# User-Centered System Design in an Aging Society: An Integrated Study on Technology Adoption

by

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Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Engineering Systems
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 2014



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## Abstract

The aging of the population is an important global phenomenon that is bringing changes and challenges to various areas of society. Technology has been explored as one way to cope with the complexities and uncertainties that are emerging with this demographic change. However, the responses from the potential user segment have been far from enthusiastic, suggesting that older adults' adoption of technology is not simply a matter of performance and price, but a complex issue that is affected by multiple factors.

This dissertation explores the topic of older adults' technology adoption and use with an integrated framework that includes the perceptions, behaviors, and decisions of both the users and the producers. First, an exhaustive set of individual, technical, and social factors are identified and defined from a literature review and from user interviews with descriptions on these factors' importance and roles in the adoption and use process. Second, the results from a large-scale national survey are presented with a discussion of the empirical validity of the factors, as well as their relative importance and associations at three main decision stages of adoption and use – purchase, initial use, and continued use. Finally, this dissertation presents a set of three cases developed from multiple sources of evidence on existing technology-enabled solutions for aging-in-place.

The integrated framework described in this dissertation suggests the importance of considering population aging as a complex issue, as well as a new opportunity, that requires user-centered thinking from various players and stakeholders. Drawing on multiple methods of quantitative and qualitative data collection and analysis, the results underscore the importance and roles of different adoption factors during the design, development, and delivery of technology, as well as in older adults' decisions around adoption and use. This dissertation finds that the various requirements, expectations, and values of older adults are closely related and collectively affect their decisions and behaviors around technology. Finally, a set of implications for research and practice are presented around the need for the continuous involvement of older adults throughout design, development, and delivery of technologies for a changing population.

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# Acknowledgments

I would first like to thank my husband Duyong for all his love and support during the course of my doctoral studies – first as my best friend, then as my boyfriend, and finally as my lifelong partner. This thesis would have been difficult to finish without his cheerful encouragements and timely distractions. I am grateful to have him in my life to laugh and cry together, and to support each other's goals as well as our mutual aspirations.

I am very fortunate to have a committee – Prof. Olivier de Weck, Dr. Joseph Coughlin, Prof. Maria Yang, and Dr. Lisa D'Ambrosio – who always made it their priority to be my mentors and to provide me with opportunities for academic and professional development. I always felt reassured and confident knowing that I have such strong, knowledgeable, and empathetic supporters. Especially, I would like to thank my advisors Joe and Oli for the generous support and meaningful discussions.

I would also like to acknowledge my colleagues and friends at MIT, including those at the MIT AgeLab, Strategic Engineering Research Group (SERG), and the ESD Student Society (ESS). The conversations, collaborations, and critical reviews truly helped the advancement and progress of my research.

My research and life at MIT was significantly supported by Samsung Scholarship in multiple ways. I would like to acknowledge the foundation for the academic funding and resources, and for providing me with a great network of scholars and peers across the globe.

It is hard to find words to express my gratitude and appreciation enough for the love, care, help, trust, and patience that my family has shown. My father, Dr. Jong-Won Lee, served as an inspiration and a motivation as I went through the ups and downs of my life as a student. My mother Yongin has always been my role model and a great friend. Watching my parents bravely go through hardships and life challenges was more valuable than any advice or guidance that one could give. My brother Siwoo also deserves a special recognition for always being the best person to talk to and learn from. This thesis is dedicated to my family.

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# 1. Introduction and overview

The growth of the older population is one of the most salient megatrends in today's world that is challenging the present and future of social, technological and political systems across the globe (KPMG, 2014). In this chapter, the phenomenon of population aging is examined with a discussion of the potential changes and effects. With a holistic description on population aging as a complex systems issue, this chapter presents the research questions and objectives posed around the topic of older adults' technology adoption and use to guide through this dissertation.

## 1.1. Motivation and background

### 1.1.1. The aging of the population

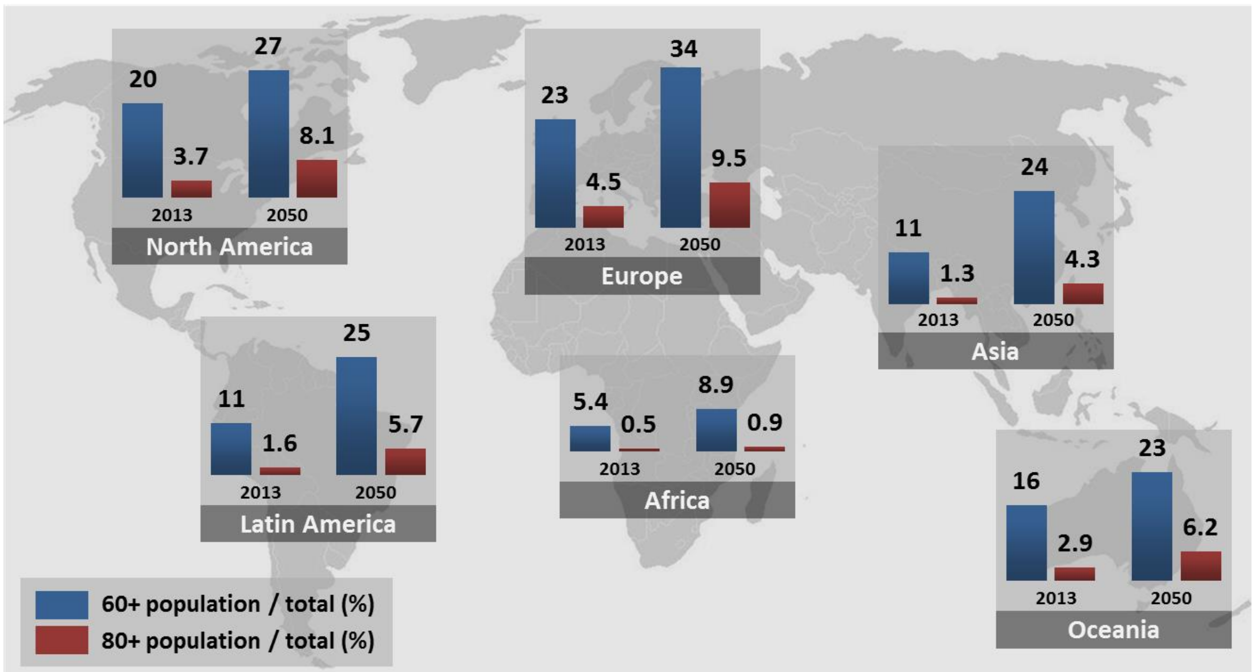
The aging of the population is a global trend that is already being observed in developed societies. According to the Population Reference Bureau (2013), the percentage of people ages 65 and older is 17% in developed countries[1], while the fertility rate remains at 1.6. In Japan, the 65 and older population already comprise 25% of population, while the total fertility rate is only 1.4. Also in Japan, an average female is expected to live until she is 86, and the average life expectancy for men is 79. While Japan is a strong leader in terms of population aging, many European countries are showing similar population compositions. For example, in Germany and Italy, about 21% of the total population are older adults 65 years of age or older.

Global aging is not just a current issue or a momentary phenomenon, but rather a trend that persists to progress with a great momentum. It has been predicted that the percentage of older adults ages 60 and older will increase by 45% by the year 2050 to comprise 32% of the total population in more developed regions. Furthermore, the number of older adults ages 80 years and older is predicted to more than double from about 57 million as of 2013 to 124 million in 2050 (United Nations, 2013). Japan is expected to remain as the most aged country in 2050, with about 36.5% of its total population aged 65 years and older, followed by South Korea (34.9%), Spain (34.5%), Italy (33.0%) and Germany (32.7%) (Pew Research Center, 2014).

[1] The Population Reference Bureau (PRB) and United Nations define more developed countries to include all of Europe and North America, Australia, Japan and New Zealand. All other regions and countries are classified as less developed (Population Reference Bureau, 2013; United Nations, 2013).

The rapid growth of the older population is expected to take place in less developed regions of the world as well. In the less developed regions, the population of older adults 60 years of age and older is expected to grow to 1.6 billion by 2050, which is about 189% increase from 554 million in 2013. The trend also holds even in the least developed regions[2], where the population of older adults 60 years of age and older is expected to increase from a total of 49 million in 2013 to 183 in 2050. While the population in the developing countries are still relatively young compared to the more developed regions, population aging is projected to happen very rapidly in the developing world with a significant drop in fertility rate. For example, the fertility rate for the least developed regions is expected to drop from the current 4.53 children per woman to 2.87 by 2045~2050 (United Nations, 2013). Figure 1 shows a summary of projected population growth in the older adult population by regions of the world.

**Figure 1. Population aging projections by global regions (source: United Nations, 2013)**




While the increase in the proportion of the population 60 years of age or older is less drastic for North America compared to other regions including Asia, Africa, and Latin America and the Caribbean, projections state that the United States will also turn grayer at a fast rate. Between 2000 and 2010, the proportion of the older adult population 65 years of age and older increased by 15.1%, which is larger than the growth rate of the total population of the U.S. during the same period, which was 9.7% (US

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2 The United Nations definition of least developed countries includes a total of 49 countries with low incomes, high economic vulnerability, and poor human development indicators (Population Reference Bureau, 2013; United Nations, 2013)

Census Bureau, 2011a). While older adults 65 years of age and older accounted for about 13.1% of the total U.S. population in 2010, the proportion is expected to grow to about 21.4% by the year 2050. In other words, one in every five Americans are expected to be 65 years of age or older by 2050 (Pew Research Center, 2014). Also, the life expectancy at birth in the U.S. is predicted to increase to 83.5 years by 2045~2050 from 78.9 of 2010~2015 (United Nations, 2013).

### 1.1.2. Population aging as a complex systems issue

The aging of the population is the most prominent trend in today's demographics. However, it is not simply the change in numbers that policymakers, engineers, managers, researchers and the general population should be concerned about. This unprecedented demographic change is bringing new demands, opportunities and challenges.

As more people are living longer, many areas of society are facing new problems and issues. Previously, aging has been thought of as a medical or safety issue, and efforts to address the issue have focused on improving clinical conditions, procedures and environments. However, the aging of the population has implications on not only health care but also education, employment, housing, transportation, marketing, product development and the economy in general.

Concerns are already being raised around economic indicators where sizable changes are expected. For example, in the U.S., the public pension expenditures are expected to grow from 6.8% of the gross domestic product (GDP) in 2010 to 8.5% in 2050. Public health care expenditures in the U.S. are expected to rise even faster to 14.9% of GDP by 2050, which is more than double from 6.7% in 2010. The old-age dependency ratio, which is defined as the number of older adults aged 65 year and older per 100 working-age people of ages from 15 to 64, is expected to significantly increase from 19 in 2010 to 36 in 2050. Also, when asked about who should bear the greatest responsibility for older adults' economic well-being, 24% of people in the U.S. pointed to the government (Pew Research Center, 2014). These expectations and predictions have great implications for policies around the health and general well-being of older adults, as well as the working-age population who will together bear the related costs.

The implications of on public policies are closely related to other areas that are likely to be strongly influenced by the population change. The aging of the population and the related implications on public policies are expected to affect the ways in which older adults and their families live and interact, as well as how formal health care is delivered, how products are designed, and how commercial and public services are structured. In short, the aging of the population can be discussed as a systems issue with structural and behavioral complexity which includes a number of subsystems and issues that are interconnected and interrelated.

The breadth of areas in society affected by the aging of the population is not the only dimension of complexity. There is another layer of complexity which can be identified in system evaluation. That is, when population aging is viewed as a system, there are complexities and uncertainties involved in defining the “outputs”, or the possible outcomes. The desired outcome, which was traditionally seen as living longer, is now being newly defined as quality of life encompassing happiness, independence and continued productivity as well as physical and mental health (Boult et al., 2009).

The transition in definition of successful aging is further strengthened as the Baby Boomers, Americans who were born after World War II between years 1946 and 1964, started to turn old. The oldest of the Baby Boomer generation is now reaching the common retirement ages. Unlike prior generations, this new group of older adults is different in that they are more independent, experienced with technology, and familiar with popular culture (Schuman and Scott, 1989). As this large group of people with a total population of 78 million, comprising about 26.1% of the total U.S. population (US Census Bureau, 2006), enters the older population, the meaning of successful aging will continue to be redefined as general well-being and quality of life as they are likely to pursue to work and play throughout their lives.

These complexities and uncertainties together form a change of paradigm with which people understand aging. While living longer traditionally referred to surviving by reacting to changes in physical needs, it is now being redefined as maintaining lifestyle values and quality living by preparing and planning for anticipated changes. Stakeholders are now increasingly realizing that the design of products, delivery of services and implementation of policies need to address emerging issues and changing needs that are brought by population aging. In short, the demographic change is acting as a trigger for established systems to adapt and evolve.

As this demographic trend persists, academia, industry and government are looking for solutions (Rodriguez et al., 2009). Particularly, as a means to address problems that arise due to complexities and uncertainties in the system structure, social context, and characteristics of older adults, technology has gained attention as a possible solution. Technology is now being regarded to be the center of strategies for effectively enabling older adults to stay healthy, independent, safe and socially connected. However, due to shortcomings in assessment of older adults’ lifestyles, needs and expectations, technologies are not being easily accessed, widely accepted or effectively used by the target group of users.

A main cause of non-adoption of technologies for older adults is that they have often been developed based on an insufficient understanding or stereotypes of older adults. While older adults today are more connected, active and independent, biased social perceptions that view older adults as weak and unhealthy still exist. Studies have identified that the older adults' needs and expectations are not properly assessed in product development and that the experiential and cultural gaps between older users and younger developers are not being fully addressed (Eisma et al., 2004; Niemelä-Nyrhinen, 2007). In design, development and delivery of technology for older adults' use, it is important to first fully understand their perceptions and requirements. However, the traditional and stereotypical perceptions that view older adults as frail and weak are still prevalent among designers, managers and the general public.

It is true that limitations in physical and cognitive capabilities are more prevalent among older adults. As people age, they are likely to experience declines in sensory abilities including vision, audition and motor perception (Mynatt and Rogers, 2001; Holzinger et al., 2007). Such age-related physical changes and disadvantages have been discussed to act as a barrier to technology use as decrements of sensory perception and motor functions make it difficult to use technology (Selwyn et al., 2003). Thus, it is in fact important to be aware of the age-related changes and to address them in the design of technology-enabled systems and their user interfaces.

However, a thorough understanding of the physical and cognitive differences is not sufficient for a correct and complete understanding of the segment. As discussed earlier, it is also important to understand and address the need for connectivity, activity and independence (Holzinger et al., 2007; Rogers and Fisk, 2010; Steele et al., 2009). The designers and managers responsible for activities and decisions related to development and distribution of technologies for older adults should be aware that their target consumers are willing to use new technologies, contrary to stereotyped views that described them as laggards or non-users who avoid and reject technologies in general (Rogers and Fisk, 2010; Mynatt and Rogers, 2001; Niemelä-Nyrhinen, 2007).

The demographic change and the related changes in needs, expectations and values are moving ahead of the existing systems and views that have been established based on assessments of previous generations or different cohorts. More effort is needed in investigating the characteristics of older adults as potential users of various technologies. In order to realize the potential benefits promised by technology advancements and innovations, older adults' individual characteristic and the broader social contexts should be comprehensively understood to inform the design, development and delivery of technology-enabled products and systems.

## 1.2. Research questions and objectives

This thesis seeks to address several limitations in the existing research and practices around the design, development and distribution of technology-enable systems and solutions for older adults. Based on a triangulation and combination of literature review, user survey and case studies, this thesis aims to provide a more complete understanding of the older population's characteristics, needs and values and their implications on design practices. More specifically, it aims to provide answers to the three following research questions.

1) What factors affect and determine how older adults accept and use technology?

This question aims to address the need for a better understanding of older adults as users and consumers of various technology-enabled systems. To answer this question, chapter 3 presents a set of factors that affect and determine older adults' perceptions, decisions and behaviors around adoption and use of technology. The results from a review of existing literature and a set of user interviews are summarized to describe the adoption factors.

2) What roles do the adoption factors play during the various stages of older users' experiences with technology?

To answer this question, a large-scale survey was conducted to empirically investigate the validity of the adoption factors identified in the previous step. The importance of the factors and the roles they play during adoption and use are presented in chapter 4 based on analyses of quantitative and qualitative data gathered from the survey. For a detailed analysis of the factors, the results are compared between different decision stages – purchase, initial use and continued use – and groups with different individual characteristics such as age, gender, income and current technology usage.

3) How are the adoption factors considered and incorporated into the design, development and delivery of technology-enabled systems?

This question seeks to complete an integrated framework by extending the findings around the adoption factors from consumer studies to product development practices. To answer this question, chapter 5 presents case descriptions developed from an investigation of three cases in which technology-enabled solutions were designed and developed for older adult users. The case descriptions include descriptions on activities related to involving users and gathering user inputs and discussions on the decisions that were based on consideration of the adoption factors. The three case descriptions are summarized and synthesized to find common patterns or processes and to explain differences between cases.

## 1.3. Thesis overview

The remainder of the thesis is structured as follows. Chapter 2 provides an overview of existing models and previous discussions related to the research questions. Prior works on the related topics, including technology adoption, product design, user studies and design for older adults, are summarized with a discussion on the key lessons and limitations. Chapter 3, 4 and 5 present the processes and results of investigation around the three research questions described in the previous section. Chapter 3 describes a set of factors that were found to affect and determine older adults' adoption and use of technology. The identification process and methods are described in chapter 3 as well. In chapter 4, the process and results of a large-scale survey on the technology adoption factors are presented. The findings are described based on various analysis techniques that were applied for investigating patterns in the quantitative and qualitative data collected from the survey. While chapter 4 focuses on the user and consumer side, chapter 5 looks at the development side with findings from a set of case studies on existing products and projects. With case descriptions developed from various sources of information, the key design activities are presented with details on development decisions, user involvement, and consideration of the adoption factors. Chapter 6 brings all the pieces together with a summary of the thesis and a discussion of its contributions. Possible directions for future research are also discussed in chapter 6.

# 2. Related works

Existing literature provides models, discussions and suggestions for describing how technologies are adopted and used by people, and how they are designed, developed and delivered by industry. While the topics of technology adoption and product design have been more widely studied for the general population, the aging of the population and related changes have recently spurred growth in the literature around older adults' adoption and use of technology, as well as practices around design and development of technologies for older users.

This chapter presents a summary of existing models and academic discussions around technology adoption and use, process of design and development, and methods and principles of user-centered design. For each topic, studies conducted specifically for the older population are summarized separately to point out the gaps present in existing research and to address the need for a more integrated framework adapted to the changes in the design and use environments. This chapter also provides a summary of limitations in existing research that need to be further discussed.

## 2.1. Studies on technology adoption

### 2.1.1. Technology adoption models

When people interact with technologies, they encounter various sensory, operational and functional characteristics that affect their perceptions and experiences. In a context where people are deciding to buy or start using technology-enabled products or services, various factors influence their attitudes, intention toward use, and actual usage (Childers et al., 2001; Ngai et al., 2007). Technology adoption is a term that is used to describe the decisions and related perceptions and attitudes around people's acceptance and use of technology. Technology adoption is sometimes distinguished from technology acceptance in that it refers to the behavioral decisions around using a technology, while the latter describes attitudes and intentions more closely. However, the two terms are usually used and discussed to be interchangeable.

Studies have sought to identify and describe the key factors that influence and determine technology adoption. In various fields of studies, models have been developed to explain how technology adoption is affected by a number of different factors. Everett Rogers' Diffusion of Innovations Theory (1995) is an influential early framework that explains the patterns in which an innovation – an idea, practice, or object that is perceived as new by individuals or other units of adoption – is adopted by individuals as well as the overall user population.

At the population level, the Diffusion of Innovations Theory categorizes adopters, based on the degree of innovativeness and the average time of adoption, into the following groups: innovators, early adopters, early majority, late majority and laggards (Rogers, 1995). According to Rogers, innovators are the first 2.5% of the population to adopt, and they play a gatekeeping role in the flow of innovations. Early adopters, who are the next 13.5% of the population to adopt, are likely to be opinion leaders who help trigger a wider spread of an innovation. The next 34% is described as the early majority, followed by the late majority, who are the next 34% to adopt, and laggards, the last 16% to adopt.

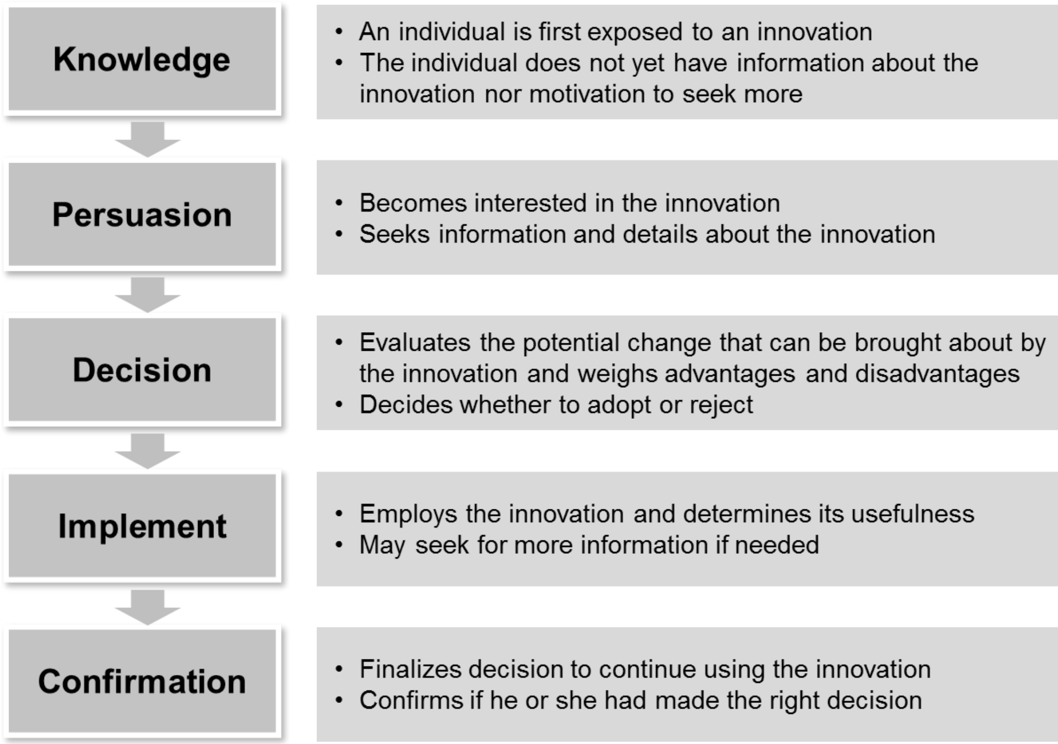
Concerning the individual adopters, the model identifies five intrinsic characteristics of innovation – relative advantage, compatibility, complexity, trialability, and observability – as the factors that influence their decision to adopt or reject an innovation. These five factors are described in Table 1.

**Table 1. Factors of individual adoption decisions (Rogers, 1995)**

| Factor | Definition |
|---|---|
| Relative advantage | The degree to which an innovation is perceived to have improved over the previous generation. |
| Compatibility | The level of compatibility that an innovation has to be assimilated into an individual's life and be perceived as perceived as consistent with the existing values, past experiences, and needs of potential adopters. |
| Complexity | The degree to which an innovation is perceived as difficult to understand and use. The perceived complexity of an innovation is negatively related to its rate of adoption. |
| Trialability | How easily an innovation may be experimented. This is positively related to an innovation's rate of adoption. That is, if a user is able to test an innovation, the individual will be more likely to adopt it. |
| Observability | The extent that an innovation is visible to others. An innovation that is more visible will drive communication among the individual's peers and personal networks and will in turn create more positive or negative reactions. |

Rogers' theory also models an individual's adoption of an innovation as a process. It describes that an innovation is adopted or rejected by people as they become aware, get interested, evaluate, and decide, employ and implement, and finally confirm the usefulness of the innovation. The five steps in the process are named knowledge, persuasion, decision, implementation, and confirmation. This five-step process is summarized in Figure 2.

**Figure 2. Rogers' five-step process model (adapted from Rogers, 1995)**




Technology Acceptance Model (TAM) by Fred Davis (1989) is another framework explains adoption of technology innovations. While Diffusion of Innovations applies more generally to innovations in various domains, TAM pertains to technologies in the information sciences domain. The model suggests that people make decisions about whether to adopt and use a new technology based on their perceived usefulness and ease-of-use. According to TAM, people evaluate observable external variables such as system features and characteristics and form subjective perceptions around potential usefulness and ease-of-use when they are introduced with a new technology. In other words, TAM explains the effect of external variables on people's attitudes and behaviors to be mediated by their perceptions of usefulness and ease-of-use. The overall model with key descriptions is summarized in Figure 3.

TAM was introduced as an adaptation of the Theory of Reasoned Action (TRA). TRA is a general model that can explain a wide range of human behavior. In contrast, TAM is a special case that uses TRA as a theoretical base but applies it specifically for computer usage and adoption behavior. Developed by Martin Fishbein and Icek Ajzen, TRA suggests that an individual's attitude about a behavior and subjective norms about the behavior affect his or her behavioral intention (Fishbein and Ajzen, 1975). That is, an individual's behavioral intention depends on his or her beliefs about the behavior, as well as the perceived expectations from relevant people around him or her. Figure 4 summarizes the key concepts suggested in TRA.

**Figure 3. Technology Acceptance Model (adapted from Davis et al., 1989)**

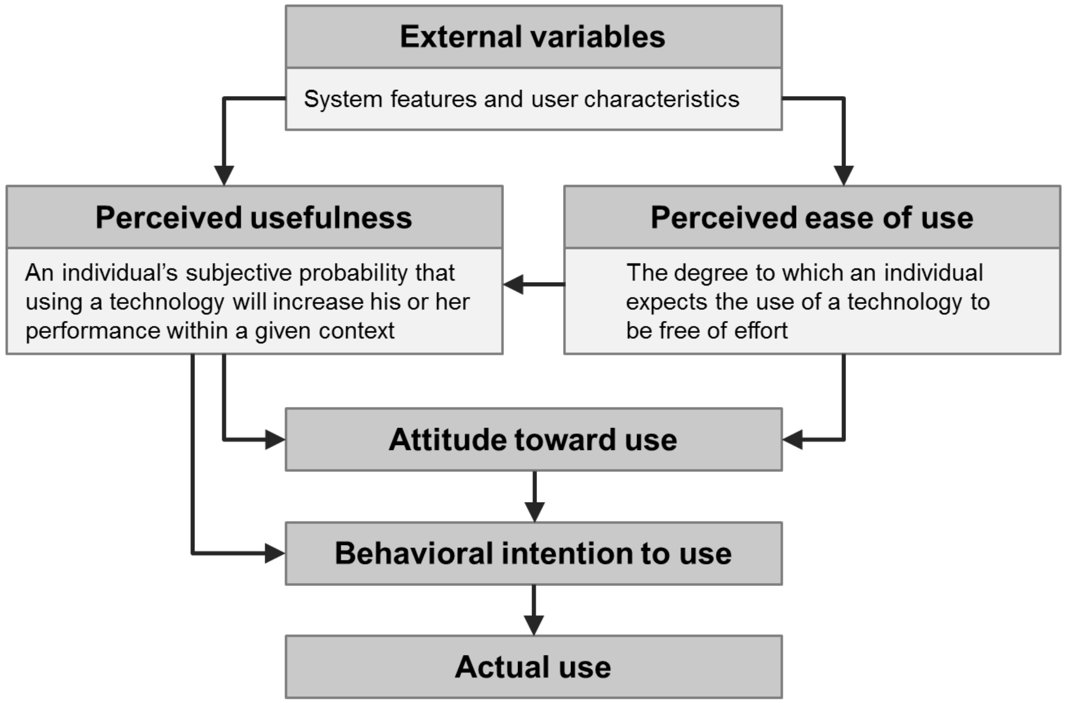
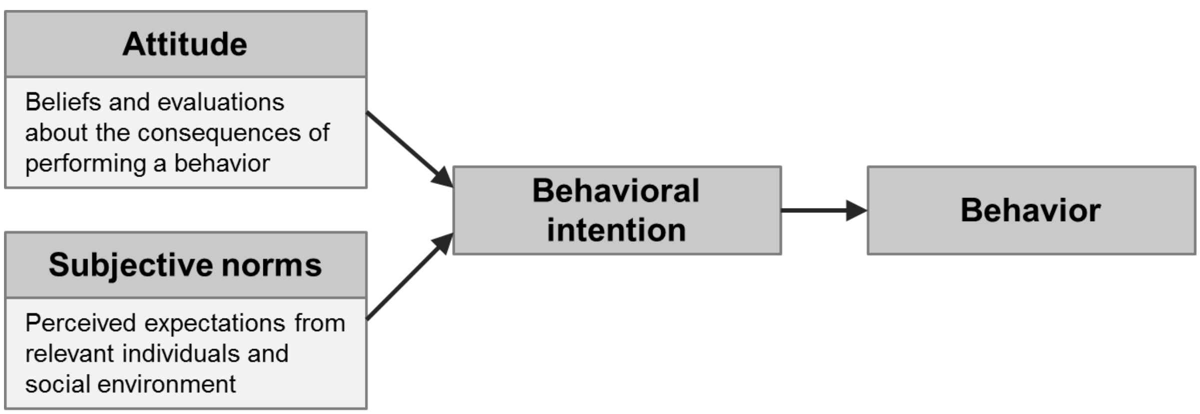



**Figure 4. Theory of reasoned action (adapted from Ajzen and Fishbein, 1980)**




These models – Diffusion of Innovations, TAM, and TRA – have been influential in that they served as theoretical bases for literature that developed around technology and innovation adoption. Extending from the earlier models, studies from related fields have sought to validate them in different application areas, apply them to systems in various domains, determine relative importance of the factors, and find other relevant factors.

In many studies, social context has been found as an important factor that influence people's attitudes toward technology. The social environment and situation around adoption and use were not identified as key factors in TAM. However, many studies have agreed with Diffusion of Innovations and TRA in that social interactions, peer support, and subjective norms can play important roles. In a study on adoption of high-tech innovations, Kulviwat et al. (2009) found that social influence affects people's adoption attitude, and that the relationship is stronger when an innovative technology is publicly consumed. Lu et al. (2003) and Barnes and Huff (2003) developed models extending from TAM to include social influence and norms as factors that affect adoption of wireless Internet. Hamre (2008) stated that users' decision to adopt a new technology is influenced by the social contexts or networks they are in. In a study on determining students' intention to use technology, Robinson (2006) found that students' attitudes about technology are affected by social influence. In other words, studies have suggested that the way people respond to technologies is influenced to some degree by their social references.

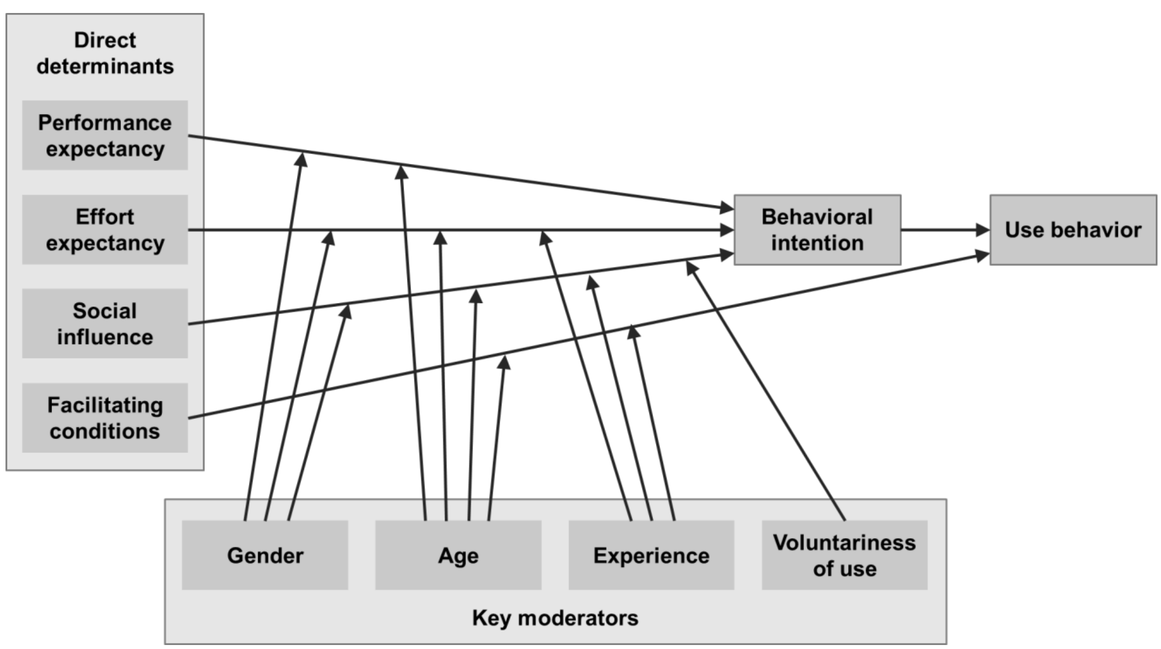
Studies have also addressed that individual differences, including age, education, income, cultural background, technology self-efficacy, and life stage, can affect adoption decisions. Venkatesh and Davis (1996) found that an individual's self-efficacy affects his or her perception of a technology's ease-of-use, which in turn determines adoption. Similarly, Sarker and Wells (2003) suggested that individual characteristics, including self-efficacy, prior experience, and age, affect people's attitude toward the adoption of mobile handheld devices. Such individual differences have been represented with demographic variables, and studies have been done to find how the demographic characteristics influence people's attitudes toward technologies. In a study on people's attitude toward the Internet, Porter and Donthu (2006) found that age, education, income and race are associated differentially, and concluded that the younger, highly educated, wealthy, and white have more positive attitudes. Golvin and Anderson (2009) reported that individuals who differ in age and family settings, whether living alone or with family, show differences in the types of technology they use and the attitudes toward them. These studies can be discussed to extend the descriptions from Diffusion of Innovations and TAM. In Diffusion of Innovation, the compatibility factor suggests that adoption decisions can depend on an individual's characteristics as it describes the importance of an innovation's ability to assimilate into one's life. Also, the individual characteristics identified in these studies are included in TAM as external variables, which can affect how perceived usefulness and ease-of-use can vary between individuals.

