	My interaction with the system is clear and understandable.
PEOU2	Interacting with the system does not require a lot of my mental effort.
PEOU3	I find the system to be easy to use.
PEOU4	I find it easy to get the system to do what I want it to do.
Computer Self-Efficacy (CSE)	
	I could complete the job using a software package…
CSE1	…if there was no one around to tell me what to do as I go.
CSE2	…if I had just the built-in help facility for assistance.
CSE3	…if someone showed me how to do it first.
CSE4	…if I had used similar packages before this one to do the same job.
Perceptions of External Control (PEC)	
PEC1	I have control over using the system.
PEC2	I have the resources necessary to use the system.
PEC3	Given the resources, opportunities and knowledge it takes to use the system, it would be easy for me to use the system.
PEC4	The system is not compatible with other systems I use.
Computer Playfulness (CPLAY)	
	The following questions ask you how you would characterize yourself when you use computers:
CPLAY1	…spontaneous
CPLAY2	…creative
CPLAY3	…playful
CPLAY4	…unoriginal
Computer Anxiety (CANX)	
CANX1	Computers do not scare me at all.
CANX2	Working with a computer makes me nervous.
CANX3	Computers make me feel uncomfortable.
CANX4	Computers make me feel uneasy.
Perceived Enjoyment (ENJ)	
ENJ1	I find using the system to be enjoyable.
ENJ2	The actual process of using the system is pleasant.
ENJ3	I have fun using the system.

Appendix 8 continues.

Objective Usability (OU)	
OU	No specific items were used. It was measured as a ratio of time spent by the subject to the time spent by an expert on the same set of tasks.
Subjective Norm (SN)	
SN1	People who influence my behavior think that I should use the system.
SN2	People who are important to me think that I should use the system.
SN3	The senior management of this business has been helpful in the use of the system.
SN4	In general, the organization has supported the use of the system.
Voluntariness (VOL)	
VOL1	My use of the system is voluntary.
VOL2	My supervisor does not require me to use the system.
VOL3	Although it might be helpful, using the system is certainly not compulsory in my job.
Image (IMG)	
IMG1	People in my organization who use the system have more prestige than those who do not.
IMG2	People in my organization who use the system have a high profile.
IMG3	Having the system is a status symbol in my organization.
Job Relevance (REL)	
REL1	In my job, usage of the system is important.
REL2	In my job, usage of the system is relevant.
REL3	The use of the system is pertinent to my various job-related tasks.
Output Quality (OUT)	
OUT1	The quality of the output I get from the system is high.
OUT2	I have no problem with the quality of the system's output.
OUT3	I rate the results from the system to be excellent.
Result Demonstrability (RES)	
RES1	I have no difficulty telling others about the results of using the system.
RES2	I believe I could communicate to others the consequences of using the system.
RES3	The results of using the system are apparent to me.
RES4	I would have difficulty explaining why using the system may or may not be beneficial.
Behavioral Intention (BI)	
BI1	Assuming I had access to the system, I intend to use it.
BI2	Given that I had access to the system, I predict that I would use it.
BI3	I plan to use the system in the next <n> months.
Use (USE)	
USE1	On average, how much time do you spend on the system each day?

APPENDIX 9. RESEARCH PHASE 1 QUESTIONNAIRE TAM3 CHANGES

	Original TAM3 setting	Modified to the FFE service robot setting
Subjective Norm		
SN1	People who influence my behavior think that I should experiment with the system.	People who influence my behavior think that I should experiment with the robot.
SN2	People who are important to me think that I should try out the system.	People who are important to me think that I should try out the robot.
Image		
IMG1	People in my organization who use the system have more prestige than those who do not.	People in my organization who use the robot have more prestige than those who do not.
IMG2	People in my organization who use the system have a high profile.	People in my organization who use the robot have a high profile.
IMG3	Having the system is a status symbol in my organization.	Testing the robot is a status symbol in my organization.
Output Quality		
OUT1	The quality of the output I get from the system is high.	The quality of the output I get using the robot is high.
OUT2	I have no problem with the quality of the system's output.	I have no problem with the quality of the robot's output.
OUT3	I rate the results from the system to be excellent.	I rate the results from the robot to be excellent.
Result Demonstrability		
RES1	I have no difficulty telling others about the results of using the system.	I have no difficulty telling others about the results of using the robot.
RES2	I believe I could communicate to others the consequences of using the system.	I believe I could communicate to others the consequences of using the robot.
RES3	The results of using the system are apparent to me.	The results of using the robot are apparent to me.
RES4	I would have difficulty explaining why using the system may or may not be beneficial.	I would have difficulty explaining why using the robot may or may not be beneficial.
Computer Self-efficacy		
	I could complete the job using a software package . . .	I could investigate the lunch menus using the robot . . .
CSE1	. . . if there was no one around to tell me what to do as I go.	. . . if there was no one around to tell me what to do as I use the robot.
CSE3	. . . if I had just the built-in help facility for assistance.	. . . if I had just the robot's built-in help facility for assistance.
CSE3	. . . if someone showed me how to do it first.	. . . if someone showed me how to do it first.
CSE4	. . . if I had used similar packages before this one to do the same job.	. . . if I had used similar robots before this one to do the same task.
Computer Anxiety		
CANX1	Computers do not scare me at all.	Robots do not scare me at all.
CANX2	Working with a computer makes me nervous.	Working with a robot makes me nervous.

Appendix 9 continues.

CANX3	Computers make me feel uncomfortable.	Robots make me feel uncomfortable.
CANX4	Computers make me feel uneasy.	Robots make me feel uneasy.
Computer Playfulness		
	The following questions ask you how you would characterize yourself when you use computers:	The following questions ask you how you would characterize yourself when you use robots:
CPLAY1	. . . spontaneous	. . . spontaneous
CPLAY2	. . . creative	. . . creative
CPLAY3	. . . playful	. . . playful
CPLAY4	. . . unoriginal	. . . unoriginal
Perceived Enjoyment		
ENJ1	I find using the system to be enjoyable.	I find using the robot to be enjoyable.
ENJ2	The actual process of using the system is pleasant.	The actual process of using the robot is pleasant.
ENJ3	I have fun using the system.	I have fun using the robot.
Objective Usability		
OU	Measured as a ratio of time spent by the subject to the time spent by an expert on the same set of tasks.	Measured time participant takes to accomplish the given task with the robot.
Perceived Usefulness		
PU1	Using the system improves my performance in my job.	Using the robot improves my performance in my task investigating the lunch menus.
PU3	Using the system enhances my effectiveness in my job.	Using the robot enhances my effectiveness in my task investigating the lunch menus.
PU4	I find the system to be useful in my job.	I find the robot to be useful in my task investigating the lunch menus.
Perceived Ease of Use		
PEOU1	My interaction with the system is clear and understandable.	My interaction with the robot is clear and understandable.
PEOU2	Interacting with the system does not require a lot of my mental effort.	Interacting with the robot does not require a lot of my mental effort.
PEOU3	I find the system to be easy to use.	I find the robot to be easy to use.
PEOU4	I find it easy to get the system to do what I want it to do.	I find it easy to get the robot to do what I want it to do.
Behavioral Intention		
		Assuming the robot would be permanently at the setup under testing . . .
BI1	Assuming I had access to the system, I intend to use it.	. . . I would use the robot if it would be accessible.
BI2	Given that I had access to the system, I predict that I would use it.	. . . I might use the robot if it would be accessible.
BI3	I plan to use the system in the next <n> months.	. . . I would plan to use the robot in the future.