Studies have also found empirical evidence around how technical features and system performance can affect adoption and use of technology. In a study on mobile ticketing service for public transportation, Mallat et al. (2008) commented that design compatibility affects people's attitude adoption of the service. Phillips and Zhao (1993) identified poor device performance as a cause in non-adoption of assistive technology for people with disabilities. Sarker and Wells (2003) suggested a more comprehensive set of product factors to explain how adoption attitudes toward mobile handheld devices are determined. In their integrated model, they included technology characteristics such as interface features and network capabilities, modality variables such as type of mobility, and task characteristics such as communication volume. In TAM, technical features and system characteristics are included as external variables that affect perceived usefulness and ease-of-use. These system features, or the improvements in such features, have been discussed as the relative advantage factor in Diffusion of Innovation. Thus, the related studies can be discussed to have corroborated and validated the role of technical features and system performance in various settings and domains.

Furthermore, studies have also found evidence around interrelationships between different factors. For instance, social factors, such as subjective norms and peer support, and individual characteristics, including age, gender, and self-efficacy, are often found to be interrelated. In a study on software use, Morris and Venketesh (2006) found that older people were more strongly influenced by subjective norms in developing attitudes toward new software compared to younger people. At the perceptions level, the interrelationship between perception factors is mainly found in a way that perceived ease-of-use affects people's perceived usefulness of a technology as also suggested by TAM. Porter and Donthu (2006) found statistical evidence that individuals who perceive the Internet as easy to use also perceive it as more useful compared to those who perceive it as more difficult to use.

Based on the discussions that have stemmed from the earlier models, an updated version of TAM – the Unified Theory of Acceptance and Use of Technology (UTAUT) – has been proposed (Venkatesh et al., 2003). Figure 5 summarizes the factors and their relationships as suggested by UTAUT.

**Figure 5. The Unified Theory of Acceptance and Use of Technology (adapted from Venkatesh et al., 2003)**



This newly unified model extends TAM to include a number of variables to describe individual characteristics – gender, age, experience, and voluntariness of use – and external factors – social influence and facilitating conditions. In UTAUT, four direct determinants – performance expectancy, which includes perceived usefulness as described in the original TAM and relative advantage in diffusion of innovations, effort expectancy, which includes perceived ease-of-use in the original TAM, social influence, which includes subjective norm as described by TRA, and facilitating conditions, which includes compatibility as described in diffusion of innovations. Also, UTAUT describes that adoption intention and behavior are influenced by these factors and their complex relationships. For example, the model explains that gender and age mediates the effect of an individual's expectations of a technology's performance on his or her behavioral intention to use.

### 2.1.2. Technology adoption among older adults

Technology adoption among the general population has been widely studied in various domains. However, the topic has been less popular for describing the decision making processes for consumers and users of the older population. Furthermore, previous studies have focused mostly on physical disabilities and safety issues, and viewed older adults as non-adopters or laggards (Niemelä-Nyrhinen, 2007). Older adults are in fact different from the general population in terms of physical and cognitive capabilities, and familiarity with new technology (Carrigan and Szmigin, 1999; Brown and Venkatesh, 2005; Czaja et al., 2006). However, while often stereotyped as weak, dependent, and unwilling to change, older adults today are among the wealthiest and most demanding consumers who pursue independent, active, and socially connected lifestyles (McCloskey, 2006; Conci et al., 2009; Coughlin, 2010). Also, quite contrary to the social perception, older adults are aware of technological benefits and are willing to try new technologies (Demiris et al., 2004). Older adults do not simply reject new technologies, but accept them under the influence of various factors, such as usefulness and cost, as the general population does (Melenhorst et al., 2001; McCreadie and Tinker, 2005; McCloskey, 2006).

Due to differences in physical age and previous experiences, there exists a gap between what the designers and developers understand and what older adults call for. The actual expectations and needs of older adults are often masked by stereotypes and not properly assessed. While older adults experience needs for various services related to everyday life, existing systems are providing them with services that are overly focused and built around stereotypes that they do not identify themselves with (Essén and Ö stlund, 2011). For example, current products are developed mostly for safety and physical assistance, although older adults strongly value independence, privacy, and social interactions (Demiris et al, 2004; Kang et al., 2010).

Studies have explored barriers to older adults' technology adoption to better understand the cause of low adoption among existing technologies. Some of the barriers, including technology anxiety and lack of experience, are specific to the individuals. Apprehensiveness, or anxiety toward technology, has been pointed out as a barrier to adoption by a number of studies (Walsh and Callan 2011; Steele et al. 2009; Czaja et al. 2006). Experience was also found to be important in that older adults often found it hard to understand a new technology if they couldn't easily relate it to something they are familiar with (Steele et al. 2009; Walsh and Callan 2011; Brown and Venkatesh 2005).

Some technological characteristics have also been identified as possible barriers to adoption. In many studies, improper and inappropriate design has been discussed as a barrier to adoption. Technologies that are designed without consideration of older adults' physical and cognitive capabilities are likely to be rejected due to lack of user-friendliness (Czaja et al. 2006; Wang et al. 2011; Mitzner et al. 2010; Piper et al. 2010). Cost has also been identified as another barrier in that some older adults expressed dislikes around technologies that are expensive (Mitzner et al. 2010; Kang et al. 2010; Steele et al. 2009). An important barrier to adoption is the possibility of stigma, which is related to not only product features but also with social influence and perception. Demiris et al. (2004) found that older adults refuse to accept some wearable devices because they thought it would stigmatize them as frail or in need of special assistance. This is especially true in the case of assistive technology. For example, Gooberman-Hill and Ebrahim (2007) found that an important cause of older adults' rejection of assistive aids was that the aids, by their purpose and design, were associated with aging and dependency. Studies have found that older adults are reluctant and even ashamed to wear and use pendant alarms because they felt that the devices are too awkward, obtrusive, and recognizable as a health monitoring device (Walsh and Callan 2011; Steele et al. 2009). Kang et al. (2010) stated that older adults want assistive technology to help them live independently but not in a way that others can see them using it, since display of using such technology may be seen by others as an admission to dependence and create a sense of restricted autonomy.

As an effort to minimize the experiential, cultural, and knowledge gaps between older adults and designers, few studies have sought to identify and describe factors that affect technology adoption and use among the older population. However, most of the studies done on this topic were exploratory in nature and were based on interviews and focus groups to gather ideas and opinions to understand the field better. Demiris et al. (2004) conducted focus groups with people over age 65, followed by a content analysis, to get a better understanding of what older adults think about smart home technologies. Mitzner et al. (2010) also did focus groups to learn about older adults' attitude about technologies in home, work, and health domains. To look into older adults' acceptance of wireless sensor networks, Steele et al. (2009) formed focus groups with older adults living independently. More recently, Heinz et al. (2013) conducted a series of focus groups to discuss older adults' perceptions around use of technology in various contexts. Rodriguez et al. (2009) relied on semi-structure interviews with older adults to gain insights in prototyping a home-based communications system.

While such exploratory methodologies were found to be useful in getting a better understanding of older adults' perceptions and attitudes, they were not able to provide enough information or data for describing and explaining how the identified factors influence and determine adoption of technology. Few studies have conducted large-scale surveys to empirically model the relationships by building on to TAM, but were limited in addressing the various individual, technical, and social factors that were suggested to be relevant. McCloskey (2006) developed a TAM-adapted model to describe older adults' acceptance of e-commerce, but only included the original factors of perceived usefulness and ease-of-use. Similarly, Czaja et al. (2006) and Chung et al. (2010) extended TAM to include individual variables such as age, education, and self-efficacy to describe attitudes toward technology, but their models did not include technical features or social aspects.

Such individual, technical, and social factors have been suggested to have influence on older adults' technology adoption. However, only few studies have sought to fully explain their relationships with perception factors, as well as their combined influence on overall attitude and behavior. Wang et al. (2011) have suggested a conceptual model titled Accelerating Diffusion of Proven Technologies (ADOPT), which is shown in Figure 6. In this model, seven strategies – user-friendliness, value, sustainability of business model, promotion and marketing, partnerships, technology champions, and coaching – are described as facilitating factors of technology adoption and diffusion. The ADOPT model focuses on home and community-based health technologies and discusses the effects of the strategies as they relate to older adults, their collaborators (technology companies, medical providers, services organizations, caregivers, family members, insurance companies, etc.), and the wider context in which older adults live. The model also describes key factors affecting technology adoption and use as they relate to the three environments – older adults, collaborators, and context.

In a study on the acceptability of assistive technology, McCreadie and Tinker (2005) suggested a model that describes potential factors and how they are related. This model, which was empirically developed based on results from in-depth interviews, suggests that older adults' felt need for assistance, which is affected by user characteristics and housing features, combines with various attributes of assistive technology, including efficiency, reliability, simplicity, safety, aesthetics, and availability, to determine acceptability. Figure 7 shows a summary of the factors and their relationships as described by the suggested model.

**Figure 6. The ADOPT model for older adults (adapted from Wang et al. 2011)**

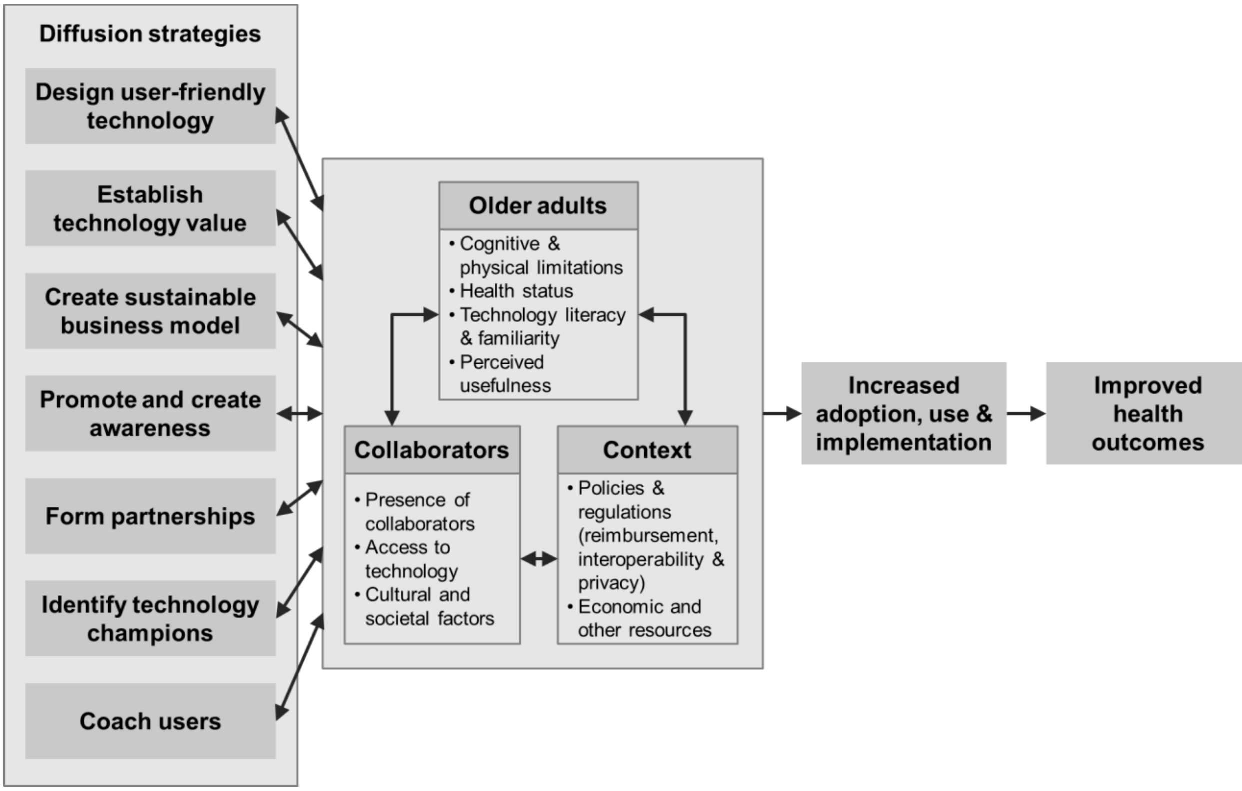
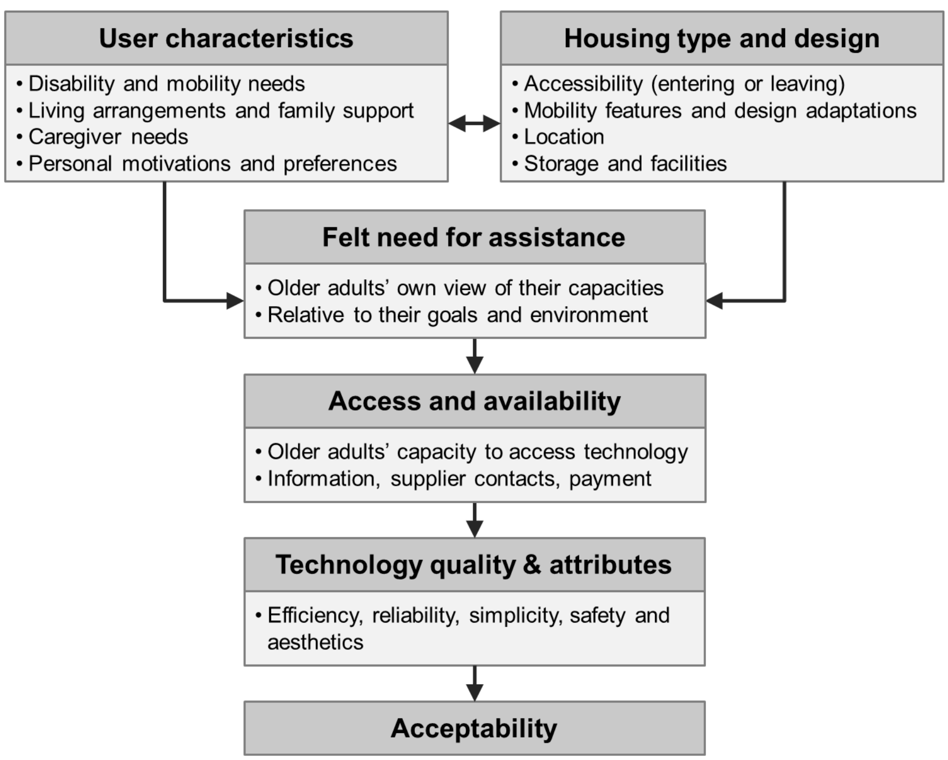
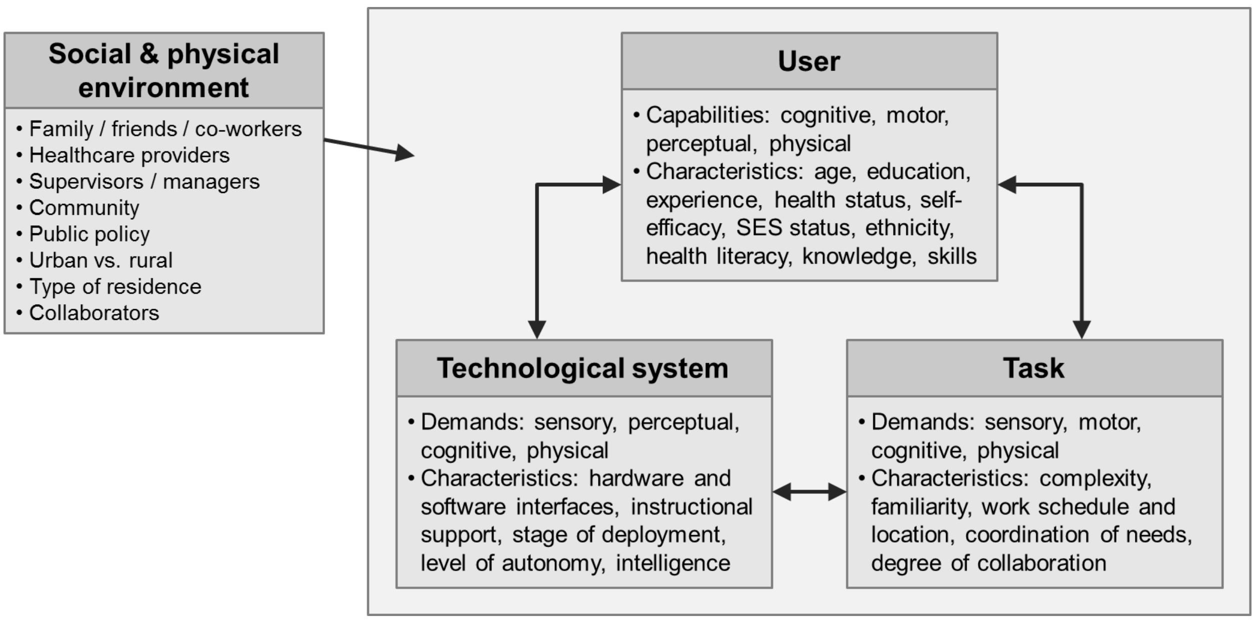



**Figure 7. A model of acceptability of assistive technology (adapted from McCreadie and Tinker, 2005)**



In a recent study that investigated the match between older adults' psychological needs and technology design features, Wendy Rogers and Arthur Fisk from The Center for Research and Education on Aging and Technology Enhancement (CREATE) proposed a model that describes the potential factors that influence successful use of technology (Rogers and Fisk, 2010). This model lists characteristics, demands, and capabilities of users, tasks, and technological systems and illustrates the interactions and interrelationships between them. Also, the CREATE model identifies social and physical environments, which include family and friends, healthcare providers, public policy, and other collaborators, as important dimensions that affect technology use. The factors and their relationships described by the CREATE model is summarized in Figure 8.

**Figure 8. The CREATE model (adapted from Rogers and Fisk, 2010)**




While the existing frameworks around older adults' adoption and use concern different application domains and differ in how they were developed, they address some important components in common. First, individual characteristics of older adults are described as key variables that affect how technology can be successfully adopted and used. These characteristics include demographics variables, such as age, gender, level of education, socio-economic status, and ethnicity, as well as experience and knowledge relevant to technology use, health status and disabilities, and cognitive and physical capabilities. Second, the models commonly address characteristics and quality attributes of technology, including value and usefulness, efficiency, familiarity and ease-of-use, complexity, reliability, safety, aesthetics, availability, and support. Lastly, the models include characteristics of external environments, collaborators and contexts of use as factors that influence the overall outcome. In the ADOPT model by Wang et al. (2011), older adults' personal connections ("technology champions"), economic resources, and related social structures and organizations are described to interact with older adults as they adopt and use community-based health technology. The acceptability of assistive technology model suggested by McCreadie and Tinker (2005) describes that older adults' housing environment and its relationships with user characteristics affect their felt need, which then determines acceptability. In the CREATE model by Rogers and Fisk (2010), the social and physical environments around technology use are described as separate dimensions that affect the overall model interactions and outcome.

## 2.2. Design of technologies for older adults

The process of designing and developing products and services has been modeled and described in many different domains and fields of study. In addition, the process frameworks and models are often affected by various design principles and philosophies. This section provides an overview of existing product development process frameworks along with a summary of related user-centered design principles and user studies methods. Also, the latter part of this section summarizes the literature on adaptations of the process frameworks to products targeted at older adults.

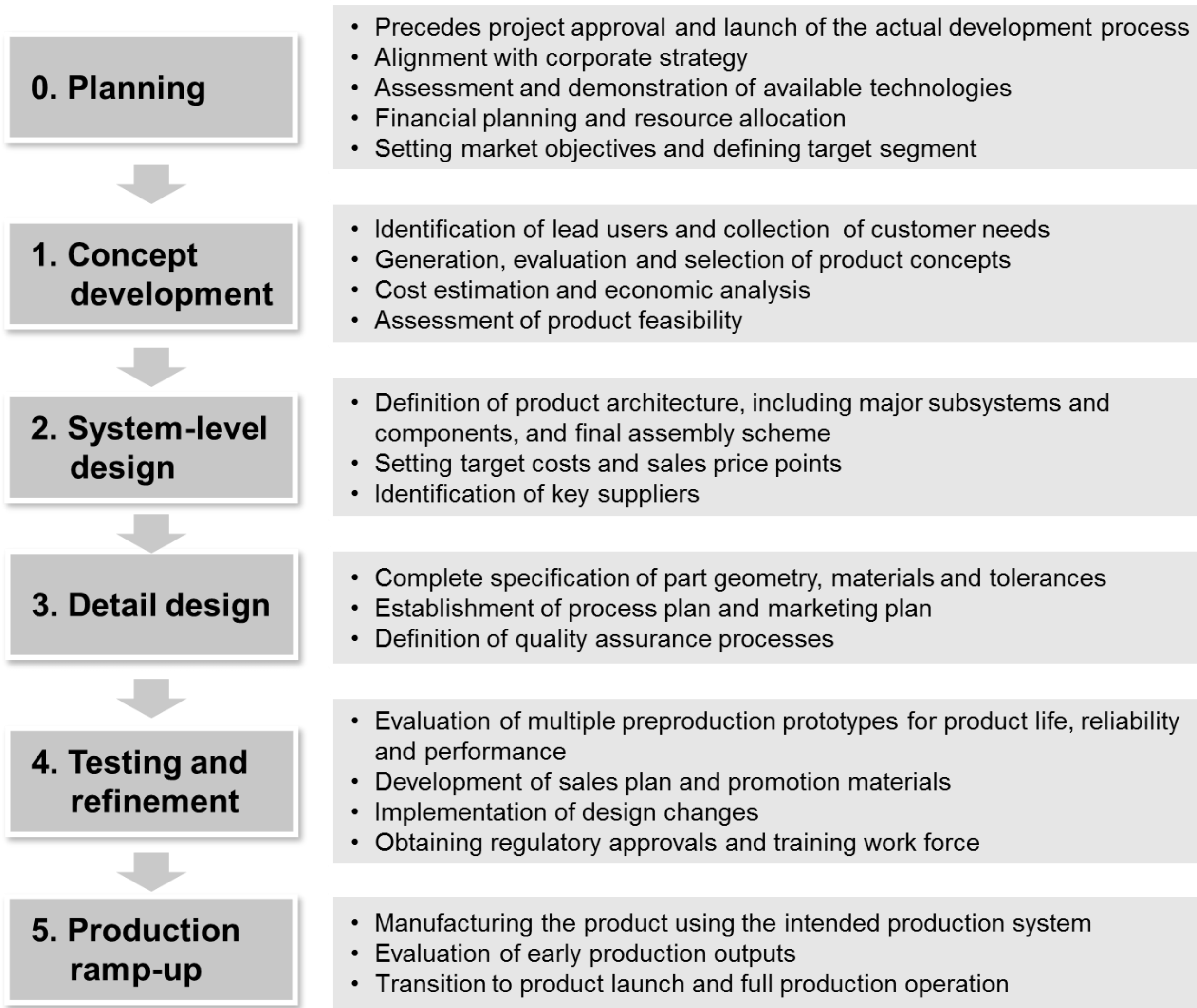
### 2.2.1. User-centered product design and development

#### 2.2.1.1. Process frameworks

A product development process is defined as the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product (Ulrich and Eppinger, 2004). In practice, a structured sequence of development activities, or a staged framework of development, is often followed for an efficient and effective development of products. While the specific names and detailed activities vary by the different contexts and domains, frameworks and models of product development commonly include the following stages and processes - the early stages where ideas and concepts are generated, developed, and finalized, the main design stages where a concept is realized into a working product, and the later stages where the product is tested and manufactured (Ulrich and Eppinger, 2004; Magrab et al., 2009; Kaulio, 1998).

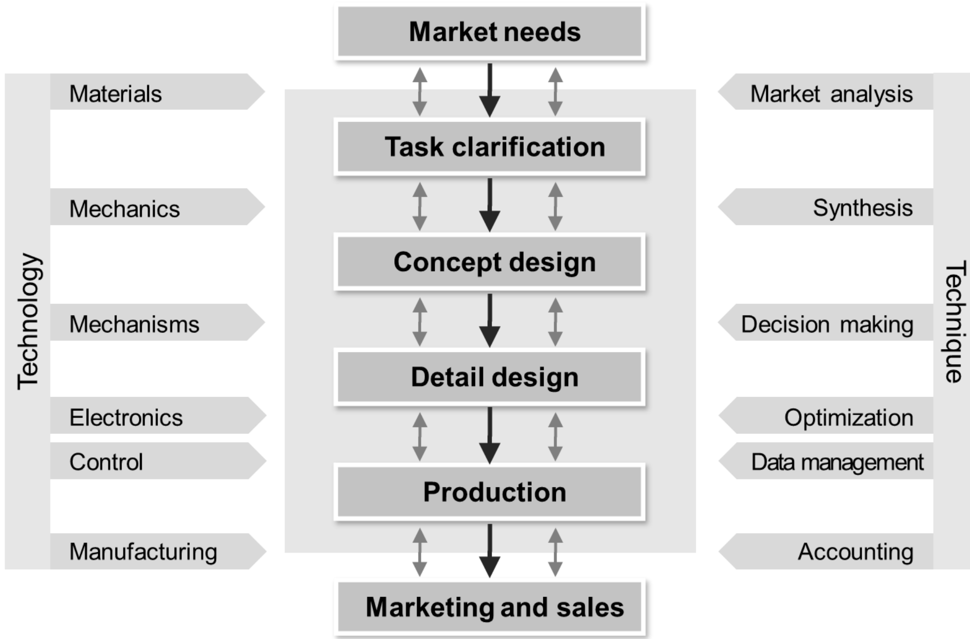
The key stages and activities as described by Karl Ulrich and Steven Eppinger (2004) in their generic model of product design and development process are summarized in Figure 9. This framework describes six stages – planning (phase 0), concept development (phase 1), system-level design (phase 2), detail design (phase 3), testing and refinement (phase 4), and production ramp-up (phase 5) – with the design, manufacturing, marketing, research, and management activities at each stage to outline how products are realized, how information and ideas are processed and communicated, and how related risks are identified and managed.

**Figure 9. Product development process (adapted from Ulrich and Eppinger, 2004)**



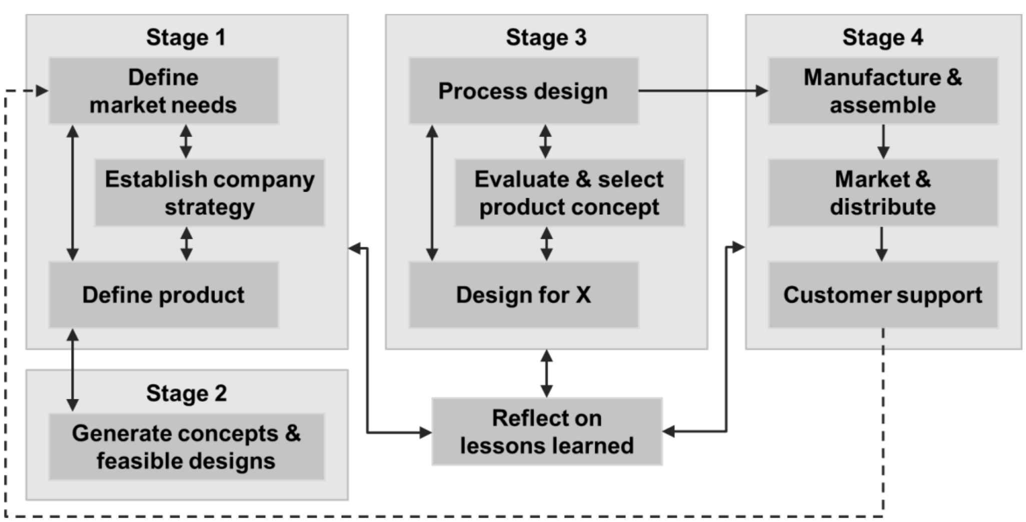

A similar but more technical framework has been described and suggested by Stuart Pugh (1991). In his Total Design Activity Model, the key stages in product design are described as identifying market needs, clarifying tasks, concept design, detail design, production, and marketing and sales. While the model is described in a sequential order, it also notes that there are possible interactions and iterations between stages. The model is described as a core set of activities aimed at Total Design, which Pugh defined as "the systematic activity necessary from the identification of the market and user needs to the distribution of the successful product to satisfy those needs – an activity that encompasses product, process, people, and organization." Figure 10 illustrates Pugh's Total Design Activity Model.

**Figure 10. Total Design Activity Model (adapted from Pugh, 1991)**



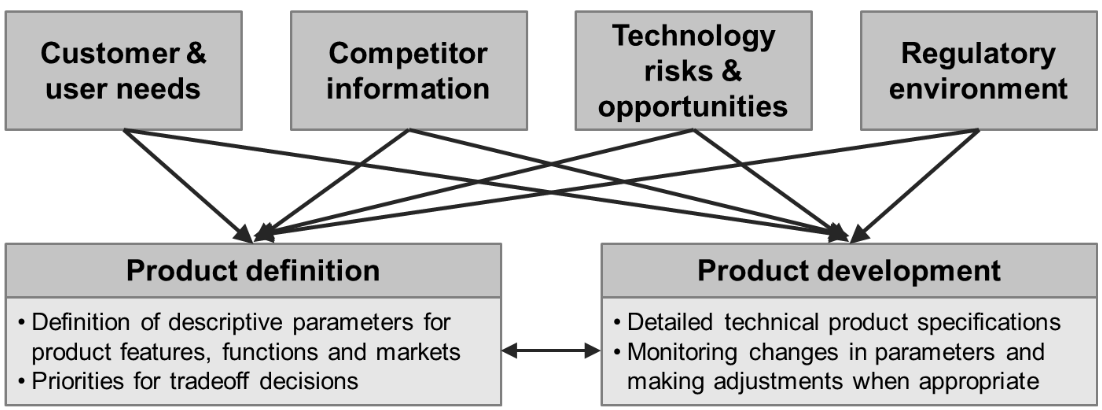

Few existing process models also include post-design or post-production activities. For example, Peters et al. (1999) developed a framework of product development and management, where post-design and post-company activities were included as key stages. The Integrated Product and Process Design and Development Team Method ($IP^2D^2$) suggested by Magrab et al. (2009) describes customer support, with activities including maintenance, service, training, and warranty, as a key stage that follows manufacturing and marketing. The $IP^2D^2$ model is illustrated in Figure 11. This model also includes key stages described by other models, such as identifying market needs, generating and evaluating concepts, and setting product specifications, but puts more emphasis on process iterations and team interactions.

**Figure 11. The $IP^2D^2$ method (adapted from Magrab et al., 2009)**



Studies on design, development and management of new products, often describe that many key activities, such as product definition and needs assessment, need to be done early on in the process. The early stages of development prior to product realization are often referred to as the fuzzy front-end, where the product is defined and most strategic decisions and business plans are made (Kim and Wilemon, 2002; Alam, 2006). Previous studies have emphasized the importance of front-end activities in determining success of new products (Khurana and Rosenthal, 1998; Zhang and Doll, 2001). While various models differ in describing the specific stages, most of them put emphasis on identifying and assessing customer needs in the front-end. Bacon et al. (1994) discuss management of the product definition process, which is defined as the initial stage that comes before design and development, as an important activity that has critical implications for product success or failure. Their research model suggests the product definition process to include assessment of customer and user needs, competitors, technological risks and opportunities, and related regulatory environment. The model suggested by Bacon et al. (1994) is illustrated in Figure 12.

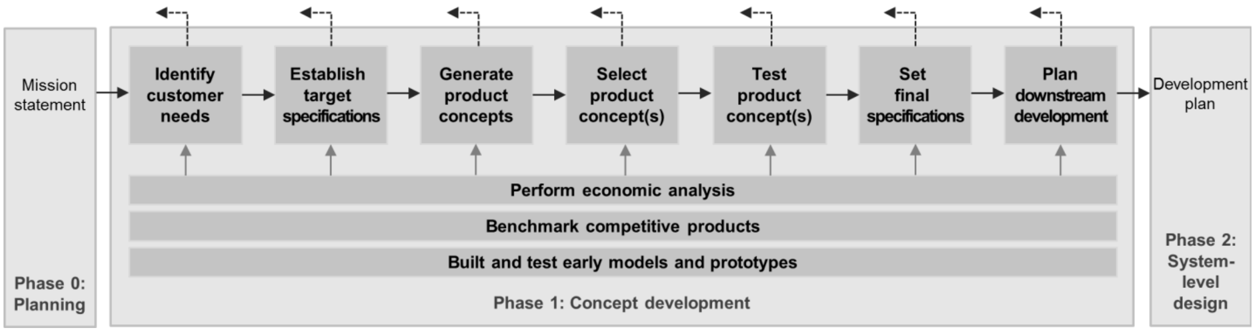
**Figure 12. The product definition process (adapted from Bacon et al., 1994)**




Similarly, Khurana and Rosenthal (1998) defined the fuzzy front-end as the process preceding the execution of product development. In their framework, the front-end is described to include product strategy formulation and communication, opportunity identification and product definition, project planning, and executive reviews. Also, they identified key success factors and problem areas related to the front-end activities, which included analysis of detailed customer needs and assessment of market.

The activities included in the front-end process have been discussed by Ulrich and Eppinger (2004) as well, in their detailed description of the generic process framework. They describe the front-end activities to take place during the concept development phase. The activities, which include identifying customer needs, establishing target specifications, concept generation, concept selection, concept testing, setting final specifications, project planning, economic analysis, benchmarking of competitive products, and modeling and prototyping. As indicated by the dashed arrows in Figure 13, these activities are described to be repeated as needed in an iterative fashion, rather than in a sequential way.

**Figure 13. Front-end activities during concept development phase (adapted from Ulrich and Eppinger, 2004)**




### 2.2.1.2. Methods of user studies for product design and development

As discussed in the previous section, a key step in the early stages of product development is to define the target customers and users, and to identify and understand their needs and requirements. Customer needs are defined as attributes of a potential product that is desired by the customers (Ulrich and Eppinger, 2004). In practice, various methods of user studies are employed to gather, interpret, and translate customer needs. For example, from a survey on design practices, Yang (2007) found that the majority of practitioners –engineers, product managers, and product designers – found need-finding techniques as useful in their work. Popular method used for direct collection and elicitation of data from customers and users include one-on-one interviews, focus groups, and observations (Kaulio, 1998).

An interview is a one-on-one question and answer sessions where the questions are mostly open and conversational (Miller, 2005). It’s a process where an interviewer – in this case a market researcher or designer - interacts with a respondent – a potential customer or user - by asking questions and gathering answers around topics to be covered, which would be around potential concepts and specifications in the product development case. The use of in-depth interviews is helpful for obtaining a rich and broad set of data in a relatively short period of time through detailed discussions (Griffin, 2007; Alam, 2005). With interviews, customers’ experiences, preferences, motives, and opinions can be explored and learned (Rubin and Rubin, 2012; Miller, 2005).

A focus group is a guided discussion session that includes a moderator/interviewer and a group of participants – typically around 10 individuals who are potential customers or users – who engage in talking about product concepts in interest (Miller, 2005; van Kleef, 2005). Also known as group interviewing, a focus group allows the moderator to question several individuals systematically and simultaneously (Babbie, 2007). The moderator guides the discussion, ensures that the important topics and questions are brought up, and encourages interactions among the group (van Kleef, 2005). Similar to interviews, focus groups are useful for gathering and understanding customers' opinions and goals. Also, with group dynamics brought about by the individuals, a focus group can also aid in seeing how responses compare to others and bringing out aspects of topic that would may not have emerged from individual interviews (Miller, 2005; Babbie, 2007).

Another useful method for obtaining detailed understanding of customer needs is observation (Griffin, 2007). Observation is done by watching customers or users as they interact with an existing product or perform a task related to the new product that is being planned (Ulrich and Eppinger, 2004; González et al., 2008). In an observation study, an observer - in this case a market researcher or designer – records things that he or she has watched, along with his or her interpretations of the empirical observations (Babbie, 2007). With a careful observation of customers and their behaviors, knowledge around interactions processes and unarticulated or latent needs can be effectively identified (Griffin, 2007).

Understanding users in the early stages of development go beyond simple needs identification. Studies have emphasized the importance of having users involved closely in design and development, and found it useful to employ various methods of user studies to generate ideas, analyze use cases, and test prototypes and products. Prior works have discussed that frequent and intimate user involvement is important for improving product concepts, innovation capabilities, and market performances (Neale, 1998; Cooper and Kleinschmidt, 1987; Kim and Wilemon, 2002; Lilien et al., 2002).

In addition to popular methods discussed earlier, various methods of user inquiry and involvement are used in the field of product design and development. These methods of user studies include questionnaire, think aloud protocol, diary studies, user experiment, and physiological measures (Kujala, 2002; González et al. 2008; Courage and Baxter, 2005; Lee et al., 2012; Mandryk et al. 2006). Descriptions of these methods are summarized in Table 2.

**Table 2. Additional methods of user studies**

| Method | Description | Reference |
|---|---|---|
| Questionnaire | – Asking potential customers or users to answer a series of specific questions presented to them<br>– Structured and often written in a standardized format | González et al. 2008 |
| Think aloud protocol | – Asking potential customers or users to talk about what they are thinking as they perform a given task<br>– Extraction of design-related information and identification of potential problem areas | Lewis and Rieman, 1994 |

| | | |
|---|---|---|
| Diary studies | – Descriptions of a user's experience with a product or system<br>– Report of events and experiences in a natural context | Lallemand, 2012 |
| Experiment | – Systematically manipulating variables or conditions and analyzing its effects on behaviors and experiences | Yin, 2009 |
| Physiological measures | – Using indicators of the human nervous system to measure mental effort and workload<br>– Measures include electroencephalography (EEG), heart rate variability (HRV), electrodermal activity (EDA), pupil diameter, etc. | Rowe et al., 1998 |

At an extreme of user-driven design and development practices is the lead user method. In a lead user product development process, information around both needs and solutions are collected from customers or users at the leading edge of the target market (Lilien et al., 2002). Lead users are innovating users who are ahead of the majority of the relevant user population and are likely to gain high benefits from a solution to their needs (von Hippel, 2005). Similarly, participatory ergonomics, which is originally an approach used in industrial ergonomics, can be applied as a method of customer and user involvement throughout the product design and development process. In a participatory ergonomics process, a small group of end-users engage in activities where they contribute to the solutions to their problems and needs (Kaulio, 1998).

The methods described thus far in this section require direct interactions with customers and users. However, while it is ideal to have customers or users deeply involved in design activities and directly engaged in ideation or evaluation, the methods described earlier may not always be feasible or economical. In situations where potential customers or users are hard to reach, where a product or prototype is not available for user interactions, or where it is expensive to study potential customers or users, other expert-driven methods can be used (Lee et al. 2010; Nielsen, 1994). These methods, which are summarized in Table 3, are primarily done by evaluators or designers to understand users without any direct user involvement.

**Table 3. Expert-driven inspection methods for understanding user interactions**

| Method | Description | Reference |
|---|---|---|
| Scenario analysis | – Developing and analyzing anticipated use scenarios to find potential problems<br>– Scenarios are written as stories based on information gathered from research and brainstorming | Carroll, 2000; Nielsen, 1990 |
| Persona | – Developing a detailed description of a fictitious user<br>– Description of potential users, who differ from the designers, and their characteristics, goals, and tasks | Cooper, 1999; Nielsen, 2004 |

| | | |
|---|---|---|
| Cognitive walkthrough | – Simulation of user interactions based on a description of detailed procedure | Nielsen, 1994 |
| Task analysis | – Analyzing a detailed description of cognitive and physical activities involved with performing an intended goal | Kirwan and Ainsworth, 1992 |

These specific methods for assessment and understanding of needs, expectations and experiences differ along a number of dimensions. As discussed earlier, they can be divided between user-driven methods and expert-driven methods, where the former includes interview, focus group, observation, lead user method and participatory ergonomics, and the latter includes the methods described in Table 3. Other dimensions can be described as qualitative – quantitative, objective – subjective, and performance-oriented – process-oriented (Lee et al., 2013b). For example, while interview and focus group are more qualitative, physiological measures and questionnaires can be described as quantitative. While diary studies and think aloud protocol are subjective as they describe events as perceived by users, experiment and physiological measures are rather objective. Also, while experiments are often performance- and result-oriented as they focus on the resulting effects, cognitive walkthrough and task analysis are more process-oriented since they investigate the detailed steps involved in possible interactions.

Different methods of user studies can be carried out at different stages of product development. For example, interview and focus group can be done to generate concepts during the early phases of design, while experiments and diary studies can be conducted later for testing working prototypes and pre-production models. It should also be noted, however, that a single method may be applicable or necessary at multiple stages. For example, interviews can be conducted during the concept generation phase as well as during the testing and refinement stage. Choosing the methods to use and deciding when and how to carry them out largely depend on the nature of the product being developed, as well as the set of skills that the development team possesses.

#### 2.2.1.3. User-centered design principles

The user studies methods and tools described in the previous section can be employed throughout the process of product design and development. This idea, philosophy or approach of involving users in the design process of interactive products, as well as understanding their needs and various contexts to inform design, is captured in the concept called user-centered design (Mao et al., 2005; Karat, 1997). The aim of user-centered design is to design and develop a product based on the needs and interests of its users so that they will find it useful and usable (Kubie et al., 2000; Norman, 2002). To aid the process of user-centered design in practice, many principles have been suggested in various domains. A selection of user-centered design principles are summarized in Table 4.

**Table 4. User-centered design principles**

| Source | Principles |
|---|---|
| Norman, 2002 | − Make it easy to determine what actions are possible at any moment<br>− Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions<br>− Make it easy to evaluate the current state of the system<br>− Follow natural mappings between intentions and required actions, between actions and resulting effect, and between visible information and the interpretation of the system state |
| ISO, 2010 | − The design is based upon an explicit understanding of users, tasks and environments<br>− Users are involved throughout design and development<br>− The design is driven and refined by user-centered evaluation<br>− The process is iterative<br>− The design addresses the whole user experience<br>− The design team includes multidisciplinary skills and perspectives |
| Gulliksen et al., 2003 | − User focus – the user's goals, tasks, needs and context of use should guide development<br>− Active user involvement – users should actively participate throughout the development process and system lifecycle<br>− Evolutionary system development – development should be iterative and incremental<br>− Simple representations – the design must be represented in ways that it can be easily understood by users and other stakeholders<br>− Prototyping – prototypes should be used early and continuously in cooperation with users<br>− Explicit and conscious design activities – the development activities should contain design activities dedicated to user interactions<br>− Professional and user-centered attitude<br>− Usability champions – experts should be involved throughout development<br>− Holistic design – all aspects that can influence use situations should be developed in parallel |

As suggested in the principles summarized in Table 4, an idea central to user-centered design is the notion of usability. Generally defined as the degree to which a system can be used by its intended users with effectiveness, efficiency, and satisfaction, the concept of usability concerns the operational and physical contact points, or the interfaces, between an interactive system and its users (ISO, 1998). According to the ISO descriptions of usability, effectiveness concerns the accuracy and completeness with which users achieve goals, efficiency looks at the resources and effort expended as users achieve goals, and satisfaction describes users' perceptions and attitudes in relation to comfort and sense of engagement.

Another important concept addressed by the principles summarized in Table 4 is user experience. While usability mainly looks at a system and its interfaces in the operational context, user experience is defined more broadly. User experience concerns the entire context in which users interact with a system or product, and its related company and services (Alben, 1996; Nielsen and Norman). The focus on usability and user experience is evident in the user-centered design principles presented earlier. In ISO (2010), the whole user experience including tasks and environments are discussed to be central to design practices. Gulliksen et al. (2003) also addresses the importance of the two concepts by emphasizing the role of usability experts and various aspects that could potentially affect use situations. The principles suggested in Norman (2002), on the other hand, are focused more on providing specific design guidelines for ensuring system usability.

Existing principles and guidelines around user-centered design share a common characteristic in which they view user-centered design as a process rather than a physical or visual aspect of a system or product. In Norman (2002), the principles are stated as a set of action statements for practitioners to follow. In ISO (2010) and Gulliksen et al. (2003), user involvement and iterations in design processes, as well as formation of team and attitudinal aspects, are emphasized.

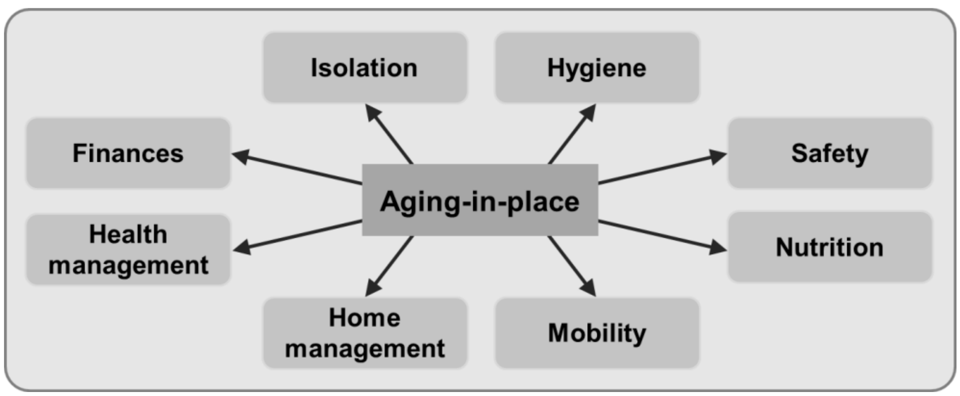
In line with the process-oriented view of user-centered design, it is desirable to employ efforts to enhance and improve usability and user experience throughout design and development of interactive products or systems. A common way of incorporating user-centered design principles to development practices is to use various methods of evaluation. While the user studies methods described in the previous section can be used for studying consumer and user needs at various stages of product development, they can also be used as method of usability and user experience evaluation (Lee, 2010; Lee et al., 2012).

### 2.2.2. Designing for older users

Studies that have addressed the implications of aging were traditionally focused on clinical care or detailed design built around ergonomics concerns (Boult et al., 2009; Naylor et al., 2009; Pak and McLaughlin, 2010). In other words, formal caregiving and physical aspects of design have been the primary focus, with less attention to other components such as processes of product and system development, patterns of innovation, and related technology policies. Recently, studies have raised the need to redefine the older population and to develop a more accurate view of their needs, values, and expectations, and what these mean in terms of product and system design and development. In other words, there is a growing need for application of user-centered design methods and ideas for addressing the older population.

A key idea that has been suggested to address older adults' needs and expectations is aging-in-place, a service concept describing older adults' desire to live in their own homes without having to move to support facilities such as nursing homes (Walsh and Callan, 2011; Gaul and Ziefle, 2009; Lee et al., 2011). However, while older adults have a strong desire to stay independent without having to give up their own lifestyle as they age, aging-in-place can create challenges including managing their own health, performing everyday activities, and maintaining social ties by themselves. As they are left alone to deal with life tasks on their own, they often face issues and problems related to isolation, mobility, hygiene, finances, health management, home management, safety, and nutrition (Lee et al., 2013b; Mynatt and Rogers, 2001; Heinz et al., 2013). The potential domains and areas where aging-in-place can cause problems and issues are described in Figure 14.

**Figure 14. Aging-in-place and related domains of potential problems**




Various technology-enabled products and systems have been studied, developed and marketed with an aim to enhance older adults' well-being and health. These systems target the potential problems that arise due to aging-in-place, and aims to enable older adults to better deal with them. Most products, services and systems currently offered for the population usually have three common characteristics – assistive purposes, service-oriented features, and home installation. First, many technology-enabled systems for older adults are categorized and placed as assistive technologies, meaning that they aim to provide help and support for older users (Walsh and Callan, 2011). These are designed to realize the potential of effectively monitoring, managing, and motivating behaviors that lead to better health outcomes (Coughlin et al., 2006). Second, aging-in-place technologies are often product-service systems, meaning that they exist as combinations of service and product rather than pure physical goods (Sakao and Lindahl, 2009). Because the focus is on utilizing technology to provide service, there is a strong focus on fulfilling user needs and creating value (Coughlin et al., 2007; Müller et al., 2008). Lastly, a common characteristic of aging-in-place technologies is that they are often made for use in the home environment. Activities of older adults who age-in-place mostly take place in the home environment. Thus, existing systems have been design and developed to serve as tools for self-care and tele-care in the home (Demiris et al., 2004; Mitzner et al., 2010).

The growth of the older population, together with the recent advancements in related technologies, has attracted interests from both academia and industry (Kang et al., 2010). As a result, new products and systems enabled by technology have been introduced to the public. However, gaps and limitations still exist. First, previous research and existing products were mostly focused on healthcare and caregiving domains. It is widely known that health is generally a bigger concern for older adults compared to younger people. Average older Americans are the primary consumers of the United States' healthcare market, spending over 13% of their total expenditures on health, which is more than twice the proportion spent by all consumers, and taking about 3 medications daily (Giron et al., 2001; ASHP, 2000; US DHHS AoA, 2011). However, health has improved over time, and at the individual level, limitations in or loss of functions is less common than before (Freedman et al., 2002). Also, many older adults do not identify themselves with negative stereotyped notions of old people, which view them as incompetent, lethargic and unhealthy (Brandtstadter and Wentura, 1995; Gerike, 1990). While health is still an important area in which researchers and practitioners should be concerned about, there can be other domains - such as transportation and gaming - that older consumers and users may have interests and needs for (Heinz et al., 2013). Second, research in this field has mostly focused on point solutions, addressing one issue at a time and not considering how various aging-in-place problems may be interrelated. For example, existing health monitoring technologies are often developed without addressing the concern of potential decrease in social contact (Kang et al., 2010). Third, user involvement has been practiced only to a limited degree in design and development of technology-enabled systems and products for older adults. Previously, studies have often relied on assumptions of the population's needs and expectations, and user evaluation has been limited to short laboratory experiments (Lee et al., 2011). In general, older adults' potential contribution to the design and development of new systems has been underestimated, especially during the early phases of development (Essén and Östlund, 2011).

Studies have identified the application of user-centered design principles as an effective way of closing in these gaps and limitations (Mynatt and Rogers, 2001). As discussed in Keates et al. (2000), the success of a product design relied on how much the design team empathized with the end users. While principles and methods of user-centered design have been applied to various degrees in development of various products targeted at the general population, design and development of systems targeted at older adults have often relied on stereotypes due to unawareness of potential needs, lack of motivation, and lack of knowledge around methods for accommodating needs during design practices (Niemelä-Nyrhinen, 2007; Keates and Clarkson, 2002; Keates et al., 2000).

Universal design and design-for-all are design approaches that employ user-centered design principles for underrepresented populations, including older adults. Universal design focuses on issues around accessibility and states that the design of products and environments should be usable to the greatest extent possible by people of all ages and abilities or disabilities (Story et al., 1998; Mynatt and Rogers, 2001). Principles of universal design are described in Story et al. (1998) as equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space appropriate for approach and use. The term design-for-all is often used synonymously with universal design, but it covers a broader range of ideas in that it reflects a philosophy for design that recognizes, respects, values, and attempts to accommodate the broadest possible range of human abilities, requirements, and preferences and ensures the usability, accessibility, and affordability of products and services (Bühler and Stephanidis, 2004).

## 2.3. Lessons learned from related works

In this section, existing models and previous studies around the design, development, and distribution or delivery of technology-enabled systems and products are summarized. Studies from various related disciplines – human factors, behavioral science, information technology, consumer studies, computer science, gerontology, and more – have built conceptual and empirical models to describe how consumers and users accept and adopt innovations, technologies and new products. As the aging of the population poses challenges and issues to various domains, a growing number of research have started investigating older adults' needs and expectations in the context of technology-enabled product, and few studies have built models to describe technology adoption focusing on this particular population.

While the studies on technology adoption focus on the stage at which products and systems are fully formed, produced and distributed in the market, another body of studies have formed around outlining the process of product design and development. Staged frameworks and process models have been suggested and applied to design practices, often with a strong emphasis on the front-end activities during early phases. The ideas around understanding user characteristics and needs, incorporating them into design activities, and involving a selection of potential users during development are captured in the concept of user-centered design. For application of user-centered design during development of products and systems, various method of user studies have been suggested. Furthermore, possibilities for employing user-centered design ideas and methods for the development of technology-enabled products and systems targeted at older adults have been discussed.

While previous studies cover a breadth of related topics, as well as various populations of consumers and users, few gaps and limitations can still be identified. While product development and user adoption are closely related, the two themes have been discussed separately. Frameworks of product design and development have mostly focused on a process that begins with planning and ends with manufacturing, with a few exceptions that have noted the importance of post-production activities. On the other hand, models of technology and innovation adoption have been limited in that they focused solely on the consumer and user side, while the implications to the design and development practices are potentially crucial. An effort to bridge the gap between the user side and the industry side would be beneficial in integrating the stages of design, development, distribution, and post-sales activities.

Another limitation of the current state in research and practice is the issue of adaptability, or a system's ability to change and reconfigure in response to changes in its external environment (de Weck et al., 2011). The current models and frameworks of product design and development are developed around mass-manufactured systems targeted at the general population. On the other hand, models that describe patterns and mechanisms of technology adoption and use are built around the needs of the general population. The engineered systems – frameworks of product design processes and models of technology adoption – are moving behind rapid changes in the potential user population. The aging of the population means a great increase in the size of the market, a new culture, and a new set of demands that were not observed before. The demographic change calls for improvements in the adaptability of related frameworks and models, and such improvements can only be brought about with a more correct and comprehensive assessment of older adults' characteristics, needs, expectations, and values.

# 3. Phase 1: Identifying factors of technology adoption

The aging of the population, which is the most prominent demographic change that is being observed, persists to pose challenges on many areas of society. It requires different ways to address problems in healthcare, housing, transportation, education, employment, and product design. In the attempt to provide solutions, technology-enabled devices and systems have been developed and introduced to the market. However, while their potential usefulness is well-recognized by academia and industry, the promise of technology benefits for successful aging is not being effectively realized. Although many products and systems have made their way into the mainstream market, their adoption rates are very low. For example, personal emergency alarms are adopted by less than 5% of older Americans who could benefit from such systems (Lau, 2006).

Technology-enabled products and systems for older adults are not adopted widely due to insufficient understanding or stereotyping of the target segment's characteristics, expectations, and needs (Eisma et al., 2004). As the typical researcher or developer is not of the aged population, there exists a substantial gap between what is developed and what is actually needed. Current development practices have not fully considered important points such as older adults' motivation to use technology, the diversity within the demographic group, and the contexts in which technology is consumed and used. Due to the lack of proper assessment of older adults' needs, industry is not yet realizing the potential benefits they can gain from the large demographic group with spending power (Carrigan and Szmigin, 1999; Hopkins et al., 2006; Niemelä-Nyrhinen, 2007).

Studies have been done to identify older adults' needs and expectations in the context of technology use. However, most were focused on generating findings only specific to the device of interest and not readily generalizable across systems. Also, previous studies have mainly looked at detailed physical design, while the development processes, service structures, organizational settings and cultural environments are also important (Djallal and Gallouj, 2006). Thus, the current state of research on older adults' adoption and use of technology calls for a broadening of perspective, an integration of insights for general application and practical implementation, and an effort toward building a theoretical framework.

This chapter focuses on identifying and defining the factors that affect how technology is adopted and used by older adults. The objective is to provide a more comprehensive understanding for making strategies in design, development, and delivery of various technology-enabled systems, and to establish a research ground that will inform further empirical investigations on the consumer side as well as the industry side. The first part of this chapter will describe how the factors were extracted through a literature review and a set of user interviews. Section 3.2 will present the definitions of the identified factors, a summary of related findings, and a discussion on how they can be applied in practice. The descriptions and evidences are presented through a review of previous studies and summary of user interview results, along with suggestions from research and examples from industry.

## 3.1. Factor identification process and methods

### 3.1.1. Consolidation of existing literature

During the initial phase of factor identification, studies on older adults' technology adoption from related fields were reviewed. A careful survey of empirical findings, theoretical discussions, and practical implications was carried out to identify common themes and important concepts. The articles were found through search on Google Scholars, Thompson Reuters Web of Science, and SciVerse Scopus, with "older adults" and "technology adoption" or "technology acceptance" as the search keywords. Relevant studies included in the references and related search results were also examined. The references include refereed journal papers, conference proceedings, research reports, book chapters, and master's and doctoral theses. The references include studies mostly from the last decade as the topic has been more popular recently. While the references are rather contemporary, important fundamental studies are also included to show the academic relevance.

Due to the interdisciplinary nature of the topic, studies from a number of different fields were reviewed, including, but not limited to, gerontology, information technology, behavioral sciences, human factors, consumer studies, and product design. The references include studies from gerontology journals such as Age and Ageing, Journal of the American Geriatrics Society, Ageing International, Psychology and Aging, Ageing and Society, and Journal of Applied Gerontology. Journals from the field of information technology, such as Internet Research, Journal of Computer-Mediated Communication, and International Journal of Emerging Technologies and Society, have been reviewed. Several business journals, such as Journal of Consumer Marketing, Journal of Business Research, and Service Industries Journal, are included to cover perspectives from consumer studies and operations management. From the field of human factors, journals including Human Factors and Universal Access in the Information Society and major conferences, such as the Human Factors and Ergonomics Society Annual Meeting, contributed to the references. Design journals and conferences, such as Design Studies and International Journal of Design were surveyed. Few journals were found to be more interdisciplinary, such as Computers in Human Behavior and Medical Informatics and the Internet in Medicine, lying across multiple fields.

The references include empirical and theoretical research on older adults' adoption and use of technology. From each reference, related findings and supporting evidences were collected, and a list of technology adoption factors was outlined. Because studies on different technologies with different samples varied in weighting of factors, factors were collected with equal importance. With the factors summarized for all studies included in the references, factors that were discussed and supported by at least five or more studies were selected. The findings converged into ten factors - value, usability, affordability, accessibility, technical support, social support, emotion, independence, experience, and confidence - all of which were described to be important from 9 (for social support) to 34 (for usability) studies. Identification and definition of the factors aimed for exhaustiveness rather than exclusiveness as some factors were found to have overlapping concepts. For generalizability, some specific factors were merged into relevant categories. For example, text readability and hardware controllability were grouped under usability. Appendix 1 shows a summary of previous studies that were surveyed in this section, along with the domain or system in interest, related methods of data collection and analysis, and the factors they have discussed.

The ten factors - value, usability, affordability, accessibility, technical support, social support, emotion, independence, experience, and confidence – were identified from the literature reviews as determinants of older adults' technology adoption. While individual studies have focused mostly on technology features and individual characteristics, these factors also cover social settings and delivery channels. Based on an integration of previous findings, they are intended to set goals toward increased adoption and use. The factors aim to provide a better understanding for making decisions, strategies and design specifications as a technology is planned, designed, developed, produced, and distributed to older adults. The ten factors are summarized in Table 5.

**Table 5. Summary of descriptions for the factors of older adults' technology adoption**

| Factor | Description |
|---|---|
| Value | The degree to which a technology is perceived as useful and communicated as potentially beneficial |
| Usability | The degree to which a technology and its interfaces are easy to learn, use, and interact with |
| Affordability | Perception of costs and expenses related to purchase and use of a technology in relation to potential benefits |
| Accessibility | Awareness and knowledge of a technology's existence and availability in the marketplace |
| Technical support | Availability and quality of professional support throughout learning, purchasing, using, and keeping a technology |

| | |
|---|---|
| Social support | Support and endorsement from family, peers, or social communities toward use of a technology |
| Emotion | Perception of a technology's potential roles for providing emotional benefits such as entertainment, enjoyment, and peace of mind |
| Independence | Expectations around how the use of a technology may or may not involve social stigmatization and stereotyping |
| Experience | The degree to which a technology's features and operations resemble a user's prior experiences with relevant systems |
| Confidence | The degree to which a technology's features and designs prevent a user from feeling anxious or intimidated |

## 3.2. Descriptions from user interviews

The papers and reports surveyed through the literature review process were mostly based on conceptual model building, laboratory experiments, or brief focus group sessions. In most of the empirical studies included in the references, participants were recruited only for a short interview or focus group session that lasted a few hours at most. However, when the target populations comprise of older adults, it is more difficult to identify needs and translate them into design than when younger people are involved. It is hard to simply ask what they need due to communication barriers, as well as experiential, cultural, and knowledge gaps between designers and older users (Sixsmith and Sixsmith, 2000; Eisma et al., 2004). While brief conversations and discussions can expose observable characteristics and key requirements, many latent needs may be difficult to identify.

It has been claimed that building a strong and continuous relationship with older adults is essential to minimize possible communication gaps (Eisma et al., 2004). Thus, to corroborate the findings from the literature review, and to seek for latent factors that may not have been identified by existing studies, a small set of in-depth interviews were carried out with people who have been frequently involved in similar research settings. To minimize potential communication gaps and to have a common context in which the older respondents can comfortably talk about their thoughts, participants of a previous long-term field study were interviewed. A total of three older adults participated in the interviews. At the time of the interview, all three participants had more than one research participation experience at the MIT AgeLab, and had been in contact with myself from previous studies. Especially, all three participants have been previous involved in the e-Home for Seniors project on which is discussed in more detail in Chapter 5. The project included a long-term field study that was conducted for eight weeks, during which each participant was provided with a medication management and remote communications system. During the field study, each participant was visited at home at least four times and contacted over telephone or via e-mail frequently. Table 6 shows a summary of the participant profile.

**Table 6. User interview participants**

| Participant no. | Gender | Age | No. of previous AgeLab studies |
|---|---|---|---|
| 1 | Male | 66 | 2 |
| 2 | Female | 68 | 4 |
| 3 | Female | 77 | 2 |

Interviews were done in participants' homes to have a comfortable setting, and to enable observation of the types of technologies being used. Each session lasted about 60 minutes. During these exploratory interviews, questions were asked around their perceptions, experiences, and behaviors around various technologies. Each interview started with a conversation around their experiences with the previous studies they have participated in to refresh their memories and to get them familiarized with the topic. After that, discussions were done around their thoughts on various technologies, and behaviors related to purchase and use of new technologies. Questions were prepared to investigate their perceptions about the previous studies and related systems, interactions with technologies they have experienced in the past, and perceptions and attitudes toward new technologies. In these semi-structured, open-ended interviews, questions with broader coverage, listed below, were asked first, and questions for probing details were asked later as necessary. A complete list of interview questions is included in Appendix 2.

- In general, what were the impacts of having the system in your home for eight weeks?
- Based on your experience with the system, what suggestions or comments to you have for possible improvement or extension?
- Did your experience with the system have an impact on the way you think about technology?
- After the study, have you bought or started using any technology-enabled products or services? What did you get and why?
- After the study, did you continue to tell your friends or other family members about your experiences? If so, what was it about the study that you discussed with them?

The findings from the interviews are discussed in the following section, along with findings from the literature review, in association with the related adoption factors.[3] In general, user voices gathered from the interviews were in line with the ten factors identified from the literature review. Additionally, the

[3] A detailed summary of user voices collected from the interviews can be found in Lee et al., 2013c.

findings from the interviews suggested that there may be other important factors that were not discussed in previous research. These additional factors include reliability at the system-level and service-level, and compatibility with lifestyles, existing technologies, and conceptual mental models. These factors are summarized in Table 7.

**Table 7. Additional adoption factors identified from user interviews**

| Factor group | Factor | Description |
|---|---|---|
| Reliability | System reliability | A technology's ability to work over a long period of time without failures or interruptions in various operational conditions |
| | Service trust | The degree to which a user can depend and rely on a technology, as well the services and organizations related to its operations |
| Compatibility | Interoperability | The degree to which a technology can seamlessly work with other technologies, as well as related products, services and usage environments |
| | Lifestyle fit | Expectations around how a technology can fit into a user's life patterns, activities and living situations without requiring the user to change them around the technology |
| | Conceptual fit | The degree to which a technology's operations, designs and languages match a user's mental models and perceptions of the world around |

## 3.3. Identified factors as determinants of technology adoption

This section presents the definition, related findings, and examples for the adoption factors summarized in Tables 5 and 7. The factors are described to be applicable to various types of technology, rather than focusing on specific domains or features. That is, the discussions around the adoption factors are developed around technology as products, services, and related systems developed and distributed to serve desired roles using mechanical, electronic, or informational means and techniques.

### 3.3.1. Value: perceived usefulness and potential benefit

Older adults tend to use technology to reach and realize a desirable outcome (The SCAN Foundation, 2010). It's what the device or system does for them that matters. While younger people often consume technological devices for advanced functionality or aesthetics of design, older adults are willing to use them if deemed useful and provide obvious benefits to their current lifestyle (Steele et al., 2009). They are attracted to technology associated with clear improvements, and are generally reluctant to use if they cannot see the advantages it may bring.