APPENDIX 10. TAM3 CONSTRUCTS NOT INCLUDED IN THE RESEARCH PHASE 1 QUESTIONNAIRE

ID	Original TAM3 question left out	Justification
Perceived Usefulness		
PU2	Using the system in my job increases my productivity.	In this setting, PU2 is too similar with PU1 and PU3, and does not offer significantly new information.
Job Relevance		
REL1	In my job, usage of the system is important.	REL construct is not relevat part of the test as in this setting the relevace is with user not an employee.
REL2	In my job, usage of the system is relevant.	
REL3	The use of the system is pertinent to my various job-related tasks.	
Perceptions of External Control		
PEC1	I have control over using the system.	Pepper service robot is not a part of a system in this setting and is not under external control.
PEC2	I have the resources necessary to use the system	
PEC3	Given the resources, opportunities and knowledge it takes to use the system, it would be easy for me to use the system.	
PEC4	The system is not compatible with other systems I use.	
Voluntariness		
VOL1	My testing of the system is voluntary.	It is perfectly voluntary to participate in this study. There are no supervisors or a job. Participants are hard-coded to be voluntary in this test.
VOL2	My supervisor does not require me to test the system.	
VOL3	Although it might be helpful, testing the system is certainly not compulsory in my job.	
Subjective Norm		
SN3	The senior management of this business has been helpful in the use of the system.	There is no organization or management in this setting. SN3 and SN4 don’t represent the use case being tested.
SN4	In general, the organization has supported the use of the system.	
Use Behavior		
USE	On average, how much time do you spend on the system each day?	In this setting the robot will not be present longer. In this test an initial impression is measured based on a shot test, maximum of a couple of minutes.

APPENDIX 11. RESEARCH PHASE ONE COMPLETE DATA COLLECTION QUESTIONNAIRE FORM

Kysymyskaavake Pepper-palvelurobotin testaamiseen TTY:n lounasravintoloissa, 16.3.2018

Koehenkilön tehtävän suorittamiseen käyttämä aika robottia hyödyntäen: ________________________ Min., sek.

Koehenkilön ikä: ___________ vuotta

Koehenkilön sukupuoli: ☐ MIES / ☐ NAINEN

Koehenkilön suoritettu koulutusaste:
- ☐ Ei korkeakoulututkintoa
- ☐ Kandidaatti
- ☐ Maisteri
- ☐ Lisensiaatti
- ☐ Tohtori

Koehenkilön ammatti:
- ☐ Opiskelija
- ☐ Työssäkäyvä
- ☐ Sekä opiskelija että työssäkäyvä
- ☐ Työtön

	Vahvasti eri mieltä	Kohtalaisen eri mieltä	Hieman eri mieltä	**Ei eri eikä samaa mieltä**	Hieman samaa mieltä	Kohtalaisen samaa mieltä	**Vahvasti samaa mieltä**
Robotti on mielestäni helppokäyttöinen.	☐	☐	☐	☐	☐	☐	☐
Nautin uuteen teknologiaan perehtymisestä.	☐	☐	☐	☐	☐	☐	☐
Robotit eivät pelota minua lainkaan.	☐	☐	☐	☐	☐	☐	☐
On helppoa saada robotti tekemään mitä haluan sen tekevän.	☐	☐	☐	☐	☐	☐	☐
Siedän hyvin uuden teknologian omaksumiseen liittyvää riskiä.	☐	☐	☐	☐	☐	☐	☐
Tuotos jonka saan robotin avulla on korkealaatuista.	☐	☐	☐	☐	☐	☐	☐
Ennen kuin omaksun uuden idean, minun täytyy olla varma ettei se epäonnistu.	☐	☐	☐	☐	☐	☐	☐
Robottien kanssa työskenteleminen tekee minut hermostuneeksi.	☐	☐	☐	☐	☐	☐	☐
Lähestyn uusia innovaatioita skeptisesti ja varovaisesti.	☐	☐	☐	☐	☐	☐	☐
Robotit saavat minut tuntemaan oloni epämukavaksi.	☐	☐	☐	☐	☐	☐	☐
Hankin uutta teknologiaa / tuotteita jo niiden esittely- ja kasvuvaiheessa.	☐	☐	☐	☐	☐	☐	☐
Kuinka luonnehtisit itseäsi, kun käytät robotteja:							
. . . spontaani	☐	☐	☐	☐	☐	☐	☐
. . . luova	☐	☐	☐	☐	☐	☐	☐
. . . leikkisä	☐	☐	☐	☐	☐	☐	☐
. . . tavallinen	☐	☐	☐	☐	☐	☐	☐
Olen hyvin perillä uusista teknologioista.	☐	☐	☐	☐	☐	☐	☐
Hankin uutta teknologiaa / tuotteita vasta niiden kypsyys- ja poistumisvaiheissa.	☐	☐	☐	☐	☐	☐	☐
Robotin käyttäminen parantaa tehokkuuttani ruokalistan selvittämisessä.	☐	☐	☐	☐	☐	☐	☐
Uskon voivani kommunikoida muille robotin käytön seuraamukset.	☐	☐	☐	☐	☐	☐	☐
Vuorovaikutus robotin kanssa on selkeä ja ymmärrettävä.	☐	☐	☐	☐	☐	☐	☐

Sivu 1 / 2

Appendix 11 continues.