Evidences for the causal relationship between perceived usefulness and adoption were found for various technologies. In a study on communication technologies, Melenhorst et al. (2001) discussed that older adults are only willing to make efforts to learn new technologies when they see the benefits. In another study that focused on the use of e-mails, Melenhorst et al. (2006) found that older adults' negative attitude toward e-mail was caused by their perception of absent benefits. A similar relationship between perceived usefulness and usage was found in older adults' adoption and use of the Internet and mobile phones (Porter and Donthu, 2006; Conci et al., 2009). In this study, perceived usefulness was asked with various measurements including perception of productivity and effect on various life activities, in addition to the overall usefulness. In another study on Internet adoption, outcome expectations, a measure of technology value, was found to have a positive and direct effect on older adults' intention to use (Lam and Lee, 2006). In another study, McCloskey (2006) found a direct and positive effect of usefulness on acceptance and usage of electronic commerce among older adults. Age was found to partly account for differences in perception of usefulness, suggesting that a technology can be perceived differently depending on how old a potential user is (Arning and Ziefle, 2007). The effect of perceived value on adoption and use was also discussed in the domain of healthcare and assistive technology. For example, in Gooberman-Hill and Ebrahim (2007), expectations around benefits and improvements on physical capabilities were found to partly predict adoption and use of walking aids. The importance of perceive value and benefits was identified for technology in general as well. In Heinz et al. (2013), older adults described that they would be more willing to adopt and use technologies with clear benefits, such as transportation or help with daily activities. When older adults discussed what they liked about various types of technology, the perceptions benefits related to a technology's ability to provide support for activities, such as communication, housework, and entertainment, was found to be an important factor (Mitzner et al., 2010).

Older adults are more likely to adopt technology when they perceive its usefulness and potential benefit, rather than for novelty sake alone. It is important to clearly show a technology's benefits and utility. A technology should have added value that its older users can easily see, understand, and appreciate (Holzinger et al., 2007). As discussed in Walsh and Callan (2010), barriers to older adults' technology adoption included the difficulties in visualizing the role of technology and understanding its potential contributions. Adoption is more likely to be achieved if one successfully communicates that a technology serves a clear purpose meaningful to them and offers easily perceived benefits (Eisma et al., 2004; Lam and Lee, 2006; Kang et al., 2010). As Aula (2005) suggested, one should first show the possible benefits and values when introducing older adults to a new technology. For successful adoption, distribution, and continued use, a technology should have added value that the older adults can easily see and understand.

### 3.3.2. Usability: ease of learning and use

When systems are developed to directly interact with end users, usability becomes a central issue. The importance of a system's requirement to be easy to learn and use as been emphasized in existing models, as described earlier in section 2.1. While user-friendliness is an essential characteristic in all types of interactive technologies, it should be given more consideration when the intended target end users are older adults. Older adults generally face physical and cognitive barriers and have lower overall technology familiarity (Czaja et al., 2006). The combined effects of such age-related changes can affect older adults' perceived ease-of-use (Zajicek, 2003). While it is important to meet older adults' needs by providing practical benefits, it is critical to make technology easy to use so that such benefits are realized (Wang et al., 2011).

Studies have empirically found evidence around the importance of usability in determining older adults' attitude toward new technologies. However, many existing systems have been evaluated as not easy to use for older adults. In a study on social media for older adults, Rodriguez et al. (2009) found that older adults, although aware of the functions and usefulness, did not use e-mail because they felt it was not easy to use. Other studies have also found usability issues with communication technologies and computer systems. Becker (2004) evaluated health information on the Web and found that it was not well communicated to older adults partly due to the fact that most are not designed properly in that they lacked readability, simplicity, and controllability. In an evaluation of how Web sites comply with usability guidelines for older adults, Hart found that majority of the sites did not follow design guidelines for texts, buttons, and hyperlinks (Hart, 2004). Murata and Iwase (2005) also found evidence that tasks involving fine control of a computer mouse could be cumbersome for older adults, acting as a barrier to using computer applications. Similar problems were found in other computer input devices as well, including touch screen interfaces (Piper et al., 2010). Healthcare and assistive technology is another area where usability issues have been identified. In a study on at-home health management systems, it was stated that the current designs are problematic and error-inducing in terms of user interfaces, which can result in compromise of patient safety and thus non-adoption (Kaufman et al., 2003). In another study on smart home technologies for aging-in-place, older adults identified user-friendliness as a major concern (Demiris et al., 2004). Across domains, experience of usability problems, such as a technology being too cumbersome and requiring excessive mental effort, was identified as a factor that cause older adults to dislike and reject a technology (Mitzner et al., 2010; Heinz et al., 2013).

In addition to findings from existing literature, usability concerns were raised during the user interviews as well. When asked about the system they had used during the previous field study, one participant described usability problems related to its detailed physical design – “it would be better if the printing was bigger.” Usability was also discussed in the context of technology use in general. During the interviews, older adults said they often decided if they liked or disliked a technology based on its usability. For example, one complained about his mobile phone because “I get arthritis in the thumbs. The buttons are way too small. You can’t see enough on the screen. I have to wear glasses for reading and stuff. When you go to a website, it’s like next to impossible to read it.”

Design principles and guidelines have been suggested for enhancing usability of technology as perceived by older adults. One rule is to keep the interfaces simple (Rodriguez et al., 2009). Technology should not overwhelm its older users with too many features, options, or information (Mitzner et al., 2010). As Steele et al. (2009) found in an interview, interactions should be “as simple as pushing a button”. Second, the features of a technology should look and feel familiar to older adults. Interfaces should be intuitively understandable and manageable, and natural language should be used when possible so that older adults can be easily informed about what the features will do and how they can be operated (Eisma et al., 2004; Lawry et al., 2009). In order to achieve this, the design should have similarity and consistency with other technologies and the real world. Lastly, because age-related functional declines and their cumulative effects can make interactions more difficult, the use of technology should not require physical dexterity or heavy cognitive processing (Kurniawan and Zaphiris, 2005). To make interaction easier and less error-prone, buttons and texts should be visible and readable. Technology should be designed so that its older users are not required to go through extensive learning and memorizing. This can be done by providing appropriate modes of control, feedback, and instructions (Emery et al., 2003; Mynatt and Rogers, 2001). For example, use of touchscreen may reduce workload by providing a clear match between display and control (Murata and Iwase, 2005; Wood et al., 2005). With appropriate feedback, a system will be able to inform older adults of its status and possible actions that can follow. Also, by providing instructions and history records, a system can minimize the need of memorizing its features so that its older users do not have to put too much effort into learning (Mynatt and Rogers, 2001).

An effective means to assuring system usability is getting older adults involved from the early stages of development (Eisma et al., 2004). While many studies have done usability assessment on technology for older adults, the principles are not being well implemented into design and development practices. For example, evaluation of usability has often been done at later stages for testing purposes, and older adults’ roles in development have often been reduced to test persons (Essén and Östlund, 2011). Consequently, early design specifications are often made around assumptions. This can be problematic because older adults often show behaviors different from younger people (Liao et al., 2000; Selvidge, 2003). To improve usability and acceptance, one should not assume that they know their target users but rather learn about their needs and characteristics before design specifications are set (Mynatt and Rogers, 2001). That is, the application of user-centered design philosophies, principles and methods is essential for designing and developing appropriate technologies targeted at older adults (Gregor et al., 2002). More attention should be paid to older adults' possible contributions during the earlier phases of design and development to ensure usability.

### 3.3.3. Affordability: perceived costs

High cost drives older adults away from using technology. While it is important for a technology to be practical and easy to use, being affordable is also essential. For example, Steele et al. (2009) found cost as a determinant of older adults' acceptance of wireless sensor networks. In a survey on home technologies, the highest proportion of the sample has rated price as very important among many factors (Ahn, 2004). In the user interviews, participants described high cost as "a stopping factor," and talked about how "when you're retired, you look at cutting costs not adding costs." A respondent also described unaffordability as a main reason that resulted in a decision to get rid of a computer she had – "it was too much money" to "have an Internet thing."

Many technologies for older adults incur a large initial cost followed by expenses over a longer period of time. For example, ambient intelligence systems and smart home technology, often developed to assist aging-in-place, are composed to various component technologies including sensors, data storage, and online communication channels. In such systems, the start-up cost is likely to be considerably large, and periodic subscription charges may incur during use. Even though they have the potential of eliminating long-term future costs, such as expenses related to hospital visits and disease management, the technology expenses may seem uneconomical. Since the potential benefits are unclear and not immediate, costs related to adoption and use can be perceived to be very high. The potential benefits in economic terms should be better communicated to older adults so that they see the possible gain. Analysis on cost-effectiveness can help to overcome the hurdle (Kang et al., 2010). Also, it has been suggested that policies around incentives and subsidies, which may be more relevant for health technologies, also play an important role in adoption, especially for older adults with lower income (Taylor et al., 2005; Tanriverdi and Iacono, 1999).

It is also important to note, however, that lowering prices is not an ideal strategy if it requires one to sacrifice quality (Moschis, 2003). While high cost can be a barrier to technology adoption, older adults evaluate costs in relation to potential benefits. For example, in the user interviews, one older adults mentioned, "(it's) a matter of the service you get as to whether it makes sense financially." If technology values and potential benefits are clearly communicated, understood and positively perceived, older adults may actually be willing to pay higher prices. In these cases where a product is perceived as suitable to older adults' needs, premium pricing can be an option (Moschis, 2003).

In short, for systems with difficulties in communicating and demonstrating immediate and clear benefits, data on cost-effectiveness, together with reimbursements and subsidies, can facilitate adoption (Kang et al., 2010). On the other hand, when technology benefits are better perceived and understood, prices can be set with strategies similar to those for the general population. In these cases, price reductions would be necessary for common and standardized products, but high prices will be tolerated for high-quality premium products (Moschis, 2003).

### 3.3.4. Accessibility: knowledge of existence and availability

Older adults are more likely to adopt technology when it is easily accessible in that they have the knowledge of its existence and availability in the marketplace. As described earlier in section 2.1.2, accessibility was found to be determining factor of older adult's adoption of assistive technology (McCreadie and Tinker, 2005). They suggested that older adults' access to technologies rely on how much information is open to them and how the delivery systems are formed. However, a greater portion of exiting literature have discussed technology adoption around characteristics that are inherent to the individuals or the technologies while, as stated in Panagos (2003), delivery is also an essential stage where the interaction between users and firms are made. Even if a technology is designed and manufactured with careful consideration of user characteristics, adoption is unlikely if it's not delivered effectively into the market.

Older adults are generally less aware of new technologies that could be helpful to them (Heinz et al., 2013). Evidences around the lack of awareness and problems with accessibility have been discussed in various contexts. For example, while technology-enabled residential solutions are currently available to assist older adults in their home environments, the target population is mostly unaware of them (Ahn, 2004). In a study on medication management, Lakey et al. (2009) found that the majority of their older adult sample has never even heard of programmable medication organizers such as automatic pill dispensers and pill boxes with alert or alarm functionality. During the user interviews, one participant talked about limitations in terms of access to technologies in the market. She described her channels of information and access as "through the mail" and "just went to the store."

It is essential to let the older users know that the technology exists, as lack of awareness and knowledge can act as a barrier to adoption (Tanriverdi and Iacono, 1999). The efforts toward a technology's success in the market should not end at development, but needs to be extended to the stages of marketing, sales, and post-sales activities. However, industry has been slow in responding to the demographic changes and is unaware of the need to market to older adults (Moschis, 2003). Marketing technology through appropriate channels is important for communicating its potential benefits to older adults (Wang et al., 2011). For example, targeted marketing based on assessment of older consumers' characteristics, and setting relatable role models can be effective (Panagos, 2003). To facilitate adoption, industry should realize the importance of marketing to older adults. In order for useful technologies to be widely adopted, businesses should focus on finding effective channels for communication and developing appropriately targeted messages so that their older target users know what's out there.

### 3.3.5. Technical support: professional support throughout use

Older adults are more likely to adopt technology if they can receive professional support in learning, using, maintenance, and repair. Even if a technology is designed with careful consideration of usability, older adults may be reluctant to use it due to the technical setting they are not familiarized to. When faced with new technology, older adults tend to express a lower level of familiarity and trust compared to younger people (The SCAN Foundation, 2010). Also, older adults tend to dislike technology that requires too much effort in learning or using (Mitzner et al., 2010). Partly due to the unavailability of technology education and experience in the earlier stages of their lives, technical support and assistance is essential for adoption (Demiris et al., 2004; Poynton, 2005).

The importance of technical assistance during purchase, installation, learning, operation, and maintenance has been discussed around various technology applications. For example, in a study on various home technologies, Ahn (2004) found that older adults perceive the availability of post-purchase services as a very important factor that influences their purchase decisions. Furthermore, in this study, the perceived importance of post-purchase service availability was higher among the "75 years or older" group than "55 to 64 years old" group and "65 to 74 years old group, suggesting an increasing need for support services with aging. In another study on computer use by Aula (2005), technical training was described as a necessity, and participants in this study commented how it would have been practically impossible for them to learn to use computers without training. Also, during the user interviews, a respondent described that he "bought an extended warranty" and was happy about the "help line," while another respondent said she wasn't using a Kindle she has because she "hasn't figured it out yet" partly due to the lack of support in learning.

Technical support for older adults can be made more effective with specialized designs (Demiris et al., 2004; Steele et al., 2009; Aula, 2005). As they may experience problems different from younger people, an extensive use case and scenario analysis can be helpful for improving technical support services. Also, as the channels of information search may differ from younger generations, technical support should be given through a medium that is appropriate for their characteristics and needs. For example, because older adults often refer to printed directions for support in using new technologies, manuals should be written with plain language and presented in a clear and readable way (Tsai et al., 2012).

In addition to technical support around making purchase decisions, installing systems, and solving maintenance issues, proper coaching and training is necessary for successful adoption and continued use. Even if when a training program is available, it wouldn't help facilitate adoption and use if it is not designed properly. For example, a respondent in the user interviews expressed frustration with computer training programs because "they really don't tell me what I want to know." Consideration of the population's possible differences from younger people, including technology literacy, computer anxiety, and physical and cognitive capabilities, is important for appropriate design of training programs. An important characteristic of older adults is that they are largely heterogeneous in terms of technology anxiety, knowledge, and experience. Existing stereotypes around older adults have simply viewed them as homogeneous. However, as discussed in Cody et al. (1999), there isn't a single optimal level for technology training programs targeted at older adults. A program that is too easy and simple can bore its learners and cause them to drop out, while an excessively fast and challenging program will inadvertently increase learners' technology anxiety and cause them to exit. A possible solution for effective training is to engage older adults in trial activities rather than providing them with unidirectional teaching. In Hollis-Sawyer and Sterns (1999), a participatory program with a goal-oriented setting was found to be more effective than verbal teaching in computer training.

### 3.3.6. Social support: peer support and social acceptability

Older adults are more likely to adopt technology when their peers or social circle support its use. When it comes to adoption and use of technology, peer pressure is not just for kids. Older adults often rely on peers for validation of behaviors, including purchase and use of technology. People within older adults' social groups, such as family, friends, and community members, play an important role in the adoption process, acting as "technology champions" (Wang et al., 2011). At the earlier stages of adoption, they foster better awareness of technology and its benefits (Walsh and Callan, 2011). Later, they act as advocates of technology, promoting use and providing guidance (The SCAN Foundation, 2010). In addition to professional and technical support in learning how to use and maintaining the system, older adults also need social support in overcoming barriers to adoption.

Previous studies have found social support as an important factor that influence older adults' adoption and use of various technologies. For example, a survey on mobile phones found that social influence significantly affects intention to use (Conci et al., 2009). In a study on older adults' Internet adoption, Lam and Lee (2006) found organizational support and encouragement by people in reference groups, including family and friends, to have a significant effect on usage intention, with the relationship mediated by self-efficacy and outcome expectations. In another study on Internet adoption and use of e-mail, Cody et al. (1999) found older adults' relationships and connections with friends and relatives as facilitators of use. Encouragement from others was also found to play a key role in older adults' decisions to adopt and use assistive products as well, such as walking aids (Gooberman-Hill and Ebrahim, 2007). In general, it was suggested that older adults may be more likely to trust a technology-savvy peer, rather than a professional (Heinz et al., 2013).

Participants in the user interviews also talked about the role of social support on their previous decisions around adoption and use of technology. Social connections were described to be important during initial adoption as well as continued use. For example, one older adult said suggestions from her grandsons to have strongly influenced her decision to start using Facebook, and another respondent said "I'm more on Facebook just to know what my kids are doing… I just look at their page and I know what's going on. I don't have to worry."

Adoption and distribution of technology can be facilitated through identifying technology champions, peer leaders and well-connected early adopters (Wang et al., 2011; Heinz et al., 2013). The use of social networks and existing communities such as encouraging older early adopter to act as technology evangelists, and placement of products in popular media with relatable characters, can also validate style and utility, thus reinforcing adoption decisions.

### 3.3.7. Emotion: emotional and affective benefits

According to the US Census Bureau, over 90% of adults over the age of 65 live independently (US Census Bureau, 2001). Since older adults in general are physically less mobile, their activities mostly take place within the home environment (Baltes et al., 2001). As a result, older adults experience constraints in terms of not only their physical and cognitive capabilities, but also social interactions and other personal activities. Furthermore, people generally fear loneliness and isolation even more than physical and cognitive decline (Walsh and Callan, 2011). Due to the potential decreases in activities and occasions for socialization and entertainment with age, older adults are more likely to adopt and use technology that offers emotional benefits and affective values.

Older adults' concerns around emotional values can in fact act as a barrier to technology adoption. In existing literature, studies have described how older adults often perceived technology as a potential threat to decreased social connectivity and emotional contacts. In a study on communications technologies, Melenhorst et al. (2001) found that older adults didn't engage in using e-mails due to their beliefs around lack of intimacy and interactivity. Potential decrease in social contact and intimacy acted as a barrier to adoption of technology-enabled healthcare systems and assistive technologies as well (Kang et al., 2010). For example, technology-enabled systems have been evaluated as possibly less desirable than personal services even though older adults wish to remain independent and avoid institutional care, because older adults fear the possible replacement of human assistance and response (Woolhead et al., 2004; Demiris et al., 2004). In addition, similar concerns were raised around technology in general. Older adults were found to be frustrated with their perception of society's reliance on technology and worried about declines in human contact and personal aspects that may be brought about with automations and simplification cause by advances in technology (Heinz et al., 2013). Related comments were also found from the result of the user interviews. For example, one respondent said "I'd rather talk to your face here like this. I think it's taking away from a lot of things" as she referred to online social media.

Another aspect of the emotional factor is the degree to which a technology can offer enjoyment and entertainment to older adults. In a study on older adults' adoption and use of mobile phones, Conci et al. (2009) found enjoyment as a factor that has a significant effect on perceived usefulness and ease-of-use, both of which have strong effects on behavioral intention to use.

In order for technology to overcome the barrier, designs and features should be based on considerations of the emotional aspect. Recreation of the sensitive and intimate nature of physical touch should be a goal of technology design and delivery. For example, a smart home system for older adults can be made more attractive by including a way to easily connect with their family and friends, have conversations, and to share their memories and thoughts (Rodriguez et al., 2009). When a technology is used in a caregiving context, it would be important to consider the emotional needs of both the older adult and the caregiver (Mynatt and Rogers, 2001). This can be more effective as the social support from the caregiver can further encourage the older adult to use technology. Part of the attraction to any new product is its ability to link the user to something they feel. While the technical capabilities are important, affective benefits and values should be visible to older adults as well.

### 3.3.8. Independence: preventing stigmatization and protecting autonomy

Older adults are more likely to adopt technology when using it does not visually make them appear old, weak, and dependent. Older adults' positive response toward use of technology is conditional on the technology enabling them to remain independent, not stigmatizing them as people in need of assistance. Older adults' needs change as they face physical and cognitive limitations as well as changes in health status. However, older adults wish to remain independent as long as possible despite the age-related changes that may cause their caregivers to consider support services (Willis, 1996; Russell, 1999; Williams et al., 2005). While the interfaces and features of a technological product or service have to be designed with consideration to the older adults' physical and cognitive capabilities in order to be easily understandable and readily usable, they should not be designed in a way that indicates or makes it visible that the users are old and dependent.

This psychosocial need to stay independent has important implications for the design and delivery of technology. The physical design of technology targeted at older adults can potentially make them appear dependent, frail, or in need of special care. Especially in the case of assistive technologies and health- or medical-oriented systems, the possibility of stigmatization can drive older adults away from adopting and using technology (Demiris et al., 2004; Kang et al., 2010). For example, studies found that older adults have negative impression of personal emergency alarms, often worn as pendants, because they are obtrusive, recognizable as a care device, and even shameful (Steele et al., 2009; Walsh and Callan, 2011). Older adults are also reluctant to use walking aids due to their associations with aging and dependency (Gooberman-Hill and Ebrahim, 2007). This principle applies to services as well, as older adults felt that the range of available services are based on stereotypes and do not meet the demands of people who are still relatively independent (Essén and Ö stlund, 2011). In the case of home technology, it has been reported that older adults dislike having to share their health information and being photographed or watched (Steele et al, 2009). As the findings suggest, devices and service systems that make older adults dependent, frail and powerless can be viewed as an admission to stereotypes and stigma around aging.

Older adults are more likely to adopt and continue to use technology that helps them remain independent, lets them have control and authority over its features and functions, and does not show signs of aging or frailty. However, while it is important to consider older adults in a broad social context, as suggested by Mynatt and Rogers (2001), existing research and products have largely focused on individual traits. The misrepresentation of characteristics and needs in existing systems is mainly due to current practices on designing around socio-cultural biases and stereotypes (Turner and Turner, 2010). Thus, it is important to gather inputs from older adults early in the development process for a correct interpretation. Also, it can be effective to embed or integrate features into existing things that people commonly use regardless of age, instead of making stand-alone devices dedicated to a single function. For example, instead of making emergency alarms as pendants, the function can be implemented into watches or earphones to make the purpose less visually obvious. Lastly, in advertising and marketing, it is important to show youthful, connected and independent self-concepts with images that appeal to broader generations instead of relying on stereotypical characters (Moschis, 2003).

### 3.3.9. Experience: perceived familiarity and relevance to previous knowledge

Previous exposure plays a big role in determining older adults' technology adoption. Older adults are more likely to adopt technology that seems familiar or similar to other technologies they have successfully used in the past. This also holds true for the general population. For people spanning all age groups, perception toward technology are founded on prior experiences to some degree (Walsh and Callan, 2011). When introduced to a new technology, people reference other familiar systems to understand its purpose and determine their perception and intention to use (Brown and Venkatesh, 2005). If interacting with a technology requires users to acquire new information, rather than letting the users to utilize existing knowledge, it is likely that the users will face difficulties in use (Lawry et al., 2009). Yet the causal relationship between past experiences and adoption is stronger for older adults, as exposure to technology is negatively correlated with age while technology anxiety is inversely correlated with experience (Niemelä-Nyrhinen, 2007; Quinn, 2010).

Research has found that older adults dislike or have difficulties understanding technologies that seemed unfamiliar. In a study on communication technologies, older adults with no experience in using e-mail judged the medium more negatively than the experienced group (Melenhorst et al., 2006). Evidences were found for computer systems as well. Wood et al. (2005) have also found experience as an important factor that determine older adults' successful use of computer systems, and described how the experiential differences between the young and old can cause them to prefer different input devices. Poynton (2005) has described how technology experiences during childhood and younger adulthood can affect technology use at older ages, and how the lack of relevant experiences can put older adults at a disadvantage when using new computer systems. In a healthcare context, Lakey et al. (2009) described how older adults' limited knowledge and experiences may have accounted for the unwillingness to use programmable medication management systems.

Suggestions for incorporating understanding of older adults' prior experiences and knowledge for facilitating technology adoption and use can also be found in the existing literature. First, it is important to consider what they may already be experienced with. Relevant prior experiences are transferable between products and contexts (Blackler et al., 2005). Since older adults often find it hard to grasp the concepts of new technologies if they cannot recall a relevant experience, it is effective to communicate using proper analogies with other systems they are familiar with. For example, Emery et al. (2003) emphasized the importance of considering older adults' prior computer experiences and related abilities in designing graphical user interfaces. Second, system interfaces should design for intuitiveness, a characteristic built upon past knowledge. Technology familiarity, a measure of prior experiences, is found to be an important factor in intuitive interaction (Blackler et al., 2009). The interfaces should be designed with a sufficient degree of familiarity to overcome the barriers to use (Holzinger et al., 2007). Third, incremental improvements and integration of existing designs can be better accepted than features that are completely new (Rodriguez et al., 2009). Lastly, when training and educating older adults for using new technology, it is important to have them first experience success in doing tasks to engage them continuously without making them frustrated and anxious. As Arning and Ziefle (2007) suggested, experience of successful interactions with technology can lead to high acceptance.

In addition to the literature, the importance of successful relevant experience on positive perceptions toward other technologies was evident in the user interviews as well. When asked to talk about perceived effect of field study experience on attitudes toward technology in general, one person said "it just opened up my eyes to different things that might be helpful." Another respondents mentioned that she "would love to have the whole house computerized," and explained it as, "maybe that had come about from the study, because that's something that had not been in my life to have something beeping at you and helping you manage your medication and stuff."

### 3.3.10. Confidence: freedom from intimidation and anxiety

Older adults are more likely to adopt technology when they are confident and not intimidated about using it. Many older adults are in fact interested and enthusiastic about using new technologies, contrary to existing stereotypes (Aula, 2005). However, their level of confidence in interacting with high-tech devices is generally lower than that of younger people. Studies have found that anxiety is positively correlated with age while self-efficacy is negatively correlated, meaning that older adults are less self-confident and more anxious when using technology (Ellis and Allaire, 1999; Czaja et al., 2006; Chung et al., 2010).

In various application domains, previous studies have discussed finding around the role of confidence on older adults' adoption and use of technology. For instance, a study on surface computing found that older adults are often intimidated by large screens (Piper et al., 2010). Similar finding was also reported in

Steele et al. (2009), where older adult participants demonstrated anxiety towards interacting with sensor-activated smart systems. In a discussion about personal emergency response systems, older adults indicated that they are afraid they might unknowingly push the button and call the monitoring center (Czaja et al., 2006). Arning and Ziefle (2007) carried out experiments on younger and older adults' interactions with personal digital assistants (PDAs), and found that technical confidence only had a significant effect on task success rate in the older adults group, whereas confidence wasn't a significant factor in the younger group.

It is important to let older adults feel confident about technology, since lack of confidence can lower the perceived benefit, satisfaction and likelihood of repeated usage (Meuter et al., 2003). To enhance user confidence, it is important to build intuitiveness and robustness into design. Through intuitive design, technology can be made less difficult for older adults. Systems have to be designed with appropriate cues and directions to prevent mistakes and to let them know that they are doing the right things, so that confidence can be built and reinforced (Gregor et al, 2002). Also, physical designs can be modified to prevent mistakes and failures, such as providing a strap to decrease user's fear of dropping a mobile device (Holzinger et al., 2007).

Education is also important to build confidence in older adults' technology usage (Poynton, 2005). In order to build confidence and reduce anxiety, it is important to offer proper training and support. When designing training programs for older adults, it is important to note a possible association between experience and confidence. Studies have reported a positive correlation between experience and confidence among older adults. For example, Niemelä-Nyrhinen (2007) found that older adults' anxiety toward using SMS and Internet decreased with more experience, and Ellis and Allaire (1999) found computer knowledge to decrease computer anxiety. Also, in the user interviews, a respondent commented that she "feel(s) more confident (about using technology) now," when she talked about the effects of successfully using a new technology during the field study she was involved in. Thus, it is important to design training interventions so that older adults experience successful interactions early in the learning process and receive constructive feedback (Arning and Ziefle, 2007).

### 3.3.11. Reliability

The model of acceptability of assistive technology (McCreadie and Tinker, 2005), described earlier in section 2.1.2, suggests reliability as an important attribute that influences acceptance. In line with the model, participants in the user interviews described the role of reliability in their experiences as well. In the user comments, reliability was described in two different dimensions: reliability of system operations and trustability of service structures. However, while a few studies have discussed its importance, reliability has not been a popular topic in the literature around older adults' adoption of technology.

#### 3.3.11.1. Reliability of system operations

System reliability concerns the ability of a technology-enabled product or system to work well over time in various situations without failing or being interrupted. Older adults are more likely to adopt and continue using technology that holds up over time reliably. In the user interviews, older adults expressed frustrations they had with the lack of reliability in current systems, and how such problems cause them to dislike technologies of the like. For example, respondents talked about problems they had with reliability of communications technology, as in "I get a lot of dropped calls," and "the services has all gone down recently."

Among the existing literature, a few studies have discussed the importance of system reliability in health management technology. As described earlier, McCreadie and Tinker (2005) found reliability as a key determinant of acceptability. They found the operational reliability to the most important attribute of assistive technologies as their respondents criticized problems with existing products, such as stair lifts that break down and grab rails that wobbled. In Mitzner et al. (2010), reliability was found to be more important for technologies in the healthcare domain compared to work or home technologies.

Only few studies have discussed reliability and its roles in determining older adults' adoption of technology. However, technologies targeted at older adults are often designed to serve vital roles. This is especially true for assistive technologies and health management home technologies, such as fall detectors, medication organizers, and walking aids, as failure to operating properly can result in serious consequences. Thus, it is important for practitioners to design robust systems, test them extensively, and communicate the results clearly so that older adults can accept them without being worried about possible problems.

#### 3.3.11.2. User trust with service structures

In addition to the operational reliability, concerns were also raised around a general sense of trust and dependability that is needed for older adults to successfully adopt and use technology. In the user interviews, one participant described that when she chooses to get a new technology, she will "stick with" a particular brand even though she hasn't yet evaluated alternatives, as in "I haven't priced them or anything, you know… I would probably go with Sony, I sort of have mostly Sony stuff, and Sony I like a lot, so I would look at a Sony first." Another participant talked about issues with communications service systems structure, and said “I don’t trust Verizon’s answering machines when you do it out in the cloud or online or whatever they want to call it.”

The issue of trust and service dependability has not been investigated extensively in the existing literature. However, in line with the second user comment on communications services, a few studies discussed trust in the online information sharing setting. In a study on older adults’ participation in electronic commerce, McCloskey (2005) has identified trust as an important factor that has a positive and direct influence on usage. Also, Quinn (2010) has found that older adults are generally more concerned about sharing personal information online compared to younger people.

Existing studies on the level of trust and its effect on older adults’ adoption and use of technology have focused on issues related to security of personal information that are stored and shared online. When it comes to information sharing, especially personal and financial information, providing older adults with a transparent system structure and ensuring them about security and safety can help to increase acceptability. Also, to strictly maintain and assure older adults’ trust with sharing information online, safeguard mechanisms, or regulations around data security may be necessary. In addition, as revealed by the user voice from the interviews, trust and dependability can also be an experience issue and a brand identity issue. Establishing a positive brand image can be a solution for facilitating adoption and increasing the rate of diffusion. There are few ways to approach this solution. One possibility is to enhance technology testability by providing opportunities to try products before buying, and to offer older adults with successful initial experiences. Another possible strategy would be to form partnerships with companies with strong, reliable, and widely accepted brand images.

### 3.3.12. Compatibility

During the user interviews, several issues related to compatibility were raised. The older adult participants described compatibility as an important technology attribute in three main dimensions: the ability to seamlessly interoperate with existing technologies, the ability to fit into lifestyle and living arrangements, and the degree to which technical features match their existing mental models. Similar to reliability, compatibility has also not been a popular research topic in the literature on older adults’ technology adoption. However, a few studies have described related issues in various contexts as well.

#### 3.3.12.1. System interoperability

Older adults are more likely to adopt and use a technology that can seamlessly interoperate and interact with other technologies they already have. Partly due to the stereotypes that viewed older adults as technology non-users or rejects, the technologies that they might already be using have not been appropriately considered in design and marketing (Niemelä-Nyrhinen, 2007). However, from the user interviews, it was found that older adults are active current users of various technologies, and that interoperability was something that they already experience problems with. For example, one respondent described his data back-up process as "every-thing goes into this machine, and then I duplicate it onto this computer and I put it onto my netbook, and I have external hard drives. So I have, like, four versions of it… It's time-consuming and not automatic." Also, when asked about his plans for using any new technologies in the future, he said "the big thing is something to better coordinate," and that he "would like to integrate everything."

In a few previous studies, system interoperability came up as an important attribute of technologies targeted at older adults. For example, in a study on a communication system for older adults and their families, Rodriguez et al. (2009) reported how participants of their study identified the functionality as something that could be integrated better with existing devices such as mobile phones and televisions. Additionally, they suggested that systems should co-habit with existing devices and systems for successful implementation and use. In another study on home technologies for older adults, Ahn (2004) found that the majority of her survey sample rated compatibility with existing products as very important.

The functions and designs of a technology's graphical, physical and cognitive interfaces with older adults have been widely studied in many related research areas for various application domains. However, a technology's interfaces with other products and systems have been largely neglected. A more comprehensive assessment of user characteristics is needed to improve and ensure that a new technology works well with existing systems. During early stages of design and development, before the system architecture is fixed, the development team needs to understand what the potential users may already have so that the new technology can interact with them better. Also, a modular design or customizable design architecture can be ideal, as these can better ensure that a technology can interoperate with various systems a user may have.

### 3.3.12.2. Lifestyle fit

In the interviews, older adults talked about how their living situations affected their decisions when choosing technologies to purchase and use. For example, one recently replaced his old air conditioner with a new one because "the management (of his residence) gave me a hard time". Another said that she recently bought a coffee machine and chose the particular model because "it was small… I have a small kitchen." Such remarks suggest that a technology's fit with lifestyles and living arrangements can be a factor that influences older adults' adoption and use of various technologies.

In existing literature, lifestyle compatibility has been discussed with importance in studies on technology adoption and diffusion among the general population. For example, compatibility, or the ability to be assimilated into one's lifestyle, was identified as a key factor in the Diffusion of Innovations Model (Rogers, 1995). However, in the context of older adults' adoption and use of technology, only a couple of studies have discussed the importance a technology's ability to fit into older adults' lifestyle. Heinz et al. (2013) suggested that designers should consider whether or not a technology is compatible with older adults' lifestyle. In this study, they found that older adults' living situations and lifestyles, such as living in rural or urban settings, may cause them to have different needs for technology. Rodriguez et al. (2009) also found evidence around the potential role of current life patterns on use of technology. In this study, the participants talked about how and when they would use technology features that they proposed, which suggests that technology needs may arise from and depend on lifestyle habits and routines.

Older adults prefer to adopt and use a technology that readily fits their lifestyles, daily activities, and living situations. A technology that requires older adults to make adjustments in their established routines will less likely be adopted. Thus, designers and researchers should have a better understanding of the users' lifestyles and living situations to find underlying needs and to facilitate adoption. It will be necessary to put effort into describing usage environments and contexts as needs are identified during early phases of design and development. Several methods can be used to assist research around the assessment of lifestyle fitness, including scenario analysis and observation techniques. Also, as Rosenthal and Capper (2006) suggested, methods of ethnographic inquiry, which involve on-site field observation and interview, can be helpful in understanding lifestyle factors.

#### 3.3.12.3. Consistency with mental models

Mental models are dynamically constructed knowledge structure around which one understands and explains occurrences of events and changes (Kaufman et al., 2003). In section 3.3.9, the importance of prior experiences and knowledge around related technologies was discussed. In addition to knowledge in the technical domains, established concepts and mental models with which older adults view the world around them are also important. In the user interviews, participants described problems they experienced with a mismatch, or lack of compatibility, between existing systems and their mental models. For example, they were confused with the use of the word “friend” on Facebook. One older adult didn't get that her daughter-in-law's friend could add her as a “friend” on Facebook, and another said “I posted it (a picture) on Facebook and so my grandson got it, because he happens to be listed as a friend, not family. Why, I don't know.” While the concept of a “Facebook friend” may come naturally to younger users, the finding suggests that it may contradict older adults' conceptual models on how they understand and label social relationships.

Previous studies on older adults' adoption and use of technology have not fully explained the potential role of mental models and conceptual fit on acceptance. The lack of research may be due to the complexities and uncertainties inherent in the concept. That is, a person's mental models have complicated structures that may be largely different from other people, and are difficult to define, describe, and measure. Furthermore, because mental models are formed with accumulation of experience and knowledge, it is even more difficult for a typical designer to understand older adults' mental models and try to translate them into design. While it is difficult, if not impossible, to effectively assess and interpret mental models, a few studies have made suggestions around ways to overcome the possibly inevitable gaps. Blackler et al. (2005) suggested the use of appropriate icons and metaphors, and making incremental changes in design to apply some existing knowledge while progressing towards a new design at the same time, and stated that it is too complex to try to apply mental models directly into design. In a study on telemedicine technologies, Kaufman et al. (2003) suggested that mental models relevant to system use can evolve with more experience, as the gap between existing and required mental models was found to be bigger among novice users. In short, while a better understanding of mental models is desirable, a more realistic method of ensuring a technology's fit may be offering older adults with technology trials and designing with small, incremental changes.

## 3.4. Summary and key takeaways

In this section, key factors and determinants of older adults' technology adoption and use have been identified and described through a literature review and user interviews. Based on the literature review, this study identified ten factors - value, usability, affordability, accessibility, technical support, social support, emotion, independence, experience, and confidence. From the user interviews, further empirical support was found around these ten factors. Also, the user interviews were able to suggest additional factors – reliability and compatibility - that have not been widely discussed in the literature. For each factor, this section discussed the role and importance in determining older adult's adoption and use of various types and domains of with research findings and industry examples.

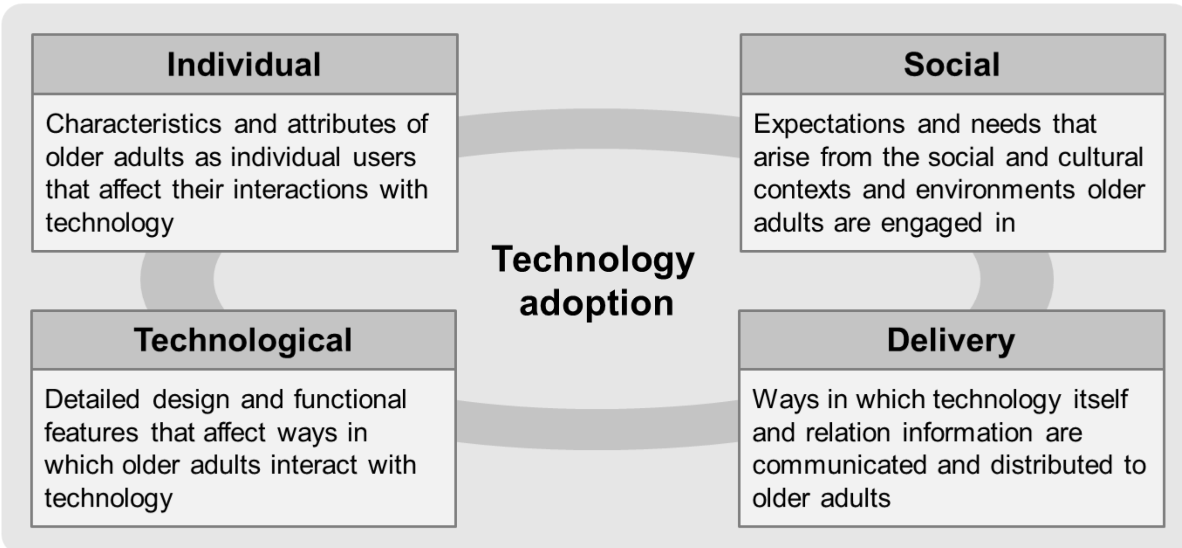
The factors can be discussed in terms of the population-level adoption pattern discussed by Rogers (1995). The related literature and user interviews concerned many examples of technologies, such as advanced assistive systems and online services, which have not yet reached a widespread diffusion among the older population. Thus, in many application areas, the factors can be discussed as enablers with which existing technologies can be improved to reach the early majority. For new technologies, the factors can be understood as conditions that need to be fulfilled to quickly reach a wide user base beyond the innovators and early adopters.

The ten factors cover a broader area of design considerations compared to the generic frameworks including TAM (Davis, 1989) and the Diffusion of Innovations Model (Rogers, 1995). Of the ten factors, value and usability are straightly aligned with the two factors identified in TAM – perceived usefulness and ease-of-use. Also, value, usability and experience are closely linked to factors discussed in the Diffusion of Innovations Model, including compatibility, complexity, and observability. However, the identification of other factors in this study – affordability, accessibility, technical support, social support, emotion, independence, and confidence – suggests that a direct application of existing models developed around the general population may be limited when designing, developing, and distributing technology to older adults. Attributes of older adults' individual and social characteristics, which are addressed by the set of factors, should also be considered to facilitate adoption and use.

The findings from the literature review and user interviews were generally consistent. However, the identification of additional factors – reliability in system operation and service trust, and compatibility with other systems, lifestyles, and conceptual models – suggests the need for a more comprehensive research. While these factors have rarely been discussed in previous studies on older adults' adoption and use of technology, other related areas of study, including ergonomics and engineering systems, have already described them as important system properties (de Weck et al., 2011; Scott et al., 2011). This gap addresses a possible limitation in existing literature, and calls for a more complete understanding of older adults' thoughts, behaviors, needs, and values. Furthermore, while the interviews were conducted in depth with probing questions, the user study part was limited in that findings were generated from a small sample. While the factor identification took an exploratory approach, quantitative methods with a larger sample can be used for better representation and ability to generalize.

The identified set of factors suggests that older adult's adoption and use of technology is not a purely technical topic, but rather a complex issue with multiple aspects. The factors span not only physical design and individual characteristics but also social settings and delivery channels. For example, social support and independence can be categorized as social factors, while experience is more individual. Some factors may belong at intersections of two or more aspects. For example, affordability concerns an individual's financial situation, but can also be a delivery factor with its relation to distribution and pricing. Also, while accessibility is a factor closely related to advertising and marketing, or how a technology is delivered, it also concerns older adults' social relationships, connections, and interactions. The four related aspects of technology adoption covered by the factors are illustrated in Figure 15.

**Figure 15. Four aspects addressed by technology adoption factors**




The findings described in this section suggest several directions for further research. First, the factors are defined mainly from a conceptual integration of existing findings, and the importance of each factor has been discussed in varying degrees across domains and applications. A large-scale empirical research can be conducted to look at a more general picture, and to investigate the factors' validity and applicability in various settings. Second, findings suggested how factors may assume different roles and relative importance throughout various stages of adoption and use. A factor may be more important during purchase but less important during continued use. For example, affordability can be perceived as more important at purchase compared to later stages such as long-term use. Also, a factor may assume act differently at purchase compared to initial use. For example, social support was found to inform older adults about technology availability before purchasing a product, but was discussed to act as assistance to learning and training from initial to continued use. Third, possible associations and relationships between factors have been discussed. For example, studies have discussed associations between experience and confidence, experience and conceptual compatibility, social support and accessibility, and value and affordability. Investigation on the underlying structure among the various factors can be further studied.

The identified factors have implications for industry practices as well, in addition to the consumer and user studies perspective. This section discussed how the factors can act as a set of actions or goals. By fully considering the factors in design, development and delivery, technology can be made more appealing, useful, and usable to older adults. The factors can be applied to various types of technology to enhance older adults' interaction with technologies for their security, health, independence, mobility, and well-being. Another conclusion that can be made from the findings is that that there is a need for approaches beyond simple question-and-answer sessions. Many of the factors, including conceptual compatibility, lifestyle fit, and usability, cannot be measured easily or directly. Furthermore, factors such as independence and confidence may be something that older adults wouldn't openly talk about. Thus, an industry-oriented study on identifying and describing when and how to implement various methods of inquiry can be helpful. A possible direction for a follow-up research would be to analyze and model industry practices in the design and development of technologies targeted at older adults, and to investigate the processes and activities in which the adoption factors can be incorporated into.

# 4. Phase 2: Analysis of technology adoption factors from users' perspectives

Older adults are being newly interpreted as potential users of various new technologies with a positive view and heterogeneous characteristics. They are in fact different from younger people in terms of the general physical and cognitive conditions. As people age, they face inevitable changes and declines in physical and cognitive capabilities (Blaschke et al., 2009; Piper et al., 2010). Such age-related changes can affect how older adults perceive ease of learning and use as they are introduced with new technology (Zajicek, 2003). Studies have found that many existing systems that younger people widely use with no difficulties, including computer mouse, e-mail, and Web sites, can be evaluated to be difficult to control and error-inducing when seen from older adults' perspective (Kaufman et al., 2003; Becker, 2004; Hart, 2004; Murata and Iwase, 2005; Rodriguez et al., 2009). Research has also found that older adults are more likely to be attracted to technology that can potentially provide clear benefits to their current lifestyle, and are generally reluctant to use if they cannot see the advantages it may bring (Melenhorst et al., 2001; Steele et al., 2009; Walsh and Callan, 2010). Also, while they are among the wealthiest of the overall consumer population, older adults are described to be more cost-conscious, especially when potential benefits are unclear (Steele et al., 2009). While older adults are willing to use new technology, studies have found that they are generally less aware of new innovations and what's available in the market (Heinz et al., 2003; Tanriverdi and Iacono, 1999; McCreadie and Tinker, 2005). A cause to the relative limitations in technology awareness has been identified as a lack of relevant past experiences (Steele et al., 2009; Walsh and Callan, 2010; Lakey et al., 2009). Also, because they generally know less about and have less relevant experiences with new technology, older adults are also likely to be more anxiety and less confident when interacting with it (Ellis and Allaire, 1999; Chung et al., 2010; Czaja et al., 2006). It been discussed that technical assistance and social support from peers can act to improve awareness, accessibility, and their overall user experience (Heinz et al., 2013; Walsh and Callan, 2010; Demiris et al., 2004; Poynton, 2005; Wang et al., 2010).

In the previous chapter, these characteristics have been summarized into 15 factors of older adults' technology adoption. In order to empirically investigate their importance, find associations between them, and analyze possible differences between people with different characteristics, a large-scale national survey was conducted. In the survey, a total of 609 adults in the United States, evenly distributed across age, gender, and geographic location, was included the sample. Respondents answered questions on how much they are knowledgeable and experienced with various types of technology, and how they value and evaluate different decision factors during stages of adoption and use. For a detailed description of general trends, as well as for a validation of the factors, the collected survey data was analyzed using various statistical methods. Additionally, in order to capture both general trends and deeper descriptions, open-ended questions were asked in addition to closed-ended, multiple-choice questions. This chapter presents a description of the process with which the survey was carried out, the instruments that were used for data collection, and the results that were analyzed based on the data gathered.

## 4.1. Questions and objectives

The survey was conducted to describe the importance and roles of the technology adoption factors during various stages of adoption and use. The discussions around the technology adoption factors, as described in the previous chapter, suggested the need for an empirical follow-up study to further investigate the validity and applicability of the factors. The national survey presented in this chapter was carried out to address the need for a deeper description and explanation of the factors. The main research questions, in which the survey was conducted to answer, can be summarized as follows. As the following research questions suggest, the main objectives of the survey included empirical validating the adoption factors, determining the relative importance of each factor, and analyzing the underlying structure to explain associations between the factors.

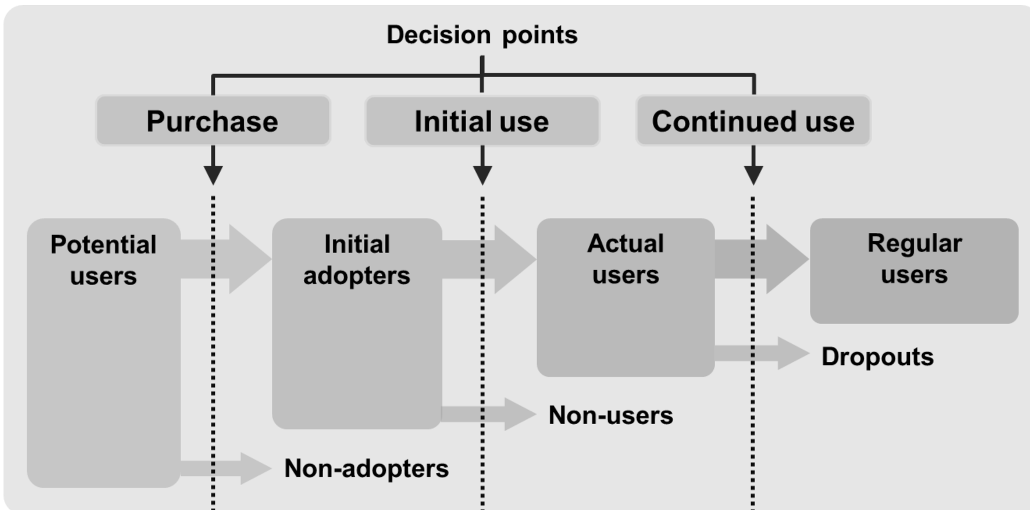
- Do older adults perceive the adoption factors to be important in their adoption and use of technology as suggested by the literature and the preliminary interview findings? How valid are the factors in general?
- Based on older adults' perceptions, are some adoption factors more important than others? What is the relative importance of each factor as compared to others?
- What are the relationships between the adoption factors? In what ways are the factors associated with one another? What is the underlying structure that explains the associations and relationships between the factors?

Furthermore, the survey sought to analyze the effect of age and other individual variables on experiences, perceptions, and decision behaviors. The existing literature discussed the potential influences that may be brought about by individual characteristics including age. In the Unified Theory of Acceptance and Use of Technology, summarized earlier in section 2.1.1, age was identified as a key moderating variable that mediates the effect of performance expectancy, effort expectancy, social influence and facilitating conditions on technology use (Venkatesh et al., 2003). Also, in the CREATE model developed by Rogers and Fisk (2010), which was introduced earlier in section 2.1.2, age was identified as a user characteristic that can influence use of technology. In addition to age, previous studies have also identified living conditions as another attribute that can affect older adults' adoption and use of technology. For example, in the model of acceptability of assistive technology, summarized in section 2.1.2, McCreadie and Tinker (2005) described living arrangements as a user characteristic that affects the felt need, which is a determinant of acceptability. In addition to these user attributes, technology experience and knowledge have been discussed as a key characteristic and was identified as one of the adoption factors in section 3.3. Furthermore, experience and knowledge have been used in previous empirical studies as both an independent variable with influence on adoption and use behaviors, and as a dependent variable that is affected by the age of an individual (Arning and Ziefle, 2007; Lawry et al., 2009; Lakey et al., 2009). Based on these premises, an additional goal of this study is to answer the previously listed research questions with a comparison between people with differences in individual characteristics including age, living situations, and technology experience. The additional research questions can be stated as follows.

- Does perception of a technology adoption factor's importance vary by age or living situations? Do people with different technology experience or knowledge differ in how they perceive the overall importance of the factors?
- Does the relative importance of each factor, as compared to others, vary between people of different ages or living situations? How do the relative weights vary between people with different technology experience or knowledge?
- How do the underlying relationships or associations between the factors differ with variations in individual consumer/user characteristics including age, living situations, and technology experience or knowledge?

While a staged framework does not exist for describing technology adoption, an integrative survey of related literature suggests that technology may happen as a process rather than a one-shot event. As discussed in section 3.4, an aggregation of findings from previous studies suggested how adoption factors may have varied effects and roles through a process of adoption and use. Technology adoption has often been discussed an action that includes an attitudinal aspect and a behavioral aspect. For example, many studies, including the earlier frameworks, have described adoption as a process where attitudes are formed, intentions are made, and actual behaviors are executed (Rogers, 1995; Davis, 1989; Venkatesh et al., 2003; Kulviwat et al., 2009; Porter and Donthu, 2006; Lu et al., 2003; Malhotra and Galletta, 1999; Gaul and Ziefle, 2009). Furthermore, a few studies have extended the discussion to include post-purchase or post-acquisition behaviors from initial early usage and continued regular usage. For example, Meuter et al. (2003) described adoption to have several levels, including infrequent use, occasional use, and regular use. Similarly, Sarker and Wells (2003) discussed different levels of adoption, and described continuous and routine use of technology over time as an ideal adoption outcome. The user interviews, described earlier in section 3.2, have also suggested a distinction between purchase activities, initial learning and use, and continued or regular use. Based on the discussion, the survey sought to further study the importance of the adoption factors during various stages of adoption and use. In the survey, technology adoption is described as a process with multiple stages and decision points, as illustrated in Figure 16.

**Figure 16. Process of technology adoption**




Based on the process framework shown in Figure 16, the survey also aimed to find answers to the following research questions.

- Does perception of a technology adoption factor's importance differ between different stages of adoption? Does the overall validity of the factors change or differ by adoption stages?
- Do the weights or relative importance of factors change or differ by adoption stages? What is the relative importance of each factor at each stage of technology adoption?
- Do the relationships or associations between the factors change by adoption stages? How does the underlying structure among the adoption factors differ between different stages of adoption?

## 4.2. Survey study design

### 4.2.1. Questionnaire design

The main objective of the survey study was to investigate the validity and generalizability of the adoption factors. Thus, it was essential to gather information from a large sample of people. Also, because the detailed objectives involved comparison of the results between different groups of people and stages of adoption, it was essential to reach a sample that includes individuals of various ages and living situations. To achieve these goals, a survey method was used as an empirical method of validating and the adoption factors, studying underlying associations, and investigating potential differences between consumer and user groups. The survey method was chosen mainly for its ability to represent general trends and characteristics of a large population. Survey is a useful method for describing the characteristics of a large population using a small sample (Babbie, 2007; Schuman and Presser, 1996). The method allows one to discover patterns and make generalizable statements through use of statistical techniques (Gable, 1994). Another strength of the survey method is its reliability. Because all respondents are presented with the same format, the survey method has an advantage in terms of reliability and consistency (Babbie, 2007).

A questionnaire was constructed to investigate the research questions summarized in section 4.1. In order to gather responses on technology experience and knowledge, demographics, living situations, and perceived importance of adoption factors, the questionnaire was composed of different sections with closed-ended choice question sets. In these sections, respondents were asked to read through the questions and the options given, and answer them by choosing one that most closely resonates with them or most accurately describes them.

In addition to the closed-ended questions, a set of open-ended questions were added for respondents to share their experiences in their own words. Open-ended questions have been discussed to be useful when questions should be answered in a narrative form, and when further reasoning behind a conclusion is needed (Fowler, 1995). Also, it has been suggested by a number of previous research that closed-ended questions may not cover the breadth of possible answers. Open-ended questions are advantageous as respondents are often influenced by the specific alternatives given in closed-ended questions, and because closed questions may fail to provide an appropriate, complete, and meaningful set of options (Schuman and Presser, 1996). Furthermore, studies have also suggested that closed-ended, multiple-choice questions can be prone to individual and social biases. It has been suggested that open-ended questions can be better than closed ones on sensitive topics (Converse and Presser, 1986). While technology adoption and use may not be a sensitive topic in general, it was decided to add the open-ended questions to avoid potential biases due to social desirability. In short, the open-ended questions were included in the survey to cover a broader perspective, gather detailed narratives, find important points that may not have been captured by the closed-ended questions, and to prevent from collecting biased responses.

Overall, the questionnaire had five sections in total. The first section included questions on how much an individual has knowledge of, or has experiences using, various types of technology – mobile devices, work and office technology, social networking services, Internet-based communication services, health management, data storage and security technology, transportation technology, home security, and home appliances technology. Table 8 describes the types of technology that were used for gathering responses on technology experience and knowledge. The types and their descriptions were revised through pre-testing, which will be described in more detail in the next section, to make sure that they are easily understood by the general population who would potentially participate in the full-scale survey.

**Table 8. Types of technology**

| Name of technology type | Description |
|---|---|
| Mobile device | Technologies that can be carried around easily |
| Office / work technology | Devices and software used for work related activities |
| Social networking service | Technology services used for networking online |
| Entertainment technology | Devices used for gaming, music or watching videos |
| Internet-based communications service | Services that use the Internet for talking or texting |
| Health management / assistive technology | Technology for managing health and assisting activities |
| Data storage / security technology | Technology used for storing and securing data |
| Transportation technology | Technologies for assisting people to move around easily |
| Home security technology | Technologies for keeping one’s home safe and secure |
| Home appliances | Technologies used for activities in and around the home |

In the first section, respondents were asked to indicate their knowledge and/or experience by selecting a single answer among a set of options that were presented in an ordinal scale from 1 to 7 (1: don’t know what it is, 2: know what it is but have not used it, 3: have seen or experienced it some time, 4: have it but have not used it for some time, 5: have it and use it occasionally, 6: have it and use it few times a week, 7: have it and use it almost daily).

The second section included open-ended question on respondents’ experiences around purchase, initial use, and continued use of a technology. In this section, respondents were asked to choose any specific technology that they feel comfortable or interested in talking about. Three separate questions were asked for respondents to talk about their experiences at the three decision points illustrated in Figure 16 – purchase, initial use, and continued use. In addition to these general experience questions, respondents were also asked to recall if they have or purchased or started using a new technology recently, and if they have gotten rid of or stopped using any technology recently. If they answered yes to either of these questions, they were asked to describe, in their own words, what and why they have adopted or rejected.

The set of open-ended questions were asked after the technology experience and knowledge questions to allow respondents to have a better idea of the types of technology that they could talk about. By having respondents review and answer questions on various types of technology, it was expected that they could refer to them as they chose a specific technology and wrote about related experiences. Also, the open-ended questions were asked before the questions around the technology adoption factors. The decision to place the open-ended questions before the adoption factors questions was based on two main reasons. The first reason was to have respondents participate in the essay-type questions before they get tired, as the questions on the adoption factors are rather repetitive. If the adoption factors questions were asked first, respondents may already be bored when they get to the open-ended questions, which may cause them to skip them or only write short answers. Another reason was to avoid biases and anchoring effects. If the questions around adoption factors were asked first, respondents may only talk about the aspects of their experiences that are related to the adoption factors. In short, the placement or ordering of the open-ended questions was strategically decided for effectively gathering a more comprehensive set of data.

In the next section, after the open-ended experience questions, participants were asked to rate, based on their perceptions, the importance of the various adoption factors. All 15 factors described in section 3.3 were included in the questions. In the survey, respondents were asked to rate the importance of these factors at three different decision points in their adoption and use of technology – purchase, initial use, and continued use. A question statement in this section of the survey included a short definition of a given adoption factor. The definitions were consistent with the descriptions in section 3.3, as well as the short descriptions in Table 5 and Table 7. However, the actual wording and phrasing of the questions were revised based on results of pre-testing, as further described in the next section, to prevent confusion and facilitate easier understanding. The statements used for questions on the importance of the adoption factors are presented in Table 9.

**Table 9. Question statements around perceived importance of adoption factors**

| Adoption factor | General question | Question statement[4] |
|---|---|---|
| Value | How important is it for you to think about the potential benefits that a technology can provide? | It is important for me to think about the potential benefits that a technology can provide… |
| Usability | How important is it for you to think about if a technology is easy for you to use? | It is important for me to think about if a technology is easy for me to use… |

[4] The question statements were all followed by each of the three decision point descriptions: purchase, initial use, and continued use. The exact question wordings were as follows: “when I choose and buy a new technology” for purchase, “when I start to use a new technology” for initial use, and “after having used a technology for some time” for continued use. For example, the three specific question statements for value were “it is important for me to think about the potential benefits that a technology can provide when I choose and buy a new technology”, “it is important for me to think about the potential benefits that a technology can provide when I start to use a new technology”, and “it is important for me to think about the potential benefits that a technology can provide after having used a technology for some time.”

| | | |
|---|---|---|
| Affordability | How important is it for you to think about the costs associated with getting a technology? | It is important for me to think about the costs associated with getting a technology… |
| Accessibility | How important is it for you to think about the where you can get a technology? | It is important for me to think about where I can get a technology… |
| Technical support | How important is it for you to think about the quality of technical and professional assistance? | It is important for me to think about the quality of technical and professional assistance… |
| Social support | How important is it for you to think about the things that others say about a technology? | It is important for me to think about the things that people around me say about a technology… |
| Emotion | How important is it for you to think about the emotional benefits with getting a technology? | It is important for me to think about if using a technology would make me happier… |
| Independence | How important is it for you to think about the how you would look to others? | It is important for me to think about how I would look to others if they see me using a technology… |
| Experience | How important is it for you to think about your past experiences with other technologies? | It is important for me to think about how a technology is relevant to my past experiences with other technologies… |
| Confidence | How important is it for you to think about how confident you feel with using a technology? | It is important for me to think about how confident I feel with using a technology… |
| System reliability | How important is it for you to think about how a technology's ability to work over time? | It is important for me to think about a technology's ability to work over time without interruptions… |
| Service trust | How important is it for you to think about how you can trust the services related to a technology? | It is important for me to think about if I can trust the services related to a technology… |
| Interoperability | How important is it for you to think about the seamless operation with other technologies you have? | It is important for me to think how a technology can operate seamlessly with other technologies I have… |
| Lifestyle fit | How important is it for you to think about how a technology would fit into your daily life patterns? | It is important for me to think how well it would fit into my daily life patterns… |
| Conceptual fit | How important is it for you to be comfortable with the labels and words used in a technology? | It is important for me to think how comfortable I am with the labels and words used in a technology… |

In this section, respondents were asked to rate the how much they agree or disagree with each specific question statements using an ordinal scale. A 7-point agree-disagree Likert scale (1: strongly disagree, 2: disagree, 3: somewhat disagree, 4: neither disagree nor agree, 5: somewhat agree, 6: agree, and 7: strongly agree) was used for these questions. Additionally, a "not sure / don't know" option was included for those who were unable to or unwilling to provide a clear answer.

The fourth part of the questionnaire included a list of life events, living conditions, and family status. In this part, respondents were asked to read and review the list and check all that apply to them. Each status question was written as a statement to which respondents could answer either yes or no. In the list, statements were written around life events and status that may affect an individual's consumption habits, such as being employed or unemployed, being retired, having regular income or no stable income, and being in school or having a family member in school. Statements on living conditions and family status included who the respondent is living with or without, having moved recently or not, and having experienced or expecting to have a change in family status.

The last section of the questionnaire included standard demographics questions. In this section, respondents were asked to answer questions about their age, gender, current employment status, level of education, household size, housing type, household income, marital status, and location of current residence[5]. The actual questionnaire that was distributed to the full-scale survey participants, after including all revisions based on pre-testing, is included in Appendix 3.

### 4.2.2. Survey pre-testing

The question statements presented in the previous section and the full questionnaire included in Appendix 3 reflect revisions that have been made through two rounds of pre-testing. In the initial round, the questionnaire was evaluated with a set of cognitive interviews. This round aimed at evaluating the questions and improving them, rather than gathering data. In the second round, a pilot study was carried out with a small group of people. During the pilot survey, respondents were asked to answer the questionnaire and to provide feedback and comments about it. This process aimed at gathering data for analysis of general trends prior to inform the full-scale survey analysis, as well as collecting feedback for improving the questionnaire. This section describes the process in which the two rounds of pre-testing was carried out, the results that were gathered from the cognitive interviews and pilot survey, and the improvements and revisions that were made to the questionnaire based on the pre-testing findings.

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[5] The ZIP code of current residence was asked to determine the region in which each respondent lives.

#### 4.2.2.1. Cognitive interviews

Cognitive interview is a tool used for design and evaluation of questionnaires. It generally refers to techniques that developers in a wide range of disciplines use to evaluate if informational materials are properly designed. In the domain of survey research, cognitive interviews study the manner in which the targeted audiences, or the potential respondents, understand, mentally process, and respond to questionnaires (Willis, 2005). A number of different techniques can be used during cognitive interviews. Possible techniques include asking respondents to think out loud, or articulate their thoughts as they go through a questionnaire, and asking probes or follow-up questions after each question (Forsyth and Lessler, 1991). Other common techniques include asking respondents to define terms, paraphrase their understanding of questions, describe their level of confidence in answering, and discuss confusions or difficulties they had (Fowler, 1995). Cognitive interviews usually involve a small number of individuals – generally between 5 and 15 – in a laboratory setting, and are usually conducted after writing an initial draft and before field distribution (Willis, 2005). While there is no standard way of conducting cognitive interviews, the process usually included implementing one or more techniques described earlier, coding and categorizing data, and extracting and summarizing key issues (Tourangeau et al., 2000).

During the initial stage of pre-testing, a draft of the survey questionnaire was reviewed with a convenience sample of six adult participants. The sample included both male and female, and both younger and older adults, because the target respondent population for the full-scale survey was defined as adults 20 years of age or older. During this evaluation stage, the subjects participated in a cognitive interviewing process, where they were asked to read through the questionnaire draft, paraphrase the questions, comment on the questions as they answered them, and speak about things that were unclear to them. It has been suggested that actually completing the questionnaire is more helpful for effective pre-testing (Babbie, 2007). Thus, in addition to reading through the questionnaire, the participants were asked to answer all the questions and to identify any ambiguities or difficulties. The initial draft of the questionnaire used during the cognitive interviews can be found in Appendix 4.

During the cognitive interviews, participants shared their experiences and thoughts related to the adoption factors as they filled out the questionnaire. Many participants talked about the role of social support in their decisions and experiences as they interact with technology. For example, one person said she chose to buy her smartphone because she "had friends who had them" and will continue to use it because she "hear(s) things about other smartphones," and because "your friends play a big role, because it's where you hear things from." Participants of various ages talked about other factors as well, such as usability, value, experience, interoperability, affordability, emotion, independence, lifestyle compatibility, and technical support. As described in chapter 3, these adoption factors may not only be of importance among older adults, but may be universal across generations. While the findings from the cognitive interviews cannot result in a strong conclusion, they show support for the universality, which can be further investigated in the full-scale survey. On the other hand, younger participants did not talk much about confidence and conceptual compatibility in their own experiences. While a strong conclusion cannot be made, this may suggest that some of the factors, including confidence and conceptual compatibility, may be particularly more important among older adults while other factors may be more universal.