	Vahvasti eri mieltä	Kohtalaisen eri mieltä	Hieman eri mieltä	**Ei eri eikä samaa mieltä**	Hieman samaa mieltä	Kohtalaisen samaa mieltä	**Vahvasti samaa mieltä**
Nautin robotin käytöstä.	☐	☐	☐	☐	☐	☐	☐
Olen usein ensimmäinen joka omaksuu innovatiivisen tuotteen.	☐	☐	☐	☐	☐	☐	☐
Jos robotti olisi pysyvästi Pääaulassa ...							
. . . käyttäisin robottia jos se olisi saatavilla.	☐	☐	☐	☐	☐	☐	☐
. . . saattaisin käyttää robottia jos se olisi saatavilla.	☐	☐	☐	☐	☐	☐	☐
. . . suunnittelisin käyttäväni robottia tulevaisuudessa.	☐	☐	☐	☐	☐	☐	☐
Robotin käyttäminen on miellyttävä prosessi.	☐	☐	☐	☐	☐	☐	☐
Robotit saavat minut tuntemaan levottomuutta.	☐	☐	☐	☐	☐	☐	☐
Minulla olisi hankaluuksia selittää miksi robotin käyttäminen on tai ei ole hyödyllistä.	☐	☐	☐	☐	☐	☐	☐
Voisin selvittää lounasruokalistat käyttämällä robottia . . .							
. . . jos lähistöllä ei olisi ketään kertomassa minulle mitä tehdä kun käytän robottia.	☐	☐	☐	☐	☐	☐	☐
. . . jos minulla olisi käytössä vain robottiin sisäänrakennetut aputoiminnot.	☐	☐	☐	☐	☐	☐	☐
. . . jos joku ensin näyttäisi minulle kuinka se tehdään.	☐	☐	☐	☐	☐	☐	☐
. . . jos olisin ennen tätä käyttänyt vastaavia robotteja saman tehtävän tekemiseen.	☐	☐	☐	☐	☐	☐	☐
Minun käyttäytymiseeni vaikuttavien ihmisten mielestä minun pitäisi kokeilla robottia.	☐	☐	☐	☐	☐	☐	☐
Opiskelu-/työyhteisössäni henkilöt jotka kokeilevat robottia ovat arvovaltaisempia kuin ne jotka eivät kokeile sitä.	☐	☐	☐	☐	☐	☐	☐
Robotin käyttäminen parantaa suorituskykyäni ruokalistan selvittämisessä.	☐	☐	☐	☐	☐	☐	☐
Minulla on mielipidejohtajuutta sosiaalisessa ympäristössäni.	☐	☐	☐	☐	☐	☐	☐
Minulla ei ole ongelmaa robotin tuotoksen laadun kanssa.	☐	☐	☐	☐	☐	☐	☐
Minulla ei ole vaikeuksia kertoa muille robotin käytön tuloksista.	☐	☐	☐	☐	☐	☐	☐
Pidän robottia hyödyllisenä ruokalistan selvittämisessä.	☐	☐	☐	☐	☐	☐	☐
Robotin kokeileminen on opiskelu-/työyhteisössäni statussymbooli.	☐	☐	☐	☐	☐	☐	☐
Arvostelen robotin tuotokset erinomaiseksi.	☐	☐	☐	☐	☐	☐	☐
Minulla on hauskaa käyttäessäni robottia.	☐	☐	☐	☐	☐	☐	☐
Robotin käytön tulokset ovat minulle ilmeisiä.	☐	☐	☐	☐	☐	☐	☐
Vuorovaikutus robotin kanssa ei vaadi minulta paljon henkistä työtä.	☐	☐	☐	☐	☐	☐	☐
Minulle tärkeät ihmiset ajattelevat, että minun pitäisi kokeilla robottia.	☐	☐	☐	☐	☐	☐	☐
Minulla on korkea sosiaalinen asema.	☐	☐	☐	☐	☐	☐	☐
Opiskelu-/työyhteisössäni robottia kokeilevilla henkilöillä on korkeampi profiili.	☐	☐	☐	☐	☐	☐	☐

Sivu 2 / 2

APPENDIX 12. RESEARCH PHASE 1 QUESTIONNAIRE MISSING DATA VALUES

Variable	Valid	Missing
DEM2	102	19
MS6	117	4
OUT1	118	3
CANX3	118	3
DEM3	119	2
MS3	119	2
MS7	119	2
MS9	119	2
SN2	119	2
OUT2	119	2
CANX4	119	2
PU3	119	2
PEOU2	119	2
BI3	119	2
DEM4	120	1
MS5	120	1
SN1	120	1
OUT3	120	1
RES1	120	1
RES4	120	1
CSE4	120	1
CANX1	120	1
CPLAY4	120	1
ENJ2	120	1
OU	120	1
PU4	120	1
PEOU4	120	1
BI1	120	1
BI2	120	1
Total missing data		64

APPENDIX 13. MARKET SEGMENTATION VARIABLES

ID	Question
MS1	I have high social status
MS2	I have opinion leadership in my social context
MS3	My risk tolerance to adopt new technology is high
MS4	I must be certain that a new idea does not fail before I adopt
MS5	I approach new innovations with a skeptical and cautious air
MS6	I adopt new technology / product in its introductory and growth stages
MS7	I adopt new technology / product in its maturity and decline stages
MS8	I'm often first to adopt an innovative product
MS9	I am knowledgeable about new technology
MS10	I enjoy learning about new technology

Model summary for testing MS8

R	R^2	Adjusted R^2	Std. Error of the Estimate	R^2 Change	F Change
0,743	0,552	0,513	1,107	0,552	14,368

Model ANOVA test

	Sum of Squares	df	Mean Square	F	Sig.
Regression	158,335	9	17,593	14,368	0,000
Residual	128,565	105	1,224		
Total	286,900	114			

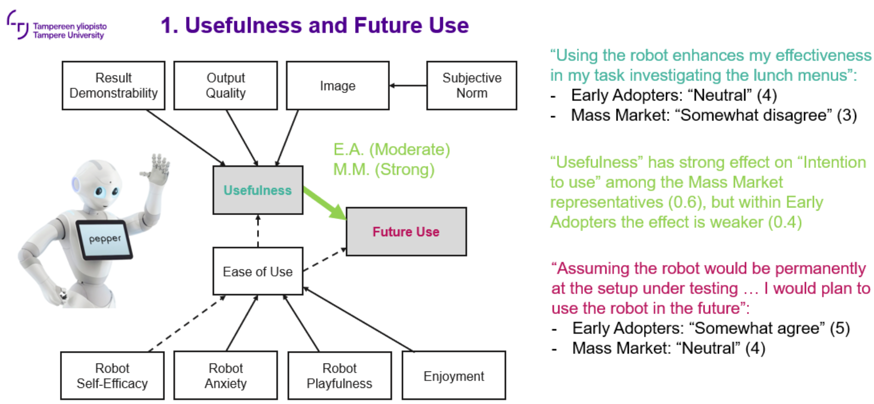
Appendix 13 continues.