As described earlier in chapter 3, existing literature and user interview findings suggested possible associations between factors. Relationships between factors were also talked about as participants of various ages shared their experiences during the cognitive interviews. For example, social support, value, and experience were suggested to be influence one another. Few people talked about a possible relationship between experience and usability, as in "it's the most intuitive. There's no learning at all. I already knew how to use it too," and about association between value and affordability, as in "if it's a good product, I don't mind paying more." These factor associations are in line with those discussed earlier in section 3.4, suggesting that the adoption factors may be associated in older and younger adults' experiences in similar ways. The full-scale survey will aim to describe the association with stronger statistical evidence and find if there are any age differences.

The main goal of the cognitive interviews was to evaluate the questionnaire, identify problem areas, and to find out where revisions may be needed. According to the ways in which the participants paraphrased them, many of the descriptions used for the technology types and the adoption factors were understood as intended. However, some terms and descriptions were easily misunderstood. For example, in the initial questionnaire, accessibility was described as "knowledge about the stores or venues in which I can buy a technology." Because of the words "stores" and "venues", many participants thought of this factor as the degree to which they can trust certain stores, and some also thought that it only referred to physical stores, as in "I think when you talk about stores and venues, you mean bricks and mortar?" Participants also found it difficult to understand conceptual compatibility, as it was described as "the degree to which a technology's symbols and languages match the words that I normally use." Few people suggested the terms "symbols" and "languages" as vague and misleading. For example, one person said "I mean, if it has Chinese characters on it I can't use it anyway," while the term "languages" was intended to describe the labels and terms used in technology interfaces. Similarly, the descriptions for emotion - the degree to which a technology makes me feel better emotionally – and independence - the degree to which a technology helps me remain independent instead of making me look stereotypic – were found to be confusing and difficult to understand.

Another key finding from the cognitive interviews was that the list of technology types was felt by some participants as not exhaustive enough. For example, one person said that the list "is kind of very 20 something" and suggested adding other types such as "kitchen technologies." Also, during the cognitive interviews, participants often answered the questions based on their perceptions of the thoughts and attitudes other people would generally have. This suggested the need for providing a more clear direction so that participants answer questions based on their own experiences and thoughts. Comments were gathered around the options given for answering the questions. While the adoption factor question only had seven options on an ordinal scale, it was suggested that a "don't know" option should be added for people who are unsure about their thoughts.

The questionnaire was revised to address these issues. The changes that were made based on findings from the cognitive interviews are summarized in Table 10. The original descriptions included in Table 10 can be found in the initial questionnaire in Appendix 4, and the revised descriptions can be found in the full survey questionnaire in Appendix 3.

**Table 10. Revisions made based on cognitive interviews**

| Problem area | Original description | Revised description |
|---|---|---|
| Accessibility | My knowledge about the stores or venues in which I can buy a technology | Where I can get the technology |
| Emotion | The degree to which a technology makes me feel better emotionally | If using it would make me feel happier |
| Independence | The degree to which a technology helps me remain independent instead of making me look stereotypic | What other people would think if they see me using it |
| Conceptual fit | The degree to which a technology's symbols and languages match the words that I normally use | If I'm comfortable with the labels and words used in the technology |
| Measurement scale | Seven-point Likert scale | Added "don't know / not sure" option |
| General directions | In this section, statements are given to describe your decisions around choosing and purchasing a new technology. Please indicate how much you agree or disagree with the following statements. | In this section, we are interested in what is important to you when you choose and buy a new technology. Please indicate how much you agree or disagree with the following statements. Remember to think about your own experiences with various technologies as you answer these questions. |
| Technology types | A total of nine types | Added home appliances (technologies used for activities in and around the home) |

#### 4.2.2.2. Pilot field survey

The pilot field study was aimed at testing the questionnaire with potential respondents before distributing the full-scale survey. During the pilot study, the revised questionnaire, with comments from the cognitive interviews incorporated, was distributed to a small of people randomly selected from the MIT AgeLab database[6]. A stratified sampling was done to draw the random sample from different age groups and to include both male and female. The age groups were divided into three brackets, where the younger group included ages from 20 to 39, the middle group included ages from 40 to 59, and the older group consisted of ages from 60 and up. The age breakdown was decided with consideration on previous practices described in the literature, and was based on how previous studies have defined older adults and how they grouped their participants based on age (Czaja et al., 2006; Ellis and Allaire, 1999; Selwyn et al., 2003; Emery et al., 2003; Murata and Iwase, 2005; Blackler et al., 2009; Piper et al., 2009; Heinz et al., 2013; Wolters et al., 2010). That is, the age brackets used in this survey was kept consistent with the way in which many related studies have designed their methods of data collection.

The pilot survey was done online. The revised questionnaire was written into an online format that is accessible on any computers or mobile devices. The online form was created using a free service at eSurveysPro.com. While the questionnaire sections were presented in order as they appear in the paper format in Appendix 4, the individual adoption factor question statements were presented in a random order to prevent from ordering effects or boredom. For example, one participant may see the statement "it is important for me to think about where I can get the technology" first and the statement "it is important for me to think about if the technology is easy for me to use" second, another participant may see "it is important for me to think about if the technology is easy for me to use" first and "it is important for me to think about if I'm comfortable with the labels and words used in the technology" second. However, the set of adoption factor question statements were presented in a consistent order in terms of the decision points they are addressing. That is, all participants were first presented with the question statements around purchase ("when I choose and buy a new technology"), followed by the statements around initial use ("when I start to use and learn a new technology"), and then the statements around continued use ("as I continue to use a technology").

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[6] The MIT AgeLab subject database includes basic demographic information (date of birth and gender), contact information (physical address, e-mail address, and phone number), and the full names of people who have volunteered to be included. The people in the database have given their information in person, by phone, or through a recruitment Web page that is available online at http://agelab.mit.edu/volunteer-study. Individuals in the database have agreed to be contacted with information about ongoing studies and invitations to studies they are eligible for. The database includes 8922 individuals in the United States as of February 18, 2014. The database is kept in a secure server that is protected with a password. Only approved staff members at the MIT AgeLab can access the database.

In addition to the questions on technology experience and knowledge, perceptions around importance of the adoption factors at various stages, living situations and demographics, the pilot questionnaire included open-ended questions aimed at collecting participants' opinions and comments on the questionnaire itself. A total of three questions were asked for the purpose of collecting feedback and improving the questionnaire before full-scale launch. The questions were asked as follows.

- Were any parts of the questionnaire difficult to understand and/or answer? What did you find difficult and why?
- Do you have any suggestions to improve the words and/or questions in the survey? Please describe the changes you would suggest.
- Do you have any other comments about the survey? Please share your thoughts in general.

A total of 90 individuals were selected by random stratified sampling from the MIT AgeLab database. An e-mail invitation was sent to the e-mail addresses that were provided by the individuals when they signed up for the database. The e-mail invitation contained the study title, a short description of the survey, an estimated of the length of time needed for participation, information about the compensation that will be provided for participation, and a link to the online questionnaire. The link was presented as a hyperlink that recipients could simply click to open the questionnaire, but it also showed the full Web address for the survey, so that anyone who may have problem with the link could simply copy the address and access the questionnaire. Also, the e-mail invitation included contact information that may be necessary in case recipients had questions or any troubles related to the study. In addition to the initial invitation, the same e-mail was sent to the sample again after one week, and after another week, as a reminder. The recruitment message that was sent to the selected individuals is included in Appendix 5.

Participants had an option to receive a $10 Amazon.com gift card each. For delivery purposes, the online questionnaire had a field at the end where the participants could optionally enter their e-mail or home addresses, whichever they wish to receive the gift card through. All who provided delivery information received gift cards within a week after filling out the survey. The delivery information was not recorded with the questionnaire data to ensure the anonymity of the responses.

Responses were collected over three weeks. Of the 90 who were initially contacted through e-mail, a total of 39 people completed the questionnaire. The overall response rate was therefore 39/90, or 43.3%. The specific numbers of participants for the age and gender brackets are summarized in Table 11. Out of the 39 participants, one person did not provide gender information. The response corresponding to this individual was excluded from gender comparison analysis.

**Table 11. Pilot survey sample summary (n=39)**

| Sub-groups | | Age | | | Total |
|---|---|---|---|---|---|
| | | Younger (20~39) | Middle (40~59) | Older (60+) | |
| Gender | Male | 5 | 5 | 5 | 15 (38.5%) |
| | Female | 7 | 8 | 8 | 23 (59.0%) |
| | No answer | 0 | 0 | 1 | 1 (2.6%) |
| Total | | 12 (30.8%) | 13 (33.3%) | 14 (35.9%) | 39 |

The percentages were rounded to the nearest tenth.

Based on the data collected from the pilot survey, a comparison between the three age groups was carried out to see if there are any generational differences. The average experience scores for all age groups are summarized in Table 12. In terms of previous experiences and usage, differences were found in the domains of social networking services, entertainment technology, Internet-based communications technology, and data storage and security technology. In these three domains, older people, respondents who were 60 years of age or older, were on average less experienced compared to the younger groups. In Table 12, the scores for the technology types where age differences were found are written in bold. The experience scores for mobile technology, office and work technology, transportation technology, and home appliances did not show noticeable differences between age groups. On the health management and home security domains, older people were found to be slightly more experienced, although the scores for all age groups were low.

**Table 12. Pilot survey results – technology experience average scores**

| Technology types | Younger (ages 20~39) | Middle (ages 40~59) | Older (ages 60+) |
|---|---|---|---|
| Mobile devices | 6.82 | 6.92 | 6.29 |
| Office technology | 6.58 | 6.92 | 6.50 |
| Social networking | **6.00** | **6.00** | **4.50** |
| Entertainment | **6.27** | **5.69** | **4.29** |
| Internet communications | **6.33** | **5.77** | **4.93** |
| Health management | **3.08** | **3.38** | **3.57** |
| Data security | **6.17** | **5.92** | **5.00** |
| Transportation | 5.75 | 5.46 | 5.36 |
| Home security | 3.33 | 2.85 | 3.93 |
| Home appliances | 4.00 | 5.15 | 4.50 |

Score range: from 1 (don't know what it is) to 7 (have it and use it (almost) daily)

Age comparison was also carried out for the perceived importance of the adoption factors. The average importance scores for all age groups at the three decision points are summarized in Table 13. Among the

15 factors, respondents of ages 60 and older generally agreed more, compared to the younger age groups, with the statements on the importance of ease-of-use, accessibility, confidence, and service trust. In addition, they agreed, more strongly so than the younger groups, that conceptual compatibility is important during continued use. On the other hand, the older respondent group generally agreed less, compared to the younger groups, on the importance of initial cost at purchase, emotion, independence, and social support. The biggest difference was found around the independence factors, where older respondents disagreed with the statement "it is important for me to think about what other people would think if they see me using it", while younger people generally agreed with the statement. In Table 13, the scores for the adoption factors for which age differences were found are written in bold.

**Table 13. Pilot survey results – importance of adoption factors**

| Decision stage | Adoption factors | Younger (20~39) | Middle (40~59) | Older (60+) |
|---|---|---|---|---|
| Stage 1 (Purchase) | Value | 6.67 | 6.77 | 6.57 |
| | Usability | **5.92** | **6.23** | **6.71** |
| | Affordability | **6.50** | **6.77** | **5.71** |
| | Accessibility | **5.08** | **6.00** | **6.07** |
| | Experience | 5.08 | 5.77 | 5.50 |
| | Confidence | **5.33** | **5.85** | **6.07** |
| | Emotion | 5.92 | 5.31 | 5.36 |
| | Independence | **4.50** | **3.31** | **2.29** |
| | Technical support | 5.42 | 6.23 | 6.14 |
| | Social support | **5.58** | **5.15** | **4.21** |
| | Interoperability | 5.83 | 6.00 | 5.79 |
| | Lifestyle fit | 5.75 | 6.23 | 6.21 |
| | Conceptual fit | 5.00 | 5.23 | 5.07 |
| | System reliability | 6.17 | 6.23 | 6.07 |
| | Service trust | **6.08** | **6.23** | **6.64** |
| Stage 2 (Initial use) | Value | 6.25 | 6.23 | 6.38 |
| | Usability | 6.08 | 5.92 | 6.38 |
| | Affordability | 6.17 | 6.62 | 6.08 |
| | Accessibility | **4.92** | **5.85** | **6.31** |
| | Experience | 5.50 | 5.54 | 5.69 |
| | Confidence | 5.83 | 5.54 | 6.23 |
| | Emotion | **5.33** | **4.92** | **4.69** |
| | Independence | **4.67** | **3.46** | **2.38** |
| | Technical support | **5.42** | **6.46** | **6.46** |
| | Social support | **5.33** | **4.62** | **4.00** |
| | Interoperability | 5.83 | 6.00 | 5.92 |
| | Lifestyle fit | 6.08 | 6.31 | 6.23 |
| | Conceptual fit | 5.33 | 4.92 | 5.46 |
| | System reliability | 5.58 | 6.46 | 6.23 |
| | Service trust | **5.50** | **6.23** | **6.69** |

| | | | | |
|---|---|---|---|---|
| Stage 3 (Continued use) | Value | 6.27 | 6.23 | 6.42 |
| | Usability | 5.82 | 5.85 | 6.50 |
| | Affordability | 5.55 | 6.62 | 5.75 |
| | Accessibility | **4.82** | **6.00** | **5.75** |
| | Experience | **5.00** | **5.15** | **5.58** |
| | Confidence | 5.91 | 6.00 | 6.42 |
| | Emotion | **5.73** | **5.38** | **4.83** |
| | Independence | **4.73** | **3.58** | **2.55** |
| | Technical support | **5.82** | **6.31** | **6.42** |
| | Social support | **5.36** | **4.15** | **3.75** |
| | Interoperability | 5.45 | 6.23 | 5.83 |
| | Lifestyle fit | 5.64 | 6.23 | 6.17 |
| | Conceptual fit | **5.45** | **4.85** | **6.00** |
| | System reliability | 6.09 | 6.54 | 6.08 |
| | Service trust | **5.91** | **6.31** | **6.58** |

Score range: from 1 (strongly disagree) to 7 (strongly agree)

Simple mean comparison analysis was conducted also to see if there were any gender differences. In general, the answers from male and female did not show much difference. The only difference from the technology experience and knowledge section was that female respondents reported to use social networking services slightly more often than male respondents. For experience with social networking services, the average score from female respondents was 5.78, whereas the average score was 4.93 for male respondents, on a scale from 1 (don’t know what it is) to 7 (have it and use it daily). For the adoption factors questions, in all three stages of use, female respondents valued interoperability of new technologies more importantly than male respondents. For the perceived importance of system interoperability, female respondents gave an average score of 6.22 for the purchase stage, 6.26 for the initial use stage, and 6.24 for the continued use stage. On the other hand, male respondents gave an average score of 5.33 for the purchase stage, 5.36 for the initial use stage, and 5.29 for the continued stage as they answered questions on the importance of interoperability. Also, females thought system reliability to be more important than males did during the purchase stage, where the females’ average score was 6.48 and the males’ average score was 5.67, and the initial use stage, at which the female’s average score was 6.48 and the male’s average score was 5.43.

Through the feedback on the pilot survey, several suggestions were gathered around ways to improve the questionnaire for the full-scale launch. First, it was evident that some terms and concepts would need to be better worded and clarified. Based on participant feedback, it was found that some found words and phrases used in the questionnaire as confusing or difficult to understand. For example, the term adoption was misunderstood by a few participants, as in the comment, “my first thought was it had to do with adopting children and using Web sources for information”. Another instance was found in the use of the term cost, as a participant commented, “do you mean financial, time, energy, etc. Guessing you mean financial but could be interpreted differently”. Few participants also suggested that the three decision stages – purchase, initial use, and continued use – would need to be better explained. For example, one respondent commented that the distinction between the three stages wasn’t clear, as in “I did have to think for a minute about what the difference between obtaining new technology and starting to use it is”.

It was clear from the qualitative feedback that not enough attention was paid to the directions given for the questionnaire. While the three sets of questions on the importance of the adoption factors each had directions stating the particular decision points – purchase, initial use, or continued use – they address, many respondents did not recall seeing the decision point information on the pages they saw. Related comments included the following. “I do not understand why the bubble portions were repeated three times. It made me think there was an error in the survey, or I wasn't filling it out appropriately.” “I couldn't figure out the difference between the 3 different stages of radio button questions.” “It seemed like you were asking the same thing 3 different times in the same way.” “It seemed odd to have to go through the same thing 3 times, at first I thought it was a computer glitch.” “Questionnaire seemed to repeat itself for a few pages.” While many participants expressed confusion with the presentation of the three different decision points, some recognized them as intended and provided suggestions for making the directions more clear. The suggestions spanned from simply making the related texts bold to adding a directions page up front. The following comments show examples of suggestions made by respondents. “Prefacing that three different time relevant question pages are coming would help.” “I was confused by the multiple choice repetition and I realized that the top question was what I really needed to respond too. You should make the top question in bolder typeface.” These comments suggest the need to present the directions more clearly, especially to point out the differences between the decision stages and make them stand out more visibly.

An examination of the data also suggested the need to reconsider the examples that were included in the first section of the questionnaire, where the technology experience and knowledge questions were asked. In this section, each type of technology and its description was accompanied by a few examples of existing products or services in its category to help the respondents understand it better. For example, Facebook, Twitter, and Foursquare were listed under the description of social networking services, and the description of office and work technology was accompanied with desktop computer, printer, and scanner as its examples. However, the examples seemed to drive the answers in some cases, rather than simply serving to assist in understanding the descriptions. For example, even though it's unlikely that people have never used a home appliance, the examples of iRobot and smart oven seemed to have led them to answer “don't know what it is”. The respondents did not mention this issue in their feedback, and such process may have occurred unknowingly. Still, the results suggested that the answers may be strongly anchored on the examples provided.

In addition to the questionnaire contents, several comments were raised around the visual design and presentation of the questionnaire pages. For example, respondents suggested the questionnaire to be written in "bigger font" and to have "a status bar as parts of the survey seemed long". The previous feedback on the difficulties related to distinguishing between the three decision points may have been an artifact of the visual design to some degree, as the directions on every page were written in small letters at the top. Such problems associated with visual design can be solved through a better choice of a survey medium, as the platform used in the pilot survey only allowed a small amount of design customizations.

Some additional issues were identified from the comments. For example, while the multiple choice questions had a column titled "don't know / not sure" after the agree-disagree options, one person still felt uncomfortable that there wasn't a "not applicable" option. A couple of respondents felt that the demographics questions were difficult to answer. For example, one person said "I am widowed and remarried but it's a radio box". This can be solved by clarifying such questions to be answered only according to the current status. Another issue was that some people expressed that they were uncomfortable if they had to disagree with a statement. An aim of the survey is to find out which factors are more or less important at different stages of adoption and use. If someone disagreed with the potential importance of a factor, he/she could simply indicate his/her disagreement. However, doing so seemed may be uneasy for a few people.

While minor issues were not incorporated into revisions, major issues that many respondents talked about were addressed with changes in questionnaire contents and format. Confusion with the term adoption was something that needed to be addressed before the full-scale launch, as it is the key concept that is applied through the whole questionnaire. As the use of the term adoption seemed to have misled few of the respondents in the pilot survey, the questionnaire was newly titled as "Survey on User Perceptions and Experiences around Purchase and Use of New Technologies" without explicitly using the term adoption, which was found to be easily misunderstood. For an easier and clearer distinction between the three decision points, the format was revised so that each adoption factor was immediately followed with the three question statements concerning the three decision points, whereas the pilot questionnaire had fifteen question statements for all fifteen adoption factors presented in one page under a heading that described a single decision point. It was expected that the participants will see the difference between the three stages more easily as they are presented together.

The technology experience and knowledge section, or the first part of the questionnaire, was changed to only include the names and descriptions of technology types. A decision was made to delete the examples that were presented during the pilot survey. As no respondents expressed any concerns with the descriptions during the cognitive interviews and the pilot survey, it was decided that the descriptions alone would be sufficient.

These major revisions were incorporated into the full questionnaire, along with other small changes in wording and format. As previously introduced in section 4.2.1, the revised questionnaire that was used for the full-scale launch can be found in Appendix 3.

### 4.2.3. Full-scale data collection

In order to gather responses from a large, balanced national sample and to avoid potential biases due to differences in individual characteristics, the recruiting of participants and collection of data were outsourced. The full-scale survey was administered online by Qualtrics (http://www.qualtrics.com), an online research and panel management company. A national sample of Qualtrics panel members received a link to the questionnaire, which the authors have designed and uploaded. The data collection progress was monitored by Qualtrics so that a balanced number of responses are collected from both genders and various age groups.

The online survey was designed using the survey design tool available on the Qualtrics Web site. Using the tool, the revised questionnaire, shown in Appendix 3, was built into an online format. Incorporating the pilot survey comments around survey format and design, the revised survey was designed with larger letters, and direction statements were placed closer to the actual questions. The online questionnaire was designed so that it can be viewed and answered on various computers, tablets, and other mobile devices. The design was tested using various devices prior to data collection.

The data collection aimed at gathering at least 600 complete responses. More specifically, the goal was to gather at least 200 complete responses from each age group, and at least 300 complete responses from each gender. The age group breakdown was kept consistent with the age division used during the pilot survey. That is, responses were evenly collected from participants who are younger (ages 20 to 39), middle-aged (ages 40 to 59), and older (ages 60 and up).

In order to ensure the quality and completeness of responses, attention filters, dummy questions added to filter out those not following directions or paying attention to the survey material, were added. As parts of the survey included questions of the same format, attention filters were necessary so that people do not simply click on random answers or “straight-line (provide same answers to all or most of questions)” their answers. Two attention filters were inserted into the section where the adoption factors questions were asked. These questions were stated as “please select answer choice ‘somewhat disagree’” and “please select answer choice ‘agree’”. Respondents who answered differently were directed to the final page of the questionnaire, and the survey was terminated.

When the first 50 responses were collected, the responses were carefully monitored for errors and quality issues. Upon collection of 50 responses, the data was examined for straight-lining issues, entries with excessive missing values, incorrect quotas, incorrect screen-out logic, and issues in open-ended responses such as gibberish. Based on a review of the first 50 responses, it was confirmed okay to proceed with the original quota conditions and screen-out logic for the full-scale data collection. After the preliminary examination, data collection was resumed until 600 complete responses, evenly distributed among gender and age groups, were gathered.

## 4.3. Data overview

### 4.3.1. Data pre-processing

Prior to analysis, the collected data was examined and pre-processed to ensure quality, screen errors, and transform variables and attributes as necessary. During the survey, participants were asked to give their exact age at the time of participation, instead of selecting an age range. The age variable was then converted into the three categories - younger (ages 20 to 39), middle-aged (ages 40 to 59), and older (ages 60 and up) – based on the numerical answers collected. Both the original answer – the exact age – and the converted value – the age group – were included in the final dataset.

Some changes in variable attributes were made based on an observation of the data structure and distribution. In the demographics section, attributes for two variables – employment status and education level – were changed based on the answers provided by the respondents. On the question about the current employment status, many of those who selected “other” specified that they were retired. Since the number was high, accounting for 11% of the sample, it was added as a separate category. Thus, the variable was changed to have five attributes – not working, self-employed, employed, full-time student, and retired – whereas the original question had four alternatives – not working, self-employed, employed, and full-time student – and an “other” option. On the question about the respondents’ highest level of education completed, only a few people have selected the alternatives “no formal education”, “elementary school”, and “junior high / middle school”. Since these categories were very small in size, they were merged together for further analysis. The merged category was renamed as “middle school or less”. Thus, the variable was changed to have five attributes – middle school or less, high school, some college or associate degree, college, and graduate school – whereas the original question had seven alternatives – no formal education, elementary school, junior high or middle school, high school, some college or associate degree, college, and graduate school – and an “other” option.

Data on geographic location was transformed, and a new categorical variable was created during the pre-processing. The questionnaire asked the ZIP code of respondents’ current physical residential location to determine where they lived. The ZIP codes that the respondents provided in the demographics section of the questionnaire were converted into the corresponding states and then into nine regional divisions – New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific.[7] The conversion was done to improve data manageability and to facilitate further analysis on regional comparison.

The responses to the open-ended technology experience questions were summarized and coded prior to further analysis. First, the raw set of data was examined for answers with random words not relevant to the questions or gibberish that did not make sense. These answers were removed from the dataset since they did not provide any information. After cleaning up the data, the raw responses were summarized into shorter phrases. This step was done to extract key information and remove less meaningful words from the responses, while still preserving the main messages. The third step involved further distilling the key phrases into short keywords. If a phrase was found to describe a specific adoption factor, the adoption factor was written as the keyword. The raw responses, the summary phrases, and the shorter keywords were all saved for further analysis. Table 14 shows examples of the data summarization process for the open-ended responses.

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[7] The divisions are consistent with the regions defined and used by the United States Census Bureau. The designations can be found at http://www.census.gov/geo/maps-data/maps/pdfs/reference/us_regdiv.pdf. The states included in the regional divisions are as follows.

- New England (Division 1): Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut
- Mid-Atlantic (Division 2): New York, Pennsylvania, New Jersey
- East North Central (Division 3): Wisconsin, Michigan, Illinois, Indiana, Ohio
- West North Central (Division 4): Missouri, North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa
- South Atlantic (Division 5): Delaware, Maryland, Washington, D.C., Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida
- East South Central (Division 6): Kentucky, Tennessee, Mississippi, Alabama
- West South Central (Division 7): Oklahoma, Texas, Arkansas, Louisiana
- Mountain (Division 8): Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico
- Pacific (Division 9): Alaska, Washington, Oregon, California, Hawaii

**Table 14. Examples of open-ended response summarization**

| Original response | Summary phrase | Keyword |
|---|---|---|
| It was what everyone kept telling me to do. I was the only one of my friends who didn't have an iPhone. | – All my friends had it.<br>– Everyone told me to get it. | – Social support (friends) |
| I relied a lot on advice from my children, they are much better than I am. | – Advice from knowledgeable family members. | – Social support (family) |
| It was compatible with the Bluetooth in my car. It is handy when I am driving. | – Compatible with existing system.<br>– Handy in daily activities. | – Interoperability<br>– Lifestyle fit |
| I went to Best Buy, where phones are sold, and was shown this phone by the sales associate. | – Went to where it is known to be sold.<br>– Assisted by sales associate. | – Accessibility<br>– Technical support (store) |

As the quantitative data, including variables in categorical, ordinal or ratio scales, were pre-processed, a list of the variables and their attributes was organized. The list was made to serve as a key for reference during analysis. It includes the name, related questionnaire section, measurement scale, a short description, and the attributes for each. The full data key can be found in Appendix 6.

### 4.3.2. Sample profile and data summary

A total of 1592 people initially started the questionnaire, and 1139 of them completed all questions. Of the 1139, responses with significant quality issues were excluded from the final dataset. These included responses with partial or overall "straight-lining" issues and responses with a large amount of missing information. The final dataset included 609 responses that were completely answered with an acceptable quality. The respondents were evenly distributed across age groups and gender, as shown in Table 15. Out of the 609 participants, one person in the older adults group did not provide the gender information. The response corresponding to this individual was excluded from analyses that involved gender comparison and other comparisons that were based on combinations of variables that included gender.

**Table 15. Pilot survey sample summary (n=609)**

<table>
<tr><th colspan="2" rowspan="2">Sub-groups</th><th colspan="3">Age</th><th rowspan="2">Total</th></tr>
<tr><th>Younger (20~39)</th><th>Middle (40~59)</th><th>Older (60+)</th></tr>
<tr><td rowspan="3">Gender</td><td>Male</td><td>100 (16.4%)</td><td>101 (16.6%)</td><td>103 (16.9%)</td><td>304 (49.9%)</td></tr>
<tr><td>Female</td><td>102 (16.7%)</td><td>102 (16.7%)</td><td>100 (16.4%)</td><td>304 (49.9%)</td></tr>
<tr><td>No answer</td><td>0</td><td>1 (0.2%)</td><td>0</td><td>1 (0.2%)</td></tr>
<tr><td colspan="2">Total</td><td>202 (33.2%)</td><td>204 (33.5%)</td><td>203 (33.3%)</td><td>609</td></tr>
</table>

The percentages were rounded to the nearest tenth.

In addition to the gender and age distribution, the sample covered a wide range of annual income. Out of the 609 respondents, 605 people provided information on their annual household income, and 4 people did not disclose the information. The income distribution as found from the survey data is summarized in Table 16, along with the data from the US Census Bureau (2011b) for comparison. It can be seen that the sample distribution closely matches the observed national distribution on the range of annual income. The sample is somewhat skewed include slightly higher proportion of the lower income ranges. The small distortion may be due to the oversampling of the older population, as the 33.3% of the sample was 60 years of age or older, while only about 19% of all Americans are 60 years of age or older (US Census Bureau, 2010a). According to the US Census Bureau (2011b), the average annual household income is significantly lower among the older population of ages 65 and older, where the median is at $33118, compared to the rest of the population, where the median is at $55640. Although the age breakdown does not match exactly, it can explain the distortion to some degree as the lower-income population was likely overrepresented with the sample composition.

**Table 16. Sample distribution: income range**

| Income range | Number of respondents | Sample proportion | US Census Bureau (2011b) |
|---|---|---|---|
| ≤$14999 | 79 | 13.0% | 13.5% |
| $15000~24999 | 84 | 13.8% | 11.5% |
| $25000~49999 | 181 | 29.7% | 24.9% |
| $50000~74999 | 126 | 20.7% | 17.6% |
| $75000~99999 | 63 | 10.3% | 11.5% |
| $100000~149999 | 45 | 7.4% | 11.9% |
| ≥$150000 | 27 | 4.4% | 9.1% |
| Total | 605 | 99.3% | 100% |

The percentages were rounded to the nearest tenth.

The sample covered various geographic regions as well. All respondents were physically living in the United States, as intended by the sampling procedure, and they represented a total of 47 states. All nine regional divisions – New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific - were represented. Out of the 609 respondents, 600 people provided the ZIP code of their physical residential location, which was converted into the corresponding states and the regional divisions during data pre-processing. Nine people did not disclose the information. The regional distribution as found from the survey data is summarized in Table 17, along with the data from the US Census Bureau (2010b) for comparison. It can be seen that the sample distribution closely matches the observed national income distribution, with the exceptions of the

West South Central region, which was underrepresented, and the Pacific region, which was overrepresented in the sample.

**Table 17. Sample distribution: geographic regions**

| Regional division | Number of respondents | Sample proportion | US Census Bureau (2010b) |
|---|---|---|---|
| New England | 23 | 3.8% | 5.1% |
| Middle Atlantic | 89 | 14.6% | 14.5% |
| East North Central | 91 | 14.9% | 16.5% |
| West North Central | 43 | 7.1% | 7.3% |
| South Atlantic | 125 | 20.5% | 21.3% |
| East South Central | 35 | 5.7% | 6.6% |
| West South Central | 47 | 7.7% | 12.9% |
| Mountain | 43 | 7.1% | 7.9% |
| Pacific | 104 | 17.1% | 7.9% |
| Total | 600 | 98.5% | 100.0% |

The percentages were rounded to the nearest tenth.

The sample also covered a wide range of employment statuses. Table 18 summarizes the distribution of answers to the question “please indicate your current employment status.” Out of the 609 respondents, 604 provided their current employment information, while 5 people did not provide an answer or specify the reason for choosing the “other” category. It can be seen from Table 18 that a large portion of the sample was not working at the time of participation. This can be attributed to the sample composition, as older adults were oversampled. It can also be discussed that the given alternatives may have been ambiguous, as individuals who were retired and not working could have selected either answer.

**Table 18. Sample distribution: employment**

| Employment status | Number of respondents |
|---|---|
| Not working | 217 (35.6%) |
| Self-employed | 60 (9.9%) |
| Employed | 233 (38.3%) |
| Student | 27 (4.4%) |
| Retired | 67 (11.0%) |
| Total | 604 (99.2%) |

The percentages were rounded to the nearest tenth.

Table 19 summarizes the distribution of answers to the question on “the highest level of education you have completed.” Out of the 609 respondents, 602 provided information on their level of education, while 7 people did not provide an answer or specify the reason for choosing the “other” category.

**Table 19. Sample distribution: education**

| Education level | Number of respondents |
|---|---|
| Middle school or less | 3 (0.5%) |
| High school | 114 (18.7%) |
| Some college / associate degree | 221 (36.3%) |
| College | 181 (29.7%) |
| Graduate school | 83 (13.6%) |
| Total | 602 (98.9%) |

The percentages were rounded to the nearest tenth.

A summary of responses on the living situation and family status questions is presented in Table 20. The first numbers in the second column shows the number of respondents who answered "yes" to the corresponding statement. The number of people who identified themselves as retired in this section, which was 154, was higher in this section compared to the number of people who answered "other" on the employment question and specified the answer as retired, only 67. As discussed earlier, it is possible that retired individuals answered their employment status as "not working" in the employment status question that was presented in the demographics section of the questionnaire.