Individual MS variable coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-0,751	0,977		-0,769	0,444
MS1	0,198	0,1	0,154	1,984	0,05
MS2	0,024	0,089	0,021	0,272	0,786
MS3	0,111	0,111	0,088	1,002	0,319
MS4	0,021	0,07	0,021	0,299	0,765
MS5	0,033	0,085	0,03	0,393	0,695
MS6	0,52	0,082	0,555	6,363	0
MS7	0,018	0,076	0,016	0,234	0,816
MS9	0,15	0,083	0,148	1,809	0,073
MS10	0,024	0,123	0,015	0,195	0,846

APPENDIX 14. RESEARCH PHASE 2 R&D SURVEY EXAMPLE DATA (QUESTION) AND QUESTIONNAIRE (ANSWER)

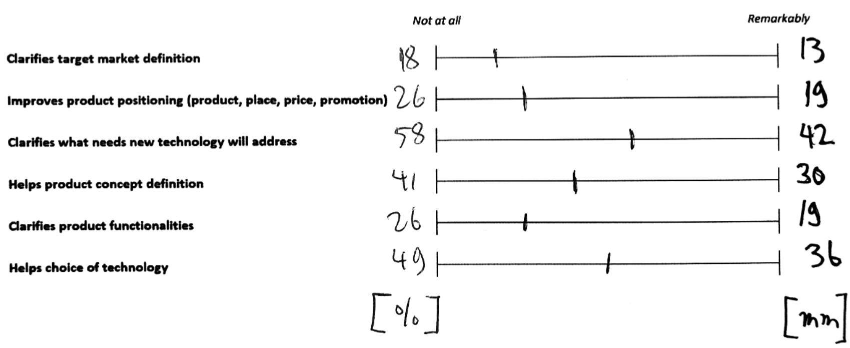
An example of TAM3 market segment data:



An example R&D questionnaire answer:

1. Usefulness and Intention to Use

- Mass Market somewhat disagrees with Pepper Usefulness (3/7)
- Early Adopters find Future Use more likely than Mass Market (5/7)
- However, the impact of Usefulness towards Future Use is stronger among Mass Market (0.6 vs 0.4)



APPENDIX 15. INDICATOR OUTER LOADINGS

	"All data"	"E.A. data"	"M.M. data"
BI1	0,905	0,887	0,909
BI2	0,884	0,893	0,874
BI3	0,908	0,879	0,916
CANX2	0,899	0,813	0,908
CANX3	0,873	0,703	0,896
CANX4	0,830	0,912	0,822
CPLAY1	0,816	0,830	0,561
CPLAY2	0,915	0,858	0,991
CPLAY3	0,834	0,897	0,463
CSE1	0,908	0,909	0,926
CSE2	0,837	0,875	0,785
ENJ1	0,886	0,941	0,863
ENJ2	0,918	0,940	0,936
ENJ3	0,729	0,899	0,485
IMG1	0,793	0,716	0,853
IMG2	0,815	0,900	0,780
IMG3	0,729	0,871	0,551
OUT1	0,841	0,753	0,869
OUT2	0,807	0,829	0,810
OUT3	0,904	0,919	0,879
PEOU1	0,769	0,842	0,702
PEOU2	0,632	0,729	0,579
PEOU3	0,798	0,827	0,797
PEOU4	0,830	0,903	0,777
PU1	0,842	0,872	0,821
PU3	0,844	0,824	0,842
PU4	0,891	0,868	0,902
RES1	0,637	0,728	0,573
RES2	0,736	0,752	0,709
RES3	0,814	0,877	0,803
SN1	0,774	0,698	0,805
SN2	0,927	0,918	0,936

APPENDIX 16. AVERAGE VARIANCE EXPLAINED (AVE) AND COMPOSITE RELIABILITY

	Composite Reliability			Average Variance Extracted (AVE)		
	"All data"	"E.A. data"	"M.M. data"	"All data"	"E.A. data"	"M.M. data"
Behavioral Intention	0,927	0,917	0,927	0,809	0,786	0,810
Image	0,823	0,871	0,778	0,608	0,694	0,547
Output Quality	0,888	0,874	0,889	0,725	0,699	0,728
Perceived Ease of Use	0,845	0,896	0,808	0,579	0,685	0,517
Perceived Enjoyment	0,884	0,948	0,820	0,720	0,859	0,619
Perceived Usefulness	0,895	0,891	0,891	0,739	0,731	0,732
Result Demonstrability	0,775	0,830	0,741	0,537	0,622	0,492
Robot Anxiety	0,901	0,853	0,908	0,753	0,662	0,768
Robot Playfulness	0,891	0,897	0,732	0,733	0,744	0,504
Robot Self-Efficacy	0,865	0,886	0,848	0,763	0,796	0,737
Subjective Norm	0,842	0,796	0,865	0,729	0,665	0,763

APPENDIX 17. BOOTSTRAPPED HETEROTRAIT-MONOTRAIT RATIO (HTMT) - CONFIDENCE INTERVALS BIAS CORRECTED

	Dataset "All"		Dataset "E.A."		Dataset "M.M."	
	Original Sample (O)	Sample Mean (M)	Original Sample (O)	Sample Mean (M)	Original Sample (O)	Sample Mean (M)
Image -> Behavioral Intention	0,350	0,376	0,478	0,519	0,280	0,337
Output Quality -> Behavioral Intention	0,505	0,506	0,683	0,686	0,386	0,391
Output Quality -> Image	0,311	0,329	0,490	0,544	0,183	0,280
Perceived Ease of Use -> Behavioral Intention	0,433	0,440	0,618	0,618	0,345	0,378
Perceived Ease of Use -> Image	0,164	0,239	0,318	0,404	0,169	0,337
Perceived Ease of Use -> Output Quality	0,880	0,884	**1,017**	**1,025**	0,845	0,841
Perceived Enjoyment -> Behavioral Intention	0,790	0,787	0,834	0,804	0,768	0,773
Perceived Enjoyment -> Image	0,246	0,299	0,276	0,370	0,208	0,327
Perceived Enjoyment -> Output Quality	0,646	0,649	0,746	0,748	0,562	0,581
Perceived Enjoyment -> Perceived Ease of Use	0,733	0,736	0,787	0,780	0,705	0,756
Perceived Usefulness -> Behavioral Intention	0,744	0,744	0,721	0,733	0,740	0,739
Perceived Usefulness -> Image	0,509	0,511	0,631	0,648	0,390	0,426
Perceived Usefulness -> Output Quality	0,681	0,680	0,737	0,764	0,630	0,633
Perceived Usefulness -> Perceived Ease of Use	0,493	0,500	0,586	0,617	0,456	0,474
Perceived Usefulness -> Perceived Enjoyment	0,633	0,640	0,537	0,556	0,693	0,717
Result Demonstrability -> Behavioral Intention	0,733	0,734	0,750	0,753	0,680	0,683
Result Demonstrability -> Image	0,277	0,344	0,316	0,436	0,339	0,468
Result Demonstrability -> Output Quality	0,689	0,698	0,691	0,733	0,655	0,675
Result Demonstrability -> Perceived Ease of Use	0,736	0,757	0,843	0,863	0,691	0,742
Result Demonstrability -> Perceived Enjoyment	0,875	0,884	0,772	0,779	**0,923**	**0,938**
Result Demonstrability -> Perceived Usefulness	0,634	0,640	0,786	0,803	0,508	0,536
Robot Anxiety -> Behavioral Intention	0,313	0,316	0,076	0,226	0,401	0,407
Robot Anxiety -> Image	0,220	0,246	0,314	0,374	0,202	0,282
Robot Anxiety -> Output Quality	0,473	0,472	0,325	0,373	0,523	0,524
Robot Anxiety -> Perceived Ease of Use	0,472	0,474	0,240	0,322	0,673	0,666
Robot Anxiety -> Perceived Enjoyment	0,388	0,394	0,105	0,227	0,575	0,588
Robot Anxiety -> Perceived Usefulness	0,363	0,365	0,163	0,279	0,439	0,445
Robot Anxiety -> Result Demonstrability	0,290	0,317	0,172	0,334	0,351	0,389
Robot Playfulness -> Behavioral Intention	0,382	0,382	0,600	0,577	0,206	0,247
Robot Playfulness -> Image	0,112	0,186	0,226	0,327	0,220	0,328
Robot Playfulness -> Output Quality	0,314	0,325	0,485	0,506	0,182	0,248
Robot Playfulness -> Perceived Ease of Use	0,201	0,251	0,359	0,393	0,231	0,315
Robot Playfulness -> Perceived Enjoyment	0,564	0,567	0,564	0,546	0,565	0,573
Robot Playfulness -> Perceived Usefulness	0,309	0,317	0,487	0,511	0,143	0,218
Robot Playfulness -> Result Demonstrability	0,363	0,399	0,401	0,464	0,356	0,428
Robot Playfulness -> Robot Anxiety	0,311	0,316	0,204	0,288	0,336	0,364
Robot Self-Efficacy -> Behavioral Intention	0,489	0,496	0,528	0,552	0,425	0,454
Robot Self-Efficacy -> Image	0,329	0,362	0,246	0,387	0,359	0,444
Robot Self-Efficacy -> Output Quality	0,426	0,434	0,527	0,556	0,335	0,359
Robot Self-Efficacy -> Perceived Ease of Use	0,521	0,525	0,642	0,656	0,452	0,480
Robot Self-Efficacy -> Perceived Enjoyment	0,467	0,473	0,587	0,587	0,345	0,395
Robot Self-Efficacy -> Perceived Usefulness	0,359	0,374	0,396	0,468	0,293	0,340
Robot Self-Efficacy -> Result Demonstrability	0,599	0,616	0,700	0,740	0,505	0,578
Robot Self-Efficacy -> Robot Anxiety	0,360	0,377	0,332	0,395	0,356	0,407
Robot Self-Efficacy -> Robot Playfulness	0,194	0,243	0,364	0,409	0,195	0,289
Subjective Norm -> Behavioral Intention	0,393	0,398	0,705	0,859	0,235	0,257
Subjective Norm -> Image	0,548	0,562	0,545	0,837	0,549	0,581
Subjective Norm -> Output Quality	0,407	0,417	0,624	0,774	0,288	0,308
Subjective Norm -> Perceived Ease of Use	0,296	0,326	0,533	0,683	0,224	0,295
Subjective Norm -> Perceived Enjoyment	0,453	0,460	0,580	0,684	0,385	0,399
Subjective Norm -> Perceived Usefulness	0,385	0,391	0,650	0,801	0,239	0,265
Subjective Norm -> Result Demonstrability	0,594	0,606	0,635	0,821	0,531	0,549
Subjective Norm -> Robot Anxiety	0,051	0,142	0,376	0,641	0,050	0,146
Subjective Norm -> Robot Playfulness	0,189	0,215	0,275	0,456	0,092	0,180
Subjective Norm -> Robot Self-Efficacy	0,256	0,280	0,117	0,394	0,286	0,329

5000 subsamples were created by the bootstrapping method using SmartPLS.

APPENDIX 18. MODEL OUTER VIF VALUES

	"All" data	"E.A. data"	"M.M. data"
BI1	2,318	1,840	2,529
BI2	2,483	2,848	2,343
BI3	2,688	2,726	2,623
CANX2	2,433	2,533	2,408
CANX3	2,412	2,037	2,649
CANX4	1,597	1,460	1,726
CPLAY1	2,237	3,038	1,912
CPLAY2	2,343	3,246	1,950
CPLAY3	1,564	1,545	1,463
CSE1	1,395	1,543	1,321
CSE2	1,395	1,543	1,321
ENJ1	2,227	4,226	1,795
ENJ2	2,128	3,641	1,769
ENJ3	1,468	2,752	1,190
IMG1	1,375	1,563	1,296
IMG2	1,483	2,411	1,290
IMG3	1,222	1,793	1,096
OUT1	1,755	1,664	1,691
OUT2	1,674	1,587	1,800
OUT3	2,111	2,060	2,080
PEOU1	1,417	1,888	1,281
PEOU2	1,223	1,453	1,145
PEOU3	1,782	2,526	1,569
PEOU4	1,896	3,328	1,562
PU1	1,805	2,049	1,673
PU3	1,770	1,586	1,836
PU4	2,115	1,990	2,177
RES1	1,214	1,399	1,212
RES2	1,223	1,278	1,214
RES3	1,146	1,552	1,068
SN1	1,298	1,145	1,424
SN2	1,298	1,145	1,424

APPENDIX 19. MODEL INNER VIF VALUES

"All" data

	Behavioral Intention	Image	Perceived Ease of Use	Perceived Usefulness
Behavioral Intention				
Image				1,230
Output Quality				2,161
Perceived Ease of Use	1,204			2,137
Perceived Enjoyment			1,460	
Perceived Usefulness	1,258			
Result Demonstrability				1,608
Robot Anxiety			1,196	
Robot Playfulness			1,299	
Robot Self-Efficacy			1,195	
Subjective Norm	1,103	1,000		1,370

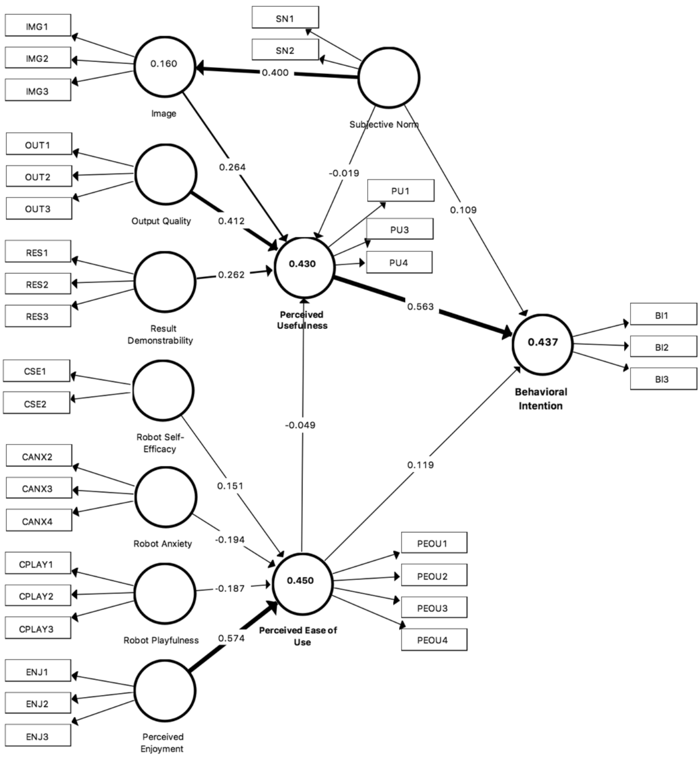
"E.A. data"