**Table 20. Sample distribution: living situation**

| Living situation / life event / family status | Number of respondents |
|---|---|
| I live alone | 159 (26.1%) |
| I live with spouse/partner/significant other | 323 (53.0%) |
| I live with friend(s)/roommates(s) | 32 (5.3%) |
| I live with my child(ren) 12 years of age or younger | 89 (14.6%) |
| I live with my child(ren) between the ages of 13 and 18 | 65 (10.7%) |
| I live with my child(ren) 19 years of age or older | 53 (8.7%) |
| I live with my parent(s) 64 years of age or younger | 37 (6.1%) |
| live with my parent(s) 65 years of age or older | 23 (3.8%) |
| I am employed (part-time or full-time) | 210 (34.5%) |
| I am retired | 154 (25.3%) |
| I have regular income | 332 (54.5%) |
| I am in school (part-time or full-time) | 47 (7.7%) |
| I have a child or family member in school | 102 (16.7%) |
| I have moved during the last 3 years | 121 (19.9%) |
| I am planning to move during the next 3 years | 119 (19.5%) |
| I had a change in family status during the last 3 years | 101 (16.6%) |
| I am expecting a change in family status during the next 3 years | 77 (12.6%) |

The percentages were rounded to the nearest tenth.

In the open-ended section of the questionnaire, 573 respondents provided full answers to all questions – choice of technology, and thoughts and experiences during purchase, initial use, and continued use of that that technology – asked in the section. The overall response rate to the open-ended questions was thus 94.1%. Out of the 609 respondents who completed the questionnaire, 36 people skipped all or parts of the open-ended questions.

Participants spent an average of 21.35 minutes on the questionnaire. The younger group (ages 20~39) completed the questionnaire in an average of 17.12 minutes. The middle-aged group (ages 40~59) spent an average of 24.31, and the older group (ages 60 and up) finished in an average of 22.60 minutes. However, the differences were not statistically significant. While the average time spent on the questionnaire showed little age differences, the mean comparison suggested that participants of various ages spent a comparable amount of time in general.

## 4.4. Survey results

This section presents detailed results and interpretations from quantitative and qualitative analyses of the data collected from the full-scale survey. The first part of this section describes the participants' responses to the first section of the questionnaire, which includes questions on the level of experience and knowledge with various technologies. Also, a part of the open-ended responses to the second section of the questionnaire, which concerns the specific technologies that the respondents chose to talk about, is included in this part as well to show an overview of their experiences and knowledge of various technologies.

In sections 4.4.2, 4.4.3, and 4.4.4, the responses related to the three main research questions – overall validity and importance of technology adoption factors, relative importance of factors and the between-factor variability, and associations and relationships among factors – are presented. Detailed results from a comparative analysis between respondents of different individual characteristics – age, gender, income, technology experience, and life status and living arrangements – and between different stages of technology adoption and use – purchase, initial use, and continued use – are presented as well. The results are based on analyses of responses to both closed-ended, multiple-choice questions and open-ended essay questions. Various statistical methods were used to quantitatively analyze the data. Table 21 shows a summary of the methods used, organized by the research questions they addressed and the types of data they were used for. The methods and detailed processes of data analysis are presented in the following sections, along with the results.

**Table 21. Methods for analysis of survey data**

| Research question | Method of analysis for close-ended responses | Method of analysis for open-ended responses |
|---|---|---|
| Do people perceive the factors as important in adoption and use of technology? How valid are the factors in general? | T-test for mean comparison[8]: comparison with the neutral point (score 4 on the 1-to-7 scale) for overall validity, comparison between respondent groups based on individual characteristics ANOVA (analysis of variance)[9]: comparison between age groups and other respondent groups based on individual characteristics | Frequency analysis (Goodness of fit test)[10]: examination of how frequent the factors were mentioned in responses |
| Are some factors more important than others? What is the relative importance of each factor as compared to others? | | |
| How are the factors associated with one another? What is the underlying structure that explains the relationships? | Factor analysis[11]: analysis of correlations between variables and joint variations in response to underlying relationships | Association rules analysis[12]: analysis of regularities and patterns in which factors are mentioned together |

Potential interaction effects between variables are discussed in section 4.4.5. Observations around the consistencies and inconsistencies between the closed-ended and open-ended responses are discussed in

[8] T-test is a procedure used for testing a hypothesis that states inferences on a population mean. In a t-test, a t-statistic is calculated using the sample size, mean, standard deviation, and a value that is hypothesized as the population mean. The t-statistic is then used to determine the discrepancy between the sample mean and the hypothesized population mean. T-test can be used for making inferences on a single sample or for comparing two sample means. Alternatively, a similar procedure called z-test can be used when the population variance is known or when the sample size is large (Hayter, 2002).

[9] ANOVA (Analysis of variance) is a statistical technique used to determine whether samples from two or more groups come from populations with equal means (Hair et al., 2009). In ANOVA, the variability in the data set are computed in two parts – the sum of squares for treatments, which measures the differences between population mean estimates and the overall mean, and the sum of squares for errors, which measures the amount of variability within each sample. Using these measures of variability, an F-statistic is calculated and tested for comparing two or more sample means (Hayter, 2002).

[10] Goodness of fit test is a procedure used for testing a hypothesis of homogeneity between groups. That is, goodness of fit test concerns the distributional assumptions of a data set rather than its descriptive statistical values. In a goodness of fit test procedure, a Pearson chi-square statistic is calculated based on observed frequencies and expected frequencies across categories in a data set. The Pearson chi-square statistic is then used to test if the categories are homogeneous, or evenly distributed (Hayter, 2002).

[11] Factor analysis a multivariate technique that is used to define the underlying structure among variables in interest. It is an interdependence method that defines sets of variables that are highly correlated. In a factor analysis, the groups of variables are assumed to represent dimensions within the data (Hair et al., 2009).

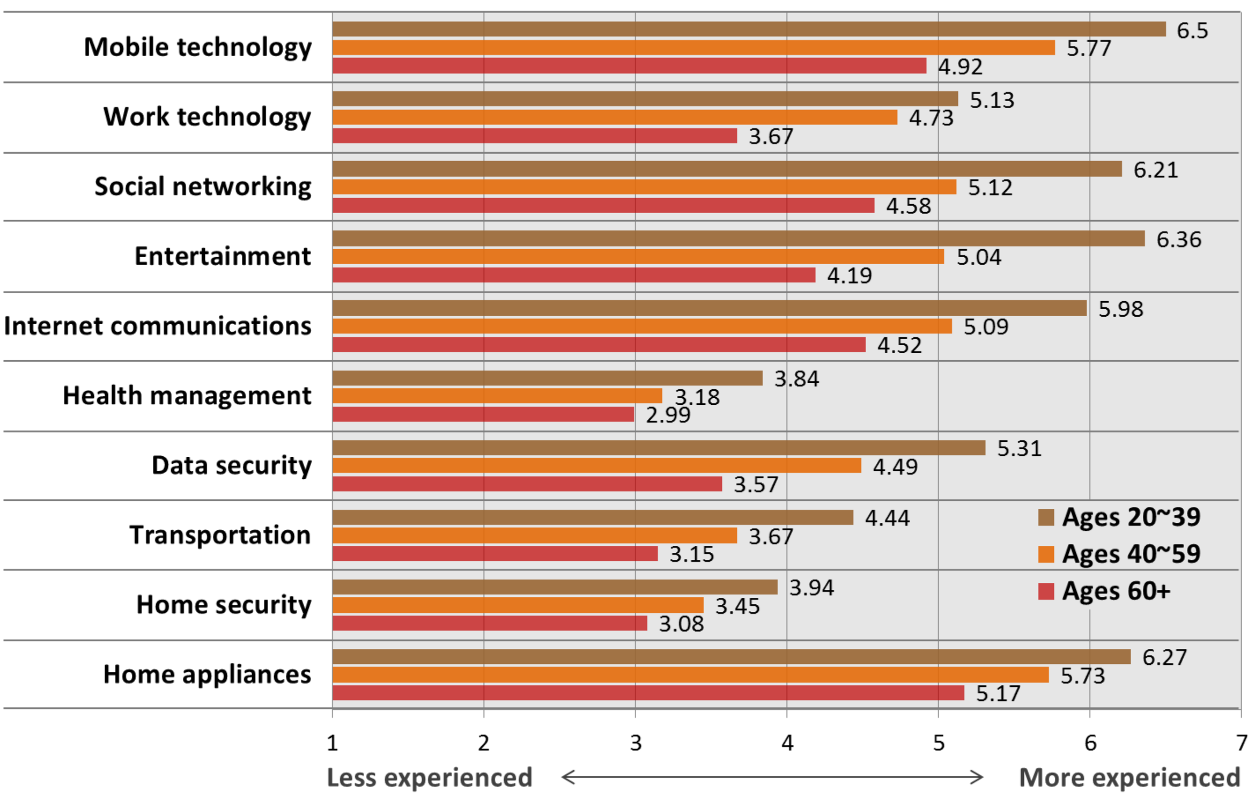
[12] Association rules analysis, or affinity analysis, examines possible rules between variables in an if-then, or antecedent-consequent, format. It is a study of "what goes with what" and concerns the dependencies between variables (Shmueli et al., 2010). A detailed description of its application and related measures can be found in section 4.4.4.

section 4.4.6. Finally, the last part of this section will present a summary of results and discuss the main conclusions and implications of the results.

### 4.4.1. Technology experience and knowledge

The first section of the questionnaire asked the degree to which respondents have knowledge of or are experienced with various types of technology. The answers collected were analyzed through mean comparison to test for any age differences in technology experience and knowledge. Figure 17 shows the average scores from the three age groups for the ten technology types that were presented in the questionnaire. For each technology type, the first bar shows the average experience score for the younger group (ages 20~39), the middle bar represents the average score for the middle-aged group (ages 40-59), and the bottom bar shows the average score for the older group (ages 60 and up).

**Figure 17. Age differences in technology experience**




In Figure 17, it can be seen that the older group was less experienced, on average, than the younger groups for all given types of technology. The younger group showed the highest average experience scores for all types of technology, while the older group showed the lowest average experience scores. In order to analyze the significance of the experience score differences between age groups, ANOVA was conducted. IBM SPSS Statistics version 21 was used to execute the statistical analysis. Based on the statistical mean comparison, it was found that the score differences were significant under $\alpha=0.01$, with all p-values found as 0.000, for all types of technology presented in the questionnaire.

The score gap was smaller for some types of technology. For example, the gap between the younger and older group's average scores was only 0.85 for health management technology, 0.86 for home security technology, 1.10 for home appliances, and 1.29 for transportation technology. On the other hand, the score gap was much wider for other types of technology. For example, the average score difference was 2.17 for entertainment technology. Here, the younger group indicated that they use entertainment technology at least a few times a week to almost everyday on average, while the older group said they have some type of entertainment technology but use it less than occasionally. Similarly, large score gaps were found for data technology (average difference of 1.74), Internet-based communication services (average difference of 1.46), and work or office technology (average difference of 1.46).

The result shown in Figure 17 suggests an inverse correlation between age and technology experience. That is one may generally state that a person who is older would be less experienced with technology compared to a person who is younger. In order to analyze the potential correlation between age and technology experience, a correlation analysis[13] was done using IBM SPSS Statistics software. For this part of the analysis, the numerical age that was entered as the original response in the questionnaire was used instead of the age category variable for a more detailed analysis on the potential relationship.

As a result, a negative correlation was found between the numerical age and technology experience scores for the given types of technology. The result further confirmed the result from the mean comparison analysis. For all types of technology, respondents' numerical age was negatively correlated with the scores they gave for knowledge and experience. Strong correlation was found between numerical age and entertainment technology ($r=-0.481$), mobile devices ($r=-0.368$), social networking services ($r=-0.363$), and data technology ($r=-0.336$). Internet-based communication services ($r=-0.298$), work technology ($r=-0.281$), home appliances ($r=-0.262$), transportation technology ($r=-0.236$), health management ($r=-0.177$), and home security ($r=-0.163$) also showed negative correlations with numerical age. All correlations were found to be statistically significant under $\alpha=0.01$, with all p-values calculated as 0.000. In short, the results showed that older adults are less experienced, compared to younger generations, with various types of technology in general.

[13] Correlation analysis measures the strength of the linear association exhibited by data points. In a correlation analysis, a sample correlation coefficient r, or the Pearson correlation coefficient, is calculated using the variances of two variables and their covariance. A sample correlation coefficient $r=0$ indicates that two variables are independent of each other. A positive sample correlation coefficient $r>0$ indicates a positive association, and a negative sample correlation coefficient $r<0$ indicates a negative association between two variables (Hayter, 2002).

In addition to the responses to the closed-ended questions on technology experience and knowledge, the answers to the open-ended questions section were also analyzed. While technology experience was not directly asked in the open-ended section of the questionnaire, the technologies that the respondents chose to talk about were categorized into the ten types, and the frequencies in which the ten types were chosen were counted. Table 22 shows a summary of the frequency analysis. The numbers in table show the number of times in which respondents in the respective age groups chose to talk about a system belonging to the respective type. Few people chose to talk about multiple technologies, and some people did not specify the exact product or service. Thus, the total for the age groups did not necessarily sum up to the total number of respondents. The information in Table 22 is also graphically presented in Figure 18.

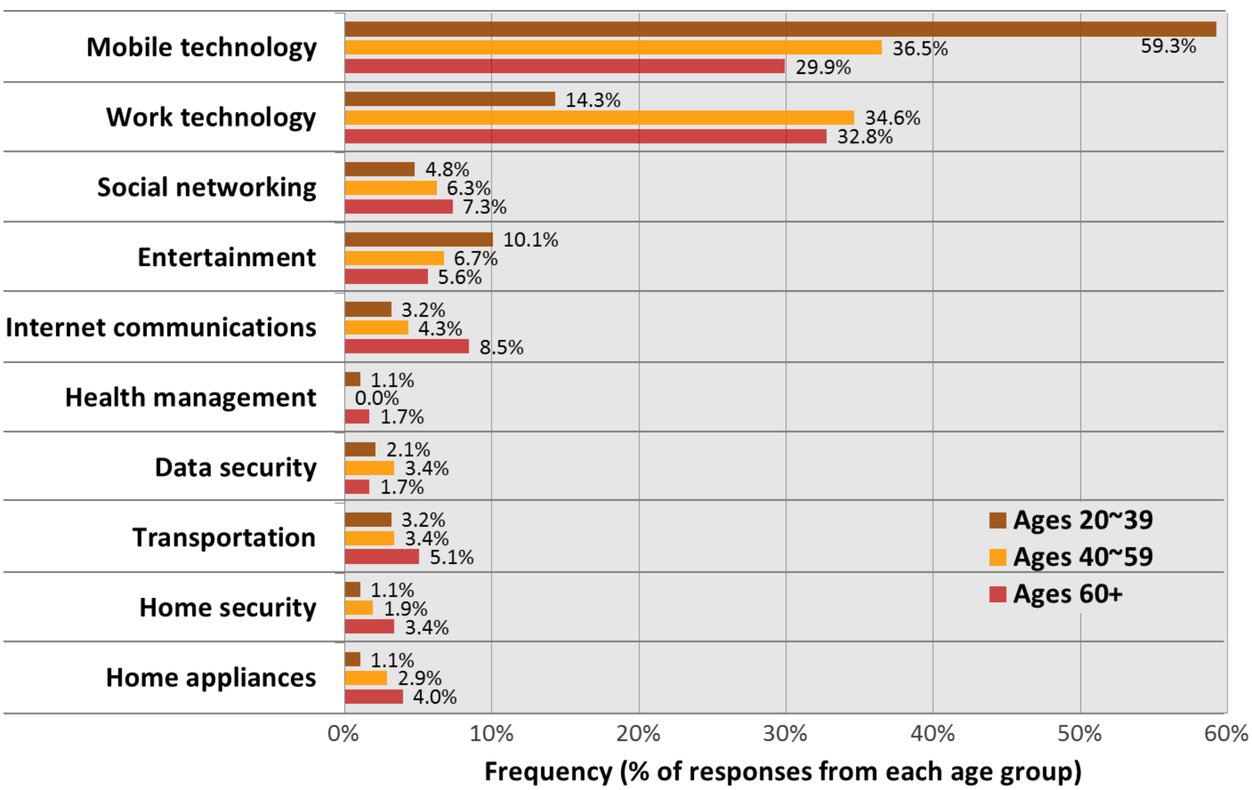
It can be seen from Table 22 and Figure 18 that the largest number of respondents chose to talk about mobile technology. Specific systems mentioned included smartphones and tablets. Among those who chose to talk about mobile technology, about half were from the younger group, while the smallest portion was from the older group. The second most popular type of technology was work and office technology. Respondents who chose to talk about work and office technology were largely from the middle-aged group, while the smallest portion was from the younger group. Other types of technology were less frequently chosen as a topic of description around individual experiences.

Technology for health management and assistance was chosen least frequently. In total, only five respondents chose to talk about health technology, where two were from the younger group and three were from the older age group. While the open-ended responses are not directly comparable with the closed-ended experience questions discussed earlier, the result is consistent in that health technology was a domain that respondents were generally inexperienced with. For all age groups, on average, respondents of all age groups responded that they don’t personally own health technologies while they have experienced it some time. While the causes for the low experience and knowledge have not been described in the survey, several possible explanations can be discussed. For example, people generally may not perceive health technologies as something they can personally own and use. Also, health technologies may have been understood as medical and clinical technologies that people rarely interact with. Furthermore, the age gap, where the older respondents were found to have less knowledge of health technologies compared to the younger group, may suggest a gap in understanding. Because of their frequent interactions and extensive usage of mobile devices, social networking services, and entertainment technologies, as found from the survey, the younger generation may have come across health and wellness management applications through other technological means compared to older adults. Overall, the low average scores from all age groups suggest health technologies to be a domain that needs to be further studied.

**Table 22. Frequency of technology types chosen in open-ended questions section**

| Technology type | Age | | | Total |
|---|---|---|---|---|
| | Younger (20~39) | Middle (40~59) | Older (60+) | |
| Mobile devices | 112 | 76 | 53 | 241 |
| Work/office technology | 27 | 72 | 58 | 157 |
| Social networking | 9 | 13 | 13 | 35 |
| Entertainment technology | 19 | 14 | 10 | 43 |
| Internet communications | 6 | 9 | 15 | 30 |
| Data storage/security | 4 | 7 | 3 | 14 |
| Health management | 2 | 0 | 3 | 5 |
| Transportation technology | 6 | 7 | 9 | 22 |
| Home security | 2 | 4 | 6 | 12 |
| Home appliances | 2 | 6 | 7 | 15 |
| Total | 189 | 208 | 177 | |

**Figure 18. Frequency of technology types chosen in open-ended questions section – graphical representation with percentages**



### 4.4.2. Overall validity of technology adoption factors

One of the main objectives of the survey study was to empirically assess the overall validity of the adoption factors identified during the previous stage. In the questionnaire, respondents were asked to rate the perceived importance of the adoption factors for the three decision stages. Also, they were asked to talk about, in an open-ended format, their thoughts and experiences with technology at the three decision stages. The answers to these questions were analyzed to determine if the factors matter in older adults' adoption and use of technology as suggested by existing literature and the previous user survey as described in chapter 3.

In the questions on the importance of adoption factors, respondents were asked to choose an answer in a given ordinal scale. The scale ranged from 1 to 7, or from "strongly disagree" to "strongly agree", respectively. The neutral point was 4, representing a position where a respondent neither agrees nor disagrees with the importance of an adoption factor. Based on this scale, it can be stated that an average rating above 4 for an adoption factor would indicate that the respondents generally thought of the factor as important, whereas an average rating below 4 would suggest the factor being perceived as unimportant.

In this part of analysis, the t-test procedure was used for comparing the sample means to the neutral value 4. Based on the average score and standard deviation of answers given for the adoption factors, the overall importance of the factors was determined. The t-test was first conducted for the older age group to assess the validity of the factors among older adults at various stages of adoption and use. Additional comparison analysis was then conducted using ANOVA to investigate possible differences associated with individual characteristics in the perceived importance of the adoption factors.

The open-ended questions on technology adoption and use asked respondents to freely talk about the thoughts, experiences, and issues they had when purchasing, starting to use, and continuously using a technology of their choice. Frequency analysis was carried out on the data coded from the responses to these open-ended questions to see if they generate similar results. For each factor, the number of related comments and discussions was recorded based on the coded data.

#### 4.4.2.1. Assessment of overall validity among older adults

The average scores calculated from the older respondents' answers to the adoption factors questions are summarized in Table 23. The scores in Table 23 represent the average ratings of responses for all adoption factors at all three decision stages. From Table 23, it can be seen that most factors, with the exceptions of independence and social support, were found to be perceived as important by adults 60 years of age or older. Usability and service were found to have received average scores at or above 6.0, or “agree” on its importance, for all three decision stages. Few other factors were found to have received average scores at or above 6.0 for two of the three decision stages. These factors include value, affordability, and system reliability. Many other factors were rated at average scores at or above 5.0, or “somewhat agree” on its importance, for all three decision stages. These factors include accessibility, experience, confidence, emotion, technical support, interoperability, lifestyle fit, and conceptual fit. For these factors – value, usability, affordability, accessibility, experience, confidence, emotion, technical support, interoperability, lifestyle fit, conceptual fit, system reliability, and service trust – the average scores were all found to be significantly above the neutral score of 4.0, suggesting a statistical evidence around their overall perceived importance at various stages of older adults’ technology adoption and use.

**Table 23. Overall importance of adoption factors: result from the older group (ages 60 and up)**

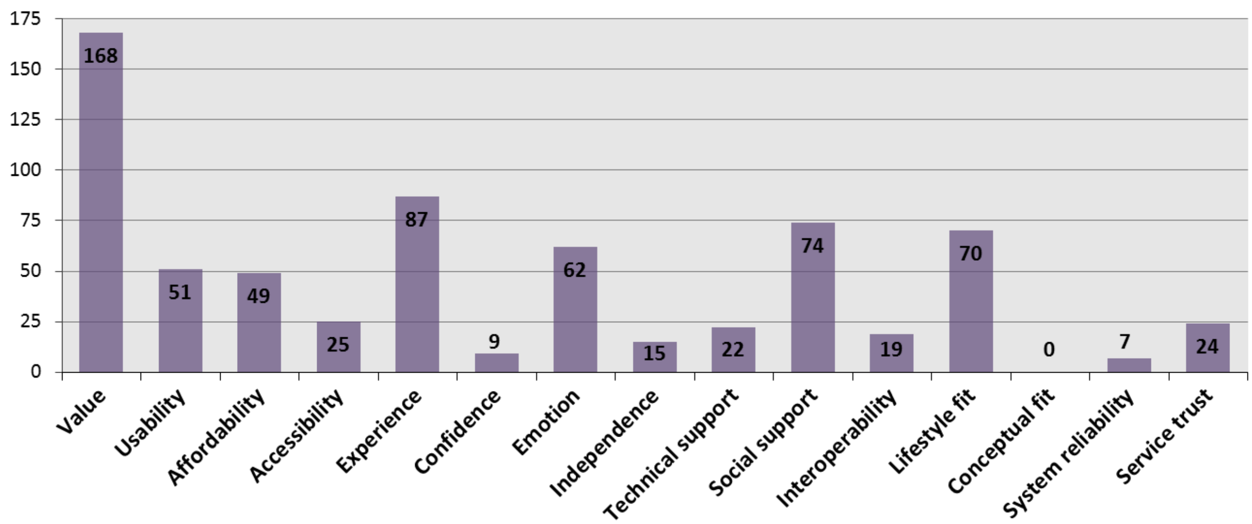
| Adoption factor | Decision stage | | |
|---|---|---|---|
| | Purchase | Initial use | Continued use |
| Value | 6.17* | 6.00* | 5.79* |
| Usability | 6.41* | 6.25* | 6.02* |
| Affordability | 6.42* | 6.13* | 5.80* |
| Accessibility | 5.55* | 5.29* | 4.83* |
| Experience | 5.70* | 5.45* | 5.13* |
| Confidence | 6.01* | 5.86* | 5.73* |
| Emotion | 5.34* | 5.21* | 5.06* |
| Independence | 2.88 | 2.90 | 2.87 |
| Technical support | 6.02* | 5.96* | 5.65* |
| Social support | 4.14 | 3.87 | 3.58 |
| Interoperability | 5.69* | 5.61* | 5.42* |
| Lifestyle fit | 5.94* | 5.77* | 5.53* |
| Conceptual fit | 5.47* | 5.38* | 5.24* |
| System reliability | 6.10* | 6.00* | 5.86* |
| Service trust | 6.38* | 6.26* | 6.07* |

*: Significantly above the neutral point 4 ($p<0.01$)

While the majority of factors were found to be important, the data suggested a few factors to be less important in older adults’ adoption and use of technology. The average scores found for social support ranged around the neutral point, suggesting that the older respondents did not perceive social support as essential, but rather indifferent in their experiences around purchase, initial use, and continued use of technology. Furthermore, the average scores for independence was found to be below the neutral point, ranging just below 3, or “somewhat disagree”. That is, the older respondents perceived independence as significantly unimportant in their experiences around adoption and use of technology.

The data coded from the open-ended responses were also analyzed for an evaluation of the overall validity of the adoption factors among the older group. For this part of assessment, the number of related comments, as previously coded, was counted for each factor. Figure 19 shows a summary of the finding from the frequency analysis on the open-ended responses from the older group. The data in Figure 19 show the total frequencies from all three stages for the adoption factors.

**Figure 19. Keyword frequency: comments related to adoption factors from the older group (ages 60 and up)**




As Figure 19 illustrates, the frequencies in which related comments were brought up during the open-ended questions section of the questionnaire varied greatly between factors. Comments related to value, or the potential benefits that a technology delivers, were mentioned most frequently (168 times). It was followed by comments around experience (87 times), social support (74 times), lifestyle fit (70 times), and emotion (62 times). None of the comments collected mentioned experiences or thoughts related to conceptual fit, and only few comments were found to be related to confidence (9 times) and system reliability (7 times).

It can be seen that results from the analysis of multiple-choice responses, summarized in Table 23, and from the frequency analysis on open-ended responses, summarized in Figure 19, differ by a great amount. Usability, affordability, confidence, system reliability, and service trust were rated with very high average scores (above or around 6 out of the 7-point scale) for perceived importance from the multiple-choice questions. However, comments around these factors were mentioned less frequently in the open-ended responses compared to other factors that were rated with lower average scores. On the other hand, factors that were rated with lower average scores (around or below 5 out of the 7-point scale), such as emotion and social support were mentioned more frequently in the open-ended responses. As shown in Table 23, the average scores for social support at the three decision stages were found not to be significantly above the neutral point. However, from the open-ended responses, social support was found to be the third most frequently mentioned factor, as shown in Figure 19. Also, the average scores for independence at the three decision stages were found to be the lowest of all factors from the multiple-choice responses as shown in Table 23. However, from the open-ended responses, comments related to independence was mentioned more frequently (15 times) compared to confidence (9 times), system reliability (7 times), and conceptual fit (0 time), which all showed higher average scores from the analysis on multiple-choice responses.

Since the closed-ended questions and the open-ended questions were not in the same scale, the responses cannot be compared directly. Also, the frequency or the number of related comments only serves as a proxy for measuring perceived importance. While the results from the analysis on the open-ended responses cannot make clear claims around older adults' perceived importance of the adoption factors, the observable differences suggest that even the factors with low average scores, such as independence, emotion, and social support, may still serve important roles throughout stages of technology adoption and use and that they should not be ignored solely based on the quantitative results.

#### 4.4.2.2. Comparison based on age and other individual characteristics

The examination on the overall perceived importance of the adoption factors among the older respondents was then followed by an age comparison. The average scores for the importance of the adoption factors were compared between the three age groups – younger (ages 20~39), middle-aged (ages 40~59), and older (ages 60 and up) – at the three decision stages – purchase, initial use, and continued use. The statistical significance of the age differences were tested using ANOVA.

Table 24 shows the averages scores for all adoption factors from all age groups at the different stages of adoption and use. As Table 24 shows, some significant differences were found between age groups. Three factors – emotion, independence, and social support – were found to show significant age differences at all three decision stages. For these factors, the older group agreed less with their importance in their experiences during adoption and use of technology, while the younger group agreed more. However, it can be seen that the average scores for these three factors were lower than the average scores for other factors, which suggests that people across all ages perceives these factors as less important than others. A similar trend was observed for value and lifestyle fit at the purchase stage, but the score difference was smaller compared to the three factors aforementioned. A different trend was found for usability, affordability, and accessibility (with the exception of the purchase stage), where the older group generally agreed more with the importance compared to the younger groups. More specifically, the score differences were significant at a confidence level of 0.05 for usability during continued use and accessibility during initial use.

**Table 24. Perceived importance of adoption factors: age comparison**

| Adoption factor | Purchase | | | Initial use | | | Continued use | | |
|---|---|---|---|---|---|---|---|---|---|
| | 20~39 | 40~59 | 60+ | 20~39 | 40~59 | 60+ | 20~39 | 40~59 | 60+ |
| Value | 6.33 | 6.20 | 6.17 | **6.32** | **6.08** | **6.00** | 5.91 | 5.75 | 5.79 |
| Usability | 6.23 | 6.24 | 6.41 | 6.08 | 6.09 | 6.25 | **5.77** | **5.68** | **6.02** |
| Affordability | 6.32 | 6.42 | 6.42 | 5.95 | 5.89 | 6.13 | 5.65 | 5.67 | 5.80 |
| Accessibility | 5.49 | 5.67 | 5.55 | **5.03** | **4.95** | **5.29** | 4.76 | 4.68 | 4.83 |
| Experience | 5.81 | 5.61 | 5.70 | 5.63 | 5.38 | 5.45 | 5.39 | 4.98 | 5.13 |
| Confidence | 5.96 | 5.88 | 6.01 | 5.81 | 5.78 | 5.86 | **5.78** | **5.45** | **5.73** |
| Emotion | **5.84** | **5.56** | **5.34** | **5.74** | **5.40** | **5.21** | **5.58** | **5.13** | **5.06** |
| Independence | **4.31** | **3.29** | **2.88** | **4.24** | **3.28** | **2.90** | **4.11** | **3.21** | **2.87** |
| Technical support | 5.84 | 5.88 | 6.02 | 5.88 | 5.73 | 5.96 | 5.64 | 5.38 | 5.65 |
| Social support | **5.03** | **4.44** | **4.14** | **4.84** | **4.21** | **3.87** | **4.41** | **3.80** | **3.58** |
| Interoperability | 5.84 | 5.70 | 5.69 | 5.71 | 5.52 | 5.61 | 5.55 | 5.30 | 5.42 |
| Lifestyle fit | **6.21** | **6.03** | **5.94** | 5.98 | 5.88 | 5.77 | **5.77** | **5.38** | **5.53** |
| Conceptual fit | 5.35 | 5.36 | 5.47 | 5.30 | 5.40 | 5.38 | 5.27 | 4.95 | 5.24 |
| System reliability | 6.11 | 6.15 | 6.10 | 5.91 | 5.94 | 6.00 | 5.89 | 5.73 | 5.86 |
| Service trust | 6.23 | 6.29 | 6.38 | 6.17 | 6.09 | 6.26 | 5.93 | 5.90 | 6.07 |

Numbers in bold indicate age differences significant at $\alpha$=0.05.