	Behavioral Intention	Image	Perceived Ease of Use	Perceived Usefulness
Behavioral Intention				
Image				1,368
Output Quality				3,874
Perceived Ease of Use	1,402			4,305
Perceived Enjoyment			1,758	
Perceived Usefulness	1,496			
Result Demonstrability				1,996
Robot Anxiety			1,121	
Robot Playfulness			1,497	
Robot Self-Efficacy			1,410	
Subjective Norm	1,285	1,000		1,449

"M.M. data"

	Behavioral Intention	Image	Perceived Ease of Use	Perceived Usefulness
Behavioral Intention				
Image				1,200
Output Quality				1,825
Perceived Ease of Use	1,140			1,710
Perceived Enjoyment			1,376	
Perceived Usefulness	1,169			
Result Demonstrability				1,444
Robot Anxiety			1,395	
Robot Playfulness			1,184	
Robot Self-Efficacy			1,153	
Subjective Norm	1,039	1,000		1,324

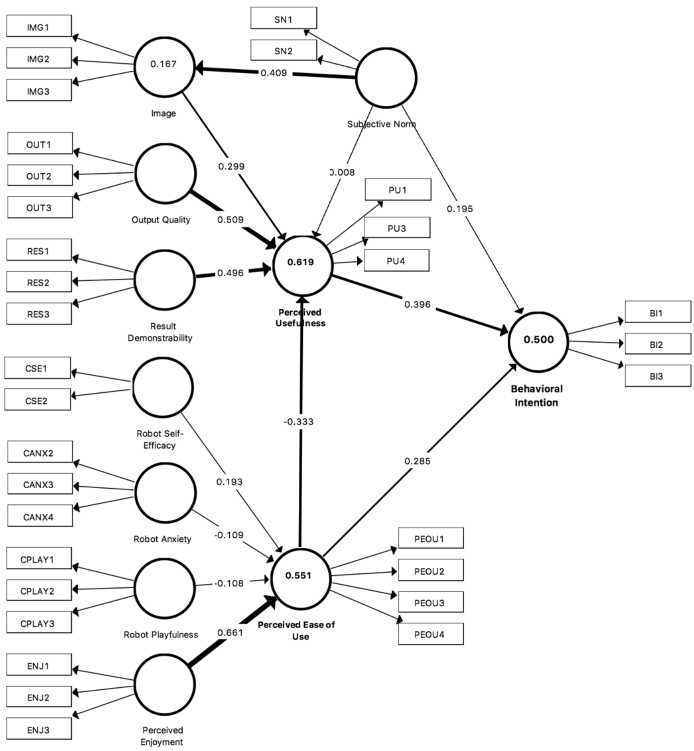
APPENDIX 20. STRUCTURAL MODEL PATH COEFFICIENTS FOR ALL DATASET



Inner model: Path coefficients, Constructs: R^2.

	Original Sample (O)	T Statistics (|O/STDEV|)	P Values
Image -> Perceived Usefulness	**0,264**	**3,570**	**0,000**
Output Quality -> Perceived Usefulness	**0,412**	**3,507**	**0,000**
Perceived Ease of Use -> Behavioral Intention	0,119	1,206	0,228
Perceived Ease of Use -> Perceived Usefulness	-0,049	0,411	0,681
Perceived Enjoyment -> Perceived Ease of Use	**0,574**	**6,734**	**0,000**
Perceived Usefulness -> Behavioral Intention	**0,563**	**8,207**	**0,000**
Result Demonstrability -> Perceived Usefulness	**0,262**	**3,089**	**0,002**
Robot Anxiety -> Perceived Ease of Use	**-0,194**	**2,282**	**0,023**
Robot Playfulness -> Perceived Ease of Use	-0,187	1,938	0,053
Robot Self-Efficacy -> Perceived Ease of Use	**0,151**	**1,964**	**0,050**
Subjective Norm -> Behavioral Intention	0,109	1,331	0,183
Subjective Norm -> Image	**0,400**	**4,888**	**0,000**
Subjective Norm -> Perceived Usefulness	-0,019	0,234	0,815

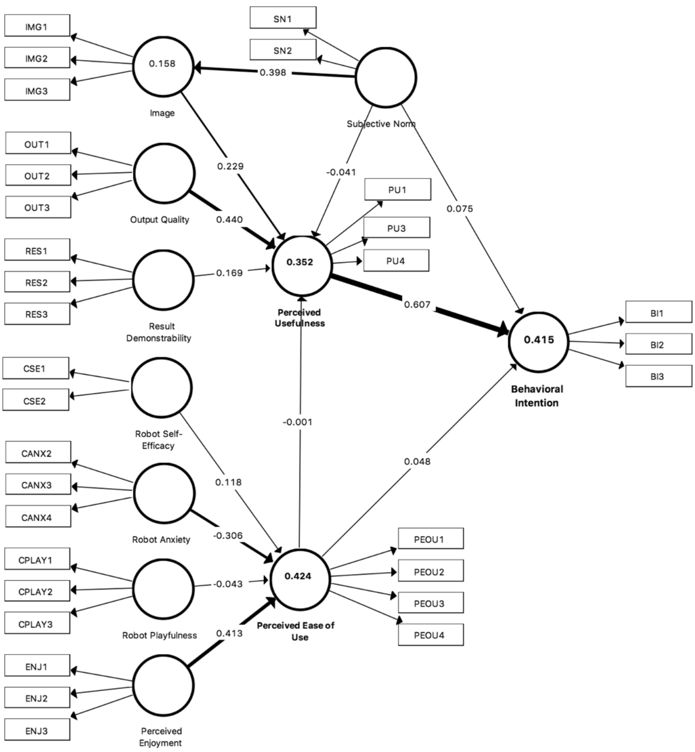
APPENDIX 21. STRUCTURAL MODEL PATH COEFFICIENTS FOR EA DATASET



Inner model: Path coefficients, Constructs: R^2.

	Original Sample (O)	T Statistics (|O/STDEV|)	P Values
Image -> Perceived Usefulness	**0,299**	**2,268**	**0,023**
Output Quality -> Perceived Usefulness	**0,509**	**2,122**	**0,034**
Perceived Ease of Use -> Behavioral Intention	0,285	1,407	0,159
Perceived Ease of Use -> Perceived Usefulness	-0,333	1,265	0,206
Perceived Enjoyment -> Perceived Ease of Use	**0,661**	**4,468**	**0,000**
Perceived Usefulness -> Behavioral Intention	**0,396**	**2,630**	**0,009**
Result Demonstrability -> Perceived Usefulness	**0,496**	**3,869**	**0,000**
Robot Anxiety -> Perceived Ease of Use	-0,109	0,612	0,540
Robot Playfulness -> Perceived Ease of Use	-0,108	0,702	0,483
Robot Self-Efficacy -> Perceived Ease of Use	0,193	1,517	0,129
Subjective Norm -> Behavioral Intention	0,195	1,373	0,170
Subjective Norm -> Image	**0,409**	**2,036**	**0,042**
Subjective Norm -> Perceived Usefulness	0,008	0,059	0,953

APPENDIX 22. STRUCTURAL MODEL PATH COEFFICIENTS FOR MM DATASET



Inner model: Path coefficients, Constructs: R^2.

	Original Sample (O)	T Statistics (|O/STDEV|)	P Values
Image -> Perceived Usefulness	**0,229**	**2,049**	**0,041**
Output Quality -> Perceived Usefulness	**0,440**	**3,296**	**0,001**
Perceived Ease of Use -> Behavioral Intention	0,048	0,462	0,644
Perceived Ease of Use -> Perceived Usefulness	-0,001	0,007	0,994
Perceived Enjoyment -> Perceived Ease of Use	**0,413**	**4,054**	**0,000**
Perceived Usefulness -> Behavioral Intention	**0,607**	**8,538**	**0,000**
Result Demonstrability -> Perceived Usefulness	0,169	1,522	0,128
Robot Anxiety -> Perceived Ease of Use	**-0,306**	**2,905**	**0,004**
Robot Playfulness -> Perceived Ease of Use	-0,043	0,232	0,817
Robot Self-Efficacy -> Perceived Ease of Use	0,118	1,129	0,259
Subjective Norm -> Behavioral Intention	0,075	0,685	0,494
Subjective Norm -> Image	**0,398**	**4,684**	**0,000**
Subjective Norm -> Perceived Usefulness	-0,041	0,377	0,706

APPENDIX 23. Q^2 EFFECT SIZE

All data:

	Behavioral Intention	Image	Perceived Ease of Use	Perceived Usefulness
Behavioral Intention				
Image				0,055
Output Quality				0,073
Perceived Ease of Use	0,006			-0,007
Perceived Enjoyment			0,146	
Perceived Usefulness	0,277			
Result Demonstrability				0,041
Robot Anxiety			0,024	
Robot Playfulness			0,016	
Robot Self-Efficacy			0,010	
Subjective Norm	0,010	0,095		-0,001

EA data:

	Behavioral Intention	Image	Perceived Ease of Use	Perceived Usefulness
Behavioral Intention				
Image				0,072
Output Quality				0,069
Perceived Ease of Use	0,048			0,023
Perceived Enjoyment			0,212	
Perceived Usefulness	0,121			
Result Demonstrability				0,122
Robot Anxiety			0,003	
Robot Playfulness			0,001	
Robot Self-Efficacy			0,013	
Subjective Norm	0,015	0,106		-0,007

MM data:

	Behavioral Intention	Image	Perceived Ease of Use	Perceived Usefulness
Behavioral Intention				
Image				0,038
Output Quality				0,091
Perceived Ease of Use	-0,002			-0,006
Perceived Enjoyment			0,073	
Perceived Usefulness	0,329			
Result Demonstrability				0,017
Robot Anxiety			0,044	
Robot Playfulness			-0,002	
Robot Self-Efficacy			-0,002	
Subjective Norm	-0,005	0,073		0,000

APPENDIX 24. SUMMARY OF P VALUE, T VALUE, F^2 AND Q^2 TEST RESULTS FOR THE THREE DATA SETS

All data:

	Behavioral Intention			Image			Perceived Ease of Use			Perceived Usefulness		
	p & t	*fSquare*	q Square	*p & t*	*fSquare*	q Square	*p & t*	*fSquare*	q Square	*p & t*	*fSquare*	q Square
Behavioral Intention												
Image										OK	OK	OK
Output Quality										OK	OK	OK
Perceived Ease of Use												
Perceived Enjoyment							OK	OK	OK			
Perceived Usefulness	OK	OK	OK									
Result Demonstrability										OK	OK	OK
Robot Anxiety							OK	OK	OK			
Robot Playfulness												
Robot Self-Efficacy							OK	OK				
Subjective Norm				OK	OK	OK						

E.A. data:

	Behavioral Intention			Image			Perceived Ease of Use			Perceived Usefulness		
	p & t	*fSquare*	q Square	*p & t*	*fSquare*	q Square	*p & t*	*fSquare*	q Square	*p & t*	*fSquare*	q Square
Behavioral Intention												
Image										OK	OK	OK
Output Quality										OK	OK	OK
Perceived Ease of Use												
Perceived Enjoyment							OK	OK	OK			
Perceived Usefulness	OK	OK	OK									
Result Demonstrability										OK	OK	OK
Robot Anxiety												
Robot Playfulness												
Robot Self-Efficacy												
Subjective Norm				OK	OK	OK						

M.M. data:

	Behavioral Intention			Image			Perceived Ease of Use			Perceived Usefulness		
	p & t	*fSquare*	q Square	*p & t*	*fSquare*	q Square	*p & t*	*fSquare*	q Square	*p & t*	*fSquare*	q Square
Behavioral Intention												
Image										OK	OK	OK
Output Quality										OK	OK	OK
Perceived Ease of Use												
Perceived Enjoyment							OK	OK	OK			
Perceived Usefulness	OK	OK	OK									
Result Demonstrability												
Robot Anxiety							OK	OK	OK			
Robot Playfulness												
Robot Self-Efficacy												
Subjective Norm				OK	OK	OK						

APPENDIX 25. R&D UNCERTAINTY REDUCTION DATA

TAM3 information	R&D uncertainty reduction topic	Mean (%)	Std. Deviation
Usefulness --> Intention to use	Clarifies target market definition	21,6	13,1
	Improves product positioning (4P)	38,7	22,2
	Clarifies what needs new technology will address	43,9	22,3
	Helps product concept definition	53,4	22,7
	Clarifies product functionalities	45,3	22,2
	Helps choice of technology	52,0	16,6
Result Demonstrability --> Usefulness	Clarifies target market definition	43,6	22,7
	Improves product positioning (4P)	41,6	24,3
	Clarifies what needs new technology will address	40,4	24,3
	Helps product concept definition	34,4	20,0
	Clarifies product functionalities	36,7	21,3
	Helps choice of technology	32,7	21,7
Robot anxiety --> Ease of Use	Clarifies target market definition	45,5	24,8
	Improves product positioning (4P)	49,2	23,7
	Clarifies what needs new technology will address	38,1	27,1
	Helps product concept definition	45,5	19,8
	Clarifies product functionalities	35,5	26,0
	Helps choice of technology	47,2	23,1
Enjoyment --> Ease of Use	Clarifies target market definition	63,2	28,9
	Improves product positioning (4P)	56,8	23,7
	Clarifies what needs new technology will address	41,8	25,3
	Helps product concept definition	50,0	18,6
	Clarifies product functionalities	42,4	22,0
	Helps choice of technology	44,5	31,0
Image --> Usefulness	Clarifies target market definition	31,7	23,3
	Improves product positioning (4P)	37,5	21,2
	Clarifies what needs new technology will address	18,8	17,6
	Helps product concept definition	23,5	17,2
	Clarifies product functionalities	21,5	17,4
	Helps choice of technology	19,9	19,7
Subjective Norm --> Image	Clarifies target market definition	32,6	27,9
	Improves product positioning (4P)	36,0	23,8
	Clarifies what needs new technology will address	22,4	18,8
	Helps product concept definition	28,4	23,1
	Clarifies product functionalities	21,6	16,3
	Helps choice of technology	30,3	27,6

Appendix 25 continues.

The whole market and whole TAM3 model	Mean (%)	Std. Deviation
Clarifies target market definition	51,1	21,4
Improves product positioning (4P)	56,3	18,1
Clarifies what needs new technology will address	43,8	22,8
Helps product concept definition	53,0	17,0
Clarifies product functionalities	42,4	14,9
Helps choice of technology	47,2	23,8

Average	Mean (%)	Std. Deviation
Clarifies target market definition	42,8	12,6
Improves product positioning (4P)	47,6	14,2
Clarifies what needs new technology will a	38,2	9,2
Helps product concept definition	42,7	7,9
Clarifies product functionalities	37,5	8,9
Helps choice of technology	42,4	13,1

TAM3 information average	Mean (%)	Std. Deviation
Usefulness --> Intention to use	42,5	15,1
Result Demonstrability --> Usefulness	38,2	18,9
Robot anxiety --> Ease of Use	43,5	16,7
Enjoyment --> Ease of Use	49,8	16,0
Image --> Usefulness	25,5	15,2
Subjective Norm --> Image	28,6	17,8
Whole Market TAM3 model	49,0	13,4

Average	Mean (%)	Std. Deviation
All market uncertainties reduced	42,9	10,5
All technology uncertainties reduced	40,9	8,7

APPENDIX 26. RESEARCH PHASE 1 QUESTIONNAIRE MARKET SEGMENTATION PART ANSWERS

Market segmentation variables' mean values (MS1 – MS10):

	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8	MS9	MS10
Strongly disagree	5,0	5,0	2,5	6,6	14,9	10,7	1,7	5,8	2,5	0,8
Moderately disagree	9,9	6,6	7,4	33,9	36,4	22,3	15,7	25,6	9,1	0,0
Somewhat disagree	8,3	9,9	0,0	20,7	23,1	17,4	25,6	17,4	19,0	1,7
Neutral	48,8	31,4	9,1	14,9	5,0	14,9	14,9	19,0	8,3	3,3
Somewhat agree	20,7	28,9	25,6	10,7	15,7	16,5	24,8	18,2	28,1	10,7
Moderately agree	5,8	17,4	35,5	10,7	4,1	11,6	12,4	10,7	24,0	39,7
Strongly agree	1,7	0,8	18,2	2,5	0,0	3,3	3,3	3,3	7,4	43,8
Missing data	0,0	0,0	1,7	0,0	0,8	3,3	1,7	0,0	1,7	0,0

APPENDIX 27. RESEARCH PHASE 1 QUESTIONNAIRE TECHNICAL PART ANSWERS

Technical part variables' mean values:

Variable	Strongly disagree	Moderately disagree	Somewhat disagree	Neutral	Somewhat agree	Moderately agree	Strongly agree	Missing data
SN1	0,8	5	4,1	47,1	15,7	18,2	8,3	0,8
SN2	5,8	12,4	9,9	42,1	15,7	9,9	2,5	1,7
IMG1	20,7	14,9	12,4	42,1	5,8	3,3	0,8	0
IMG2	14	10,7	12,4	47,9	10,7	2,5	1,7	0
IMG3	14	16,5	12,4	28,1	18,2	9,1	1,7	0
OUT1	1,7	5	17,4	11,6	30,6	20,7	10,7	2,5
OUT2	1,7	9,9	16,5	13,2	25,6	24,8	6,6	1,7
OUT3	6,6	16,5	17,4	14	24,8	18,2	1,7	0,8
RES1	0,8	0,8	5,8	5,8	27,3	37,2	21,5	0,8
RES2	0,8	4,1	3,3	21,5	33,1	29,8	7,4	0
RES3	1,7	3,3	9,1	19	29,8	26,4	10,7	0
RES4	7,4	24	25,6	24	9,1	5,8	3,3	0,8
CSE1	4,1	7,4	8,3	14	17,4	29,8	19	0
CSE2	2,5	8,3	5	27,3	23,1	21,5	12,4	0
CSE3	2,5	12,4	8,3	16,5	14	24	22,3	0
CSE4	4,1	9,9	8,3	12,4	12,4	22,3	29,8	0,8
CANX1	0,8	4,1	9,9	5,8	13,2	31,4	33,9	0,8
CANX2	14	38,8	19,8	10,7	12,4	4,1	0	0
CANX3	22,3	38,8	18,2	5	9,9	3,3	0	0
CANX4	14	40,5	18,2	7,4	15,7	1,7	0,8	1,7
PU1	17,4	26,4	25,6	13,2	9,9	4,1	3,3	0
PU3	22,3	25,6	15,7	14	15,7	2,5	2,5	1,7
PU4	11,6	19,8	20,7	7,4	18,2	17,4	4,1	0,8
ENJ1	0,8	1,7	13,2	8,3	25,6	32,2	18,2	0
ENJ2	0,8	4,1	12,4	9,9	30,6	29,8	11,6	0,8
ENJ3	1,7	0,8	0,8	4,1	20,7	34,7	37,2	0
CPLAY1	0	5,8	14,9	13,2	33,1	26,4	6,6	0
CPLAY2	1,7	7,4	13,2	19	29,8	24	5	0
CPLAY3	0	7,4	9,1	13,2	23,1	34,7	12,4	0
CPLAY4	0,8	3,3	13,2	20,7	21,5	33,1	6,6	0,8
PEOU1	1,7	7,4	20,7	5	28,1	26,4	10,7	0
PEOU2	1,7	0,8	10,7	7,4	23,1	31,4	23,1	1,7
PEOU3	1,7	5,8	9,1	6,6	19,8	41,3	15,7	0
PEOU4	2,5	10,7	21,5	10,7	21,5	24,8	7,4	0,8
BI1	5,8	12,4	10,7	9,9	30,6	20,7	9,1	0,8
BI2	2,5	5,8	5	9,9	38	22,3	15,7	0,8
BI3	4,1	7,4	10,7	18,2	27,3	19,8	10,7	1,7