**Table 25. Perceived importance of adoption factors: correlations with age**

| Adoption factors | Purchase | Initial use | Continued use |
|---|---|---|---|
| Value | -0.066 | -0.115** | -0.052 |
| Usability | 0.066 | 0.054 | 0.069 |
| Affordability | 0.030 | 0.051 | 0.034 |
| Accessibility | 0.018 | 0.071 | 0.027 |
| Experience | -0.069 | -0.080 | -0.081* |
| Confidence | -0.007 | -0.005 | -0.031 |
| Emotion | -0.156** | -0.167** | -0.155** |
| Independence | -0.307** | -0.302** | -0.278** |
| Technical support | 0.049 | -0.001 | -0.019 |
| Social support | -0.190** | -0.206** | -0.180** |
| Interoperability | -0.049 | -0.049 | -0.038 |
| Lifestyle fit | -0.124** | -0.093* | -0.090* |
| Conceptual fit | 0.023 | 0.025 | -0.029 |
| System reliability | -0.016 | 0.005 | -0.019 |
| Service trust | 0.059 | 0.015 | 0.029 |

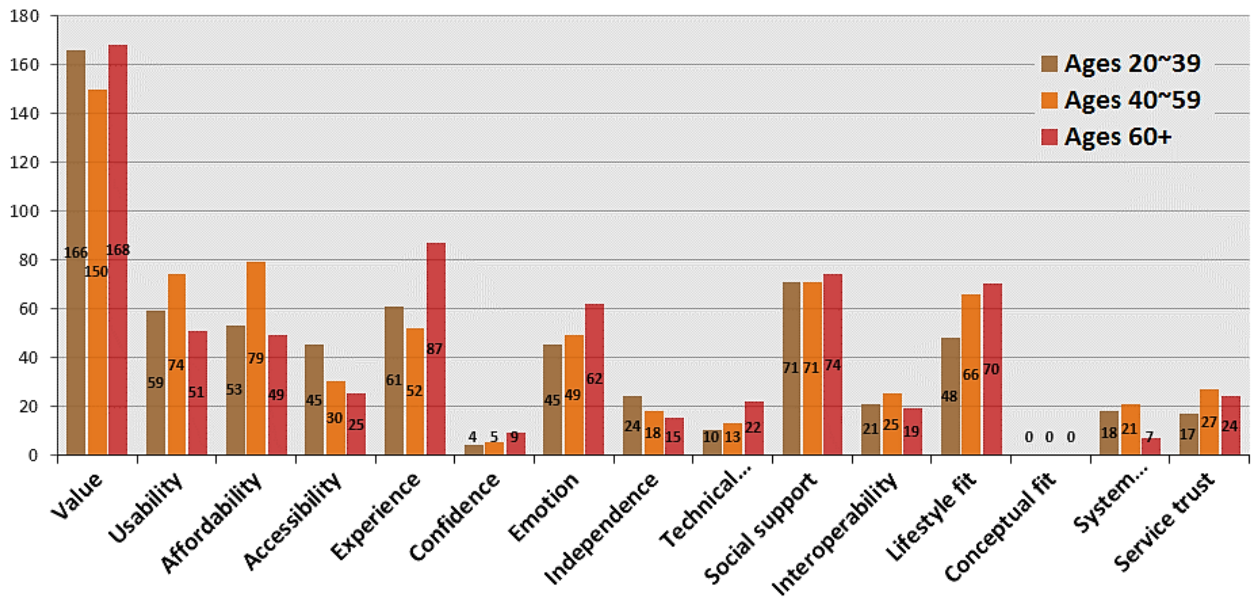
*: significant at $\alpha$=0.05, **: significant at $\alpha$=0.01

The result shown in Table 24 suggests correlations between age and perceived importance of adoption factors in varied directions. Based on Table 24, it can be suggested that the perceived importance of emotion, independence, social support, value, and lifestyle fit may be negatively correlated with age, while the perceived importance of usability, affordability, and accessibility may be positively correlated with age. In order to analyze the potential correlations between age and perceived importance of adoption factors, a correlation analysis was conducted. For this part of the analysis, the numerical age that was entered as the original response in the questionnaire was used instead of the age category variable for a more detailed analysis. The result of the correlation analysis, with the Pearson correlation coefficients, is summarized in Table 25.

As shown in Table 25, the result showed significant negative correlations between age and perceived importance of emotion (r=-0.156), independence (r=-0.307), social support (r=-0.190), and lifestyle fit (r=-0.124) during purchase. During initial use, significant negative correlations were found between age and perceived importance of value (r=-0.115), emotion (r=-0.167), independence (r=-0.302), social support (r=-0.206), and lifestyle fit (r=-0.093). Similar findings can be observed for the continued use stage, where age was found to be negatively correlated with perceived importance of emotion (r=-0.155), independence (r=-0.278), social support (r=-0.180), lifestyle fit (r=-0.090), and experience (r=-0.081). The result of correlation analysis show patterns similar to those found from the mean comparison analysis. Also, while some correlations were found to be statistically significant, the relationships are not strong, as indicated by the small correlation coefficient values. This is similar to how the differences between the average scores were small in the mean comparison analysis as shown in Table 24. That is, the perceived importance of the adoption factors did not show much difference between people of different ages, and only minimal differences were found for some factors.

The data coded from the open-ended responses were also analyzed for a comparison on overall perceived importance of the adoption factors between age groups. For this part of assessment, the number of related comments, as previously coded, was counted for each factor. Figure 20 shows a summary of the finding from the frequency analysis on the open-ended responses from the three age groups. The data in Figure 20 show the total frequencies from all three stages for the adoption factors. It can be seen from Figure 20 that the three age groups showed similar patterns, with small differences, as to how many comments related to various factors were collected. In all age groups, comments related to value were mentioned most frequently. Also, in all age groups, no comment had described experiences or thoughts related to conceptual fit, or the degree to which a technology matches existing mental models and ideas. Similar to the older group, comments around the roles of emotion and social support were frequently mentioned, in contrary to the lower average scores from the multiple-choice responses, among the younger and middle-aged groups as well.

**Figure 20. Keyword frequency: comments related to adoption factors from the three age groups**




In addition to these similarities, Figure 20 shows some differences between the three age groups. While the comments from the younger group were mostly focused on discussions around value, the middle-aged group also frequently mentioned experiences and thoughts around usability and affordability, more so than the other two age groups. The role of prior experience on technology adoption and use was most frequently mentioned by the older group, but system reliability was least frequently discussed among the older respondents compared to other age groups. For a couple of factors, the number of related responses decreased with age. These factors include accessibility and independence. Few other factors showed a different pattern in which the number of related responses increased with age. This pattern can be observed for emotion, technical support, and lifestyle fit. While the frequencies do not directly describe perceived importance, this pattern contradicts the results from the analyses on the multiple-choice responses, where the importance for these factors decreased with age. The result from the analysis of open-ended responses cannot directly be compared with the results from the mean comparison shown in Table 24 or the correlation analysis shown in Table 25 due to the differences in data formats and the nature of the question contents. However, the discrepancies between the two may suggest that even the factors rates as less important by the older groups still play key roles in their decisions around technology adoption and use.

In addition to age, the perceived importance of adoption factors was compared between other individual characteristics that were discussed as relevant in existing literature, such as income and prior experience. The possible relationships between income and perceived importance of adoption factors, as well as between prior technology experiences and perceived importance, were analyzed using correlation analysis. In the questionnaire, income and technology experience were asked using an ordinal scale. That is, the responses to income and technology experience were not gathered in a continuous format, but rather in a given scale that was ordered in one direction. Responses to annual income were gathered in an increasing ordered scale from 1 ($0~$14999) to 7 ($150000 or more). Similarly, responses around experience with various technologies were gathered in an increasing ordered scale from 1 (don't know what it is) to 7 (have it and use it daily) as shown in Appendix 6. Since the responses were gathered in an ordinal scale, the correlation analysis was conducted using Spearman's rank correlation coefficient, or Spearman's rho[14], instead of the Pearson correlation coefficient r that was used for analyzing the relationship between the perceived importance of adoption factors and age, which is a continuous ratio variable. Table 26 shows the result of correlation analysis, with the Spearman correlation coefficients, between income and perceived importance of adoption factors.

**Table 26. Perceived importance of adoption factors: correlations with annual income**

| Adoption factors | Purchase | Initial use | Continued use |
|---|---|---|---|
| Value | 0.085* | 0.042 | 0.022 |
| Usability | 0.049 | 0.086* | 0.003 |
| Affordability | -0.079 | -0.088* | -0.079 |
| Accessibility | 0.018 | -0.006 | 0.016 |
| Experience | -0.038 | -0.073 | -0.018 |
| Confidence | -0.016 | -0.002 | 0.037 |
| Emotion | 0.005 | 0.023 | 0.049 |
| Independence | 0.103* | 0.113** | 0.105** |
| Technical support | -0.004 | -0.019 | 0.019 |
| Social support | 0.065 | 0.072 | 0.089* |
| Interoperability | 0.057 | 0.110** | 0.077 |
| Lifestyle fit | -0.008 | 0.003 | 0.041 |
| Conceptual fit | -0.074 | -0.024 | 0.009 |
| System reliability | 0.033 | 0.075 | 0.086* |
| Service trust | 0.027 | 0.056 | 0.064 |

*: significant at α=0.05, **: significant at α=0.01

[14] The Spearman correlation coefficient ρ is a nonparametric metric that measures the strength and direction of correlation between two sets of variables in ranked or ordinal format (Myers et al., 2010). The Spearman correlation coefficient is calculated using ranks, whereas the Pearson correlation coefficient is calculated using raw scores.

It can be concluded from Table 26 that income level is not strongly correlated with perceived importance of adoption factors at all decision stages. People with different amount of annual income did not necessarily have difference perceptions around importance of adoption factors during purchase, initial use and continued use of technology. Some factors were shown to have statistically significant correlations with income, such as independence. However, even these significant correlations did not show strong relationships, as indicated by the small Spearman correlation coefficient values. Thus, it can be stated that an individual's income level and his or her perceived overall importance of adoption factors are independent of each other.

On the other hand, people's experience and knowledge with various types of technology had stronger correlations with the perceived importance of adoption factors. Based on the result of the correlation analysis using the Spearman correlation coefficient, it was found that individuals who are more experienced with various types of technology perceived several factors as more important than individuals who are less experienced with technology in general. The positive correlations between the perceived importance for some factors and technology experience were found to be significant at all three stages of adoption and use for all given types of technology. These factors include value, experience, emotion, independence, and interoperability. For these factors, the Spearman correlation coefficient ranged mostly from about 0.150 to 0.300. Perceived importance of other factors, including usability, accessibility, confidence, technical support, social support, lifestyle fit, conceptual fit, system reliability, and service trust, were found to be significantly correlated with experience with most of the given technology types at all stages. The Spearman correlation coefficient had smaller values, mostly ranging from about 0.050 to 0.200. Perceived importance of affordability was found to be only significantly correlated with experience with mobile devices and social networking services to some degree. Overall, it can be concluded that people's experience and knowledge with technology in general is positively correlated with the overall perceived importance of adoption factors at various stages of technology adoption and use, with the relationship stronger for some factors such as value, experience, emotion, independence, and interoperability, and weaker for other factors such as affordability. Details around the result of the correlation analysis can be found in Appendix 7.

Alternatively, the effect of technology experience on the perceived importance of the adoption factors was also analyzed by comparing between respondents who have recently bought or started using a technology in the last 12 months to respondents who have not made a recent acquisition. The differences between the two respondent groups were compared using the t-test procedure. The result of the mean comparison is shown in Table 27. In summary, it can be seen that people who were recently involved in decisions around purchase and acquisition of technologies generally perceived most of the adoption factors as more important in all stages.

**Table 27. Perceived importance of adoption factors: comparison based on recent adoption experience**

| Adoption factor | Purchase | | Initial use | | Continued use | |
|---|---|---|---|---|---|---|
| | Recent acquisition | No recent acquisition | Recent acquisition | No recent acquisition | Recent acquisition | No recent acquisition |
| Value | **6.40** | **6.07** | **6.33** | **5.94** | **6.00** | **5.65** |
| Usability | 6.37 | 6.24 | 6.18 | 6.11 | 5.89 | 5.75 |
| Affordability | 6.43 | 6.34 | 5.98 | 5.99 | 5.74 | 5.66 |
| Accessibility | 5.65 | 5.50 | 5.14 | 5.02 | 4.84 | 4.66 |
| Experience | **5.85** | **5.53** | 5.55 | 5.38 | **5.32** | **4.93** |
| Confidence | **6.05** | **5.83** | 5.87 | 5.77 | **5.81** | **5.48** |
| Emotion | **5.84** | **5.28** | **5.61** | **5.26** | **5.49** | **4.95** |
| Independence | **3.78** | **3.09** | **3.76** | **3.08** | **3.61** | **3.08** |
| Technical support | 5.98 | 5.85 | **5.98** | **5.72** | **5.68** | **5.41** |
| Social support | **4.78** | **4.23** | **4.47** | **4.05** | **4.08** | **3.72** |
| Interoperability | **5.97** | **5.50** | **5.85** | **5.36** | **5.63** | **5.18** |
| Lifestyle fit | **6.23** | **5.87** | **6.05** | **5.68** | **5.71** | **5.35** |
| Conceptual fit | 5.45 | 5.32 | 5.44 | 5.25 | 5.26 | 5.01 |
| System reliability | 6.19 | 6.04 | 6.01 | 5.88 | **5.93** | **5.70** |
| Service trust | **6.38** | **6.22** | 6.25 | 6.09 | **6.09** | **5.84** |

Numbers in bold indicate age differences significant at α=0.05.

Responses to the living situations and family arrangement questions were also used as bases for comparing the perceived importance of adoption factors. T-tests were conducted to compare the average scores for the adoption factors at the three decision stages for people with different living situations. As a result, it was found that living with young child(ren) 12 years of age or younger, living with parent(s) 65 years of age or older, being employed, being retired, having a regular source of income, having a family member or more in school, and planning to move in the near future affect the perceived importance of some adoption factors, mainly value, accessibility, experience, emotion, independence, social support, interoperability and system reliability. Living alone accounted for differences in average scores for emotion, independence, social support, interoperability, lifestyle fit, and conceptual fit only at the continued use stage. Whether or not an individual lives with a spouse, a friend, child(ren) 13 years of age or older, parent(s) 65 years of age or younger, being in school, have recently moved, have recently had a change in family status, or expects a change in family status in the near future were associated with only few adoption factors, if any. However, the differences between average scores for perceived importance as gathered from respondents with different living situations were mostly less than 0.5 out of the 7-point scale. That is, while some differences were found to be statistically significant, the actual score differences were very small. Detailed result of the mean comparison analysis can be found in Appendix 8.

Similar to other individual variables, not much difference in the average scores for perceived importance of adoption factors was found between male and female. The score differences between genders were very small, mostly less than 0.3 out of the 7-point scale, and were rarely statistically significant, as shown in Table 28.

**Table 28. Perceived importance of adoption factors: gender comparison**

| Adoption factor | Purchase | | Initial use | | Continued use | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| Value | 6.21 | 6.26 | 6.13 | 6.14 | 5.82 | 5.83 |
| Usability | **6.21** | **6.38** | 6.09 | 6.19 | 5.82 | 5.84 |
| Affordability | **6.24** | **6.54** | **5.86** | **6.11** | 5.61 | 5.79 |
| Accessibility | 5.51 | 5.63 | 5.08 | 5.10 | 4.73 | 4.79 |
| Experience | 5.67 | 5.75 | 5.42 | 5.55 | 5.17 | 5.17 |
| Confidence | 5.85 | 6.05 | **5.71** | **5.92** | 5.61 | 5.70 |
| Emotion | 5.52 | 5.65 | 5.40 | 5.51 | 5.26 | 5.26 |
| Independence | 3.64 | 3.34 | 3.61 | 3.34 | 3.50 | 3.28 |
| Technical support | 5.86 | 5.97 | 5.80 | 5.92 | 5.49 | 5.64 |
| Social support | 4.65 | 4.42 | 4.41 | 4.20 | 4.06 | 3.80 |
| Interoperability | 5.74 | 5.74 | 5.64 | 5.59 | 5.50 | 5.34 |
| Lifestyle fit | 6.02 | 6.11 | 5.86 | 5.90 | 5.59 | 5.53 |
| Conceptual fit | 5.30 | 5.50 | **5.24** | **5.48** | 5.13 | 5.19 |
| System reliability | 6.10 | 6.15 | 5.94 | 5.96 | 5.83 | 5.83 |
| Service trust | 6.23 | 6.37 | 6.15 | 6.21 | 5.97 | 5.97 |

Numbers in bold indicate age differences significant at α=0.05.

Comparisons between demographic variables including as age, gender, and income level suggest that such characteristics do not account for big differences in how people perceive the importance of various factors that affect adoption and use decisions. Rather than the observable traits, people's experiences with various technologies were found to be more strongly associated with differences in their perceived importance of adoption factors. Also, a few characteristics related to living situations, such as living with young child(ren), living with older parent(s), being employed, being retired, having a regular source of income, having a family member in school, and planning to move in the near future, were found to be associated with significant differences in perceptions toward importance of adoption factors, although the score differences were not big. Based on the comparative analyses, it can be concluded that, for the most part, the criteria for making decisions around purchase, initial use, and continued use of various technologies are universal across demographic groups, but more affected by relevant experiences and life events that may affect people's consumption habits. While this conclusion holds for most of the cases that were analyzed in this section, age was found to be negatively associated with some factors, including emotion, independence, and social support. It suggests that observable characteristics, mainly age, can be a predictor for technology adoption attitudes and behaviors to some degree, but that one cannot rely on such variables for determining adoption and use of technology. That is, segmenting markets solely by demographic variables such as age is likely to be limited in explaining and predicting how technology will be adopted and used at various stages of consumer and user decision making.

#### 4.4.2.3. Comparison between decision stages

In addition to the comparative analysis between respondents grouped based on individual characteristics, possible score discrepancies between the three decision stages were investigated to see if the perceived importance of each factor differs by at which point of adoption and use people are involved in. Table 29 summarizes the average scores for the adoption factors at the three stages of technology adoption and use. The scores in Table 29 are calculated from respondents of all ages.

**Table 29. Overall importance of adoption factors: result from all age groups**

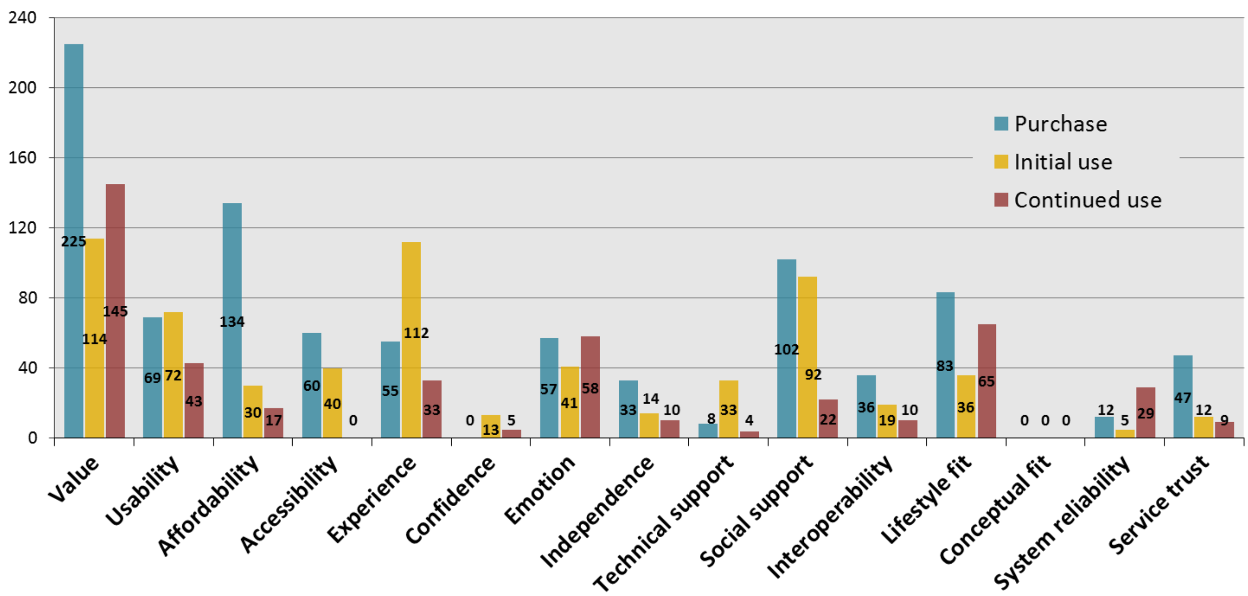
| Adoption factor | Decision stage | | |
|---|---|---|---|
| | Purchase | Initial use | Continued use |
| Value* | 6.23 | 6.13 | 5.82 |
| Usability* | 6.29 | 6.14 | 5.83 |
| Affordability* | 6.39 | 5.99 | 5.71 |
| Accessibility* | 5.57 | 5.09 | 4.76 |
| Experience* | 5.71 | 5.48 | 5.16 |
| Confidence* | 5.95 | 5.82 | 5.65 |
| Emotion* | 5.58 | 5.45 | 5.26 |
| Independence | 3.49 | 3.47 | 3.39 |
| Technical support* | 5.91 | 5.86 | 5.56 |
| Social support* | 4.54 | 4.31 | 3.93 |
| Interoperability* | 5.74 | 5.61 | 5.42 |
| Lifestyle fit* | 6.06 | 5.88 | 5.56 |
| Conceptual fit* | 5.40 | 5.36 | 5.15 |
| System reliability* | 6.12 | 5.95 | 5.83 |
| Service trust* | 6.30 | 6.17 | 5.97 |

*: Between-stage difference significant at $\alpha=0.01$

It can be seen from Table 29 that people across all ages and individual characteristics responded that they generally thought of the adoption factors as more important, except for independence, when they were making purchase decisions, rather than when they were starting to use a technology or getting involved in continued use. Lowest average scores were found for the continued use stage, except for independence. However, the score discrepancies were mostly around or smaller than 0.5 out of the 7-point scale. That is, while people perceived the adoption factors to be more important during purchase, the factors still weighed in to some degree when they made decisions during initial use and continued use of technology. More specifically, the score differences between decision stages showed similar patterns in all age groups. As shown earlier in Table 24, the average score for perceived importance of adoption factors decreased by a small amount from purchase to initial use, then from initial use to continued use.

In addition to the analysis of average scores gathered from the multiple-choice questions, the data coded from the open-ended responses were also analyzed for a comparison on perceived importance of the adoption factors between decision stages. Figure 21 summarizes the finding from the frequency analysis on the open-ended responses for the three decision stages. The data in Figure 21 show the total frequencies from all three age groups for the adoption factors.

**Figure 21. Keyword frequency: comments related to adoption factors for the three decision stages**




Similar to the result from the mean comparison based on average score, the open-ended responses showed big differences between the three stages for most of the factors, with the exception of conceptual fit, to which no related comment was gathered. It can be seen that, across age groups, some factors were mentioned much more often during the earlier stages compared to the later continued use stage. These factors include affordability, accessibility, independence, social support, interoperability, and service trust. These factors were described to have affected the respondents' thoughts, experiences and decisions more so during purchase compared to the later stages. More specifically, affordability was mentioned second-most frequently, following value, when respondents described their purchase experiences. This suggests that users and consumers perceive costs related to getting and using a technology to be most influential during the purchase stage, but that the considerations around costs diminishes quickly after acquisition. Social support was mentioned very often for both purchase and initial use stages. From the comments, it was seen that family and friends made the respondents aware of, or recommended, the technologies they discussed during the purchase stage, and that they motivated and helped the respondents to quickly learn or use the technologies during the initial use stage. Service trust was mentioned frequently during the purchase stage, as many comments were related to trust and dependability related to brands.

Different patterns were observed for other factors, as shown in Figure 21. Value, emotion, lifestyle fit, and system reliability were discussed less frequently around the initial use stage, while they were more frequently discussed for the purchase and continued use stages. On the other hand, experience and technical support were found to be mentioned most frequently for the initial use stage, while they were not frequently discussed for the purchase and continued use stages. These patterns suggest that people may think about different aspects of technology and make their decisions on different criteria throughout the stages of adoption and use.

While the result from the open-ended responses cannot directly be compared with the results from the mean comparison shown in Table 29, it is important to note the difference in the patterns the two types of data have found. The multiple-choice responses showed that the average scores for the perceived importance of adoption factors generally decreased through the stages of adoption and use, with the scores being higher for the purchase stage and lower for the continued use stage in general. However, the open-ended responses suggested that the pattern may not be as linear. The discrepancies between the two suggest that, while people may generally think about the adoption factors less important as they keep using technologies, some factors still play key roles during the later stages of technology adoption and use.

### 4.4.3. Relative importance of technology adoption factors

In addition to evaluating the overall validity of the adoption factors, the survey study also aimed to analyze the possible variance among the perceived importance of the technology adoption factors. Similar to the previous section, the answers to the multiple-choice questions on the perceived importance of the adoption factors and the open-ended questions around technology experiences were analyzed to determine if there is any significant variability.

In this part of analysis, ANOVA was primarily used for comparing the average scores between the adoption factors. ANOVA was first conducted for the older age group to assess the variance between the importance of the factors among older adults at various stages of adoption and use. Additional comparison analysis was then conducted to investigate possible differences associated with individual characteristics in the perceived importance of the adoption factors.

Similar to the previous section, the open-ended responses were analyzed based on the frequency in which the adoption factors were discussed. The number of related comments and discussions, as recorded based on the coded data, were analyzed using Pearson's chi-squared test to investigate any frequency variability between the adoption factors.

#### 4.4.3.1. Assessment of relative importance among older adults

In order to statistically test the differences between factors, the average scores for the perceived importance from the older group for all three decision stages were compared using ANOVA. Following the overall analysis using ANOVA, the score differences between individual factors were further analyzed to have a more detailed understanding around the overall variability. Table 30 lists the adoption factors ordered by the average scores to summarize the individual score differences, and shows the result from the mean comparison analysis. In Table 30, the numbers in parentheses indicate the average scores from the older group.

As shown in Table 30, the overall differences between the average scores for the adoption factors were found to be significant at all decision stages for the older group of respondents 60 years of age or older. The range of the average scores for the adoption factors was slightly greater for the purchase stage (3.54 out of the 7-point scale) compared to the initial use stage (3.36) and the continued use stage (3.20), as indicated by the small differences in the between-factor variability values. At all three stages, independence was found to be perceived as least important, followed by social support. For the purchase stage, affordability was found to be perceived as most important, followed by usability and service trust. On the other hand, service trust was found was rated as the most important factor during initial use and continued use of technology in general.

As shown in Table 30, the overall differences between the average scores for the adoption factors were found to be significant at all decision stages for the older group of respondents 60 years of age or older. The range of the average scores for the adoption factors was slightly greater for the purchase stage (3.54 out of the 7-point scale) compared to the initial use stage (3.36) and the continued use stage (3.20), as indicated by the small differences in the between-factor variability values. At all three stages,

independence was found to be perceived as least important, followed by social support. For the purchase stage, affordability was found to be perceived as most important, followed by usability and service trust. On the other hand, service trust was found was rated as the most important factor during initial use and continued use of technology in general.

**Table 30. Comparison between perceived importance scores for the adoption factors: the older group[15]**

| Decision stage | Purchase | Initial use | Continued use |
|---|---|---|---|
| Between-factor variability[16] | 182.13 | 173.75 | 165.25 |
| Adoption factor rankings | Affordability (6.42)<br>Usability (6.41)<br>Service trust (6.38)<br>Value (6.17)<br>System reliability (6.10)<br>Technical support (6.02)<br>Confidence (6.01)<br>Lifestyle fit (5.94)<br>Experience (5.70)<br>Interoperability (5.69)<br>Accessibility (5.55)<br>Conceptual fit (5.47)<br>Emotion (5.34)<br>Social support (4.14)<br>Independence (2.88) | Service trust (6.26)<br>Usability (6.25)<br>Affordability (6.13)<br>Value (6.00)<br>System reliability (6.00)<br>Technical support (5.96)<br>Confidence (5.86)<br>Lifestyle fit (5.77)<br>Interoperability (5.61)<br>Experience (5.45)<br>Conceptual fit (5.38)<br>Accessibility (5.29)<br>Emotion (5.21)<br>Social support (3.87)<br>Independence (2.90) | Service trust (6.07)<br>Usability (6.02)<br>System reliability (5.86)<br>Affordability (5.80)<br>Value (5.79)<br>Confidence (5.73)<br>Technical support (5.65)<br>Lifestyle fit (5.53)<br>Interoperability (5.42)<br>Conceptual fit (5.24)<br>Experience (5.13)<br>Emotion (5.06)<br>Accessibility (4.83)<br>Social support (3.58)<br>Independence (2.87) |

Between-factor score differences were significant at $\alpha$=0.01 for all three decision stages.

The data coded from the open-ended responses were also analyzed to describe the variability between the frequencies in which comments around the adoption factors were mentioned. For a statistical test on the between-factor differences, the Pearson chi-squared test was conducted. This method was used to test the homogeneity of the frequencies for the adoption factors. In order to conduct the test, observed and expected values of frequencies are necessary. The number of times counted from the coded data represented the observed frequencies. The expected frequencies were calculated based on an examination of the data. Because many respondents commented around two or more factors in their responses, the

[15] The average scores for all factors can be found in Table 24, section 4.2.2.2.

[16] The between-factor variability in this table refers to the mean square of treatments, which is a measure of between-group variation calculated during ANOVA. It is calculated by dividing the sums of squares of treatments, or the sum of squares of the differences between average scores for the individual factors and the overall average, by the degree of freedom. The mean square of treatments is used for calculating the F statistic, which is a measure used for testing the significance of differences between mean values (Hayter, 2002). This table used the mean square of treatments as an indicator of the variability between the scores for the adoption factors.

total count for the factor frequency summed to 2004. Among the 2004 counts, 682 were mentioned from the older group. If there is no difference between the 15 factors, the frequency of comments around each factor would be at 682/15, or about 45.47. This value was thus used as the expected frequency for each factor during the Pearson chi-squared test for homogeneity.

The Pearson chi-squared test of homogeneity showed a p-value of 0.000, meaning that there is a significant variability among the frequencies in which comments around the adoption factors were mentioned. As previously shown in Figure 19 in section 4.4.2.1, the largest number of open-ended responses concerned value (168 times). The rank is followed by experience (87 times), social support (74 times), lifestyle fit (70 times), emotion (62 times), usability (51 times), affordability (49 times), accessibility (25 times), service trust (24 times), technical support (22 times), interoperability (19 times), independence (15 times), confidence (9 times), and system reliability (7 times), in this order. As mentioned earlier, no comment concerned conceptual fit. The variance between the frequencies, which was found to be statistically significant, suggest that older adults may have thought about or experienced issued related to the adoption factors to varied degrees, with value being the most influential factor across stages.

#### 4.4.3.2. Comparison based on age and other individual characteristics

The comparison between the average scores for the adoption factors among the older respondents was then followed by an age comparison. The variability between the adoption factors was compared between the three age groups – younger (ages 20~39), middle-aged (ages 40~59), and older (ages 60 and up) – at the three decision stages – purchase, initial use and continued use. The statistical significance of the differences between the adoption factors was tested using ANOVA. Table 31 summarizes the result with the ranks for the adoption factors for the three age groups at the three decision stages, assigned in order of descending average scores, and shows the result from the mean comparison analysis. The actual average scores can be found in Table 24 in section 4.4.2.2.

For all age groups, the differences in the average scores for the perceived importance of the adoption factors were found to be statistically significant at all decision stages. Some age differences were found in the degree of the variability between factors. The values for the mean square of treatments, which is shown in Table 31 as between-factor variability, were the smallest for the younger group and the biggest for the older group at all stages. While the variability was significant for all groups, the values suggest that the range of average scores for the adoption factors may be slightly larger for the older group, compared to the younger and middle-aged group.

**Table 31. Comparison between perceived importance scores for the adoption factors: age comparison**

| Decision stage | | Purchase | | | Initial use | | | Continued use | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20~39 | 40~59 | 60+ | 20~39 | 40~59 | 60+ | 20~39 | 40~59 | 60+ |
| Between-factor variability | | 62.11 | 134.52 | 182.13 | 63.36 | 123.88 | 173.75 | 63.75 | 115.18 | 165.25 |
| Ranks | Value | 1 | 4 | 4 | 1 | 3 | 4 | 2 | 2 | 5 |
| | Usability | 3 | 3 | 2 | 3 | 2 | 2 | 5 | 4 | 2 |
| | Affordability | 2 | 1 | 1 | 5 | 5 | 3 | 7 | 5 | 4 |
| | Accessibility | 12 | 10 | 11 | 13 | 13 | 12 | 13 | 13 | 13 |
| | Experience | 11 | 11 | 9 | 11 | 12 | 10 | 11 | 11 | 11 |
| | Confidence | 7 | 7 | 7 | 8 | 7 | 7 | 4 | 6 | 6 |
| | Emotion | 8 | 12 | 13 | 9 | 10 | 13 | 9 | 10 | 12 |
| | Independence | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| | Technical support | 9 | 8 | 6 | 7 | 8 | 6 | 8 | 8 | 7 |
| | Social support | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| | Interoperability | 10 | 9 | 10 | 10 | 9 | 9 | 10 | 9 | 9 |
| | Lifestyle fit | 5 | 6 | 8 | 4 | 6 | 8 | 6 | 7 | 8 |
| | Conceptual fit | 13 | 13 | 12 | 12 | 11 | 11 | 12 | 12 | 10 |
| | System reliability | 6 | 5 | 5 | 6 | 4 | 5 | 3 | 3 | 3 |
| | Service trust | 4 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | 1 |

Between-factor score differences were significant at $\alpha=0.01$ for all three age groups and decision stages.

The relative importance of the individual factors can be evaluated from the rankings summarized in Table 31. The rankings show that all age groups are similar in terms of how they perceive the adoption factors to be more or less important relative to one another. Several factors, such as value, usability, affordability, service trust, and reliability, were ranked high on the scale for all age groups. At the other end of the scale, independence was found to be the least important, followed by social support, for all age groups. While the relative importance of the factors was generally common across age groups, some small differences can be noted. For example, the result suggests that value may be more important among the younger respondents. The rank for value was very high for the younger group, but was behind few other factors for the middle-aged and older groups. Also, affordability, usability, and service trust were found to be perceived as more important among the middle-aged and older groups compared to the younger group.

The data coded from the open-ended responses were also analyzed for age comparison. For this part of analysis, the variability among the frequencies in which comments around the adoption factors were mentioned was tested for each age group. The actual frequencies were compared for a detailed analysis. Similar to the process described previously in section 4.4.3.1 for the older group, the number of times counted from the coded data represented the observed frequencies. The expected frequencies were calculated based on an examination of the data. It was found that the total count for the factor frequency summed to 642 for the younger group and 680 for the middle-aged group. As mentioned earlier, the older group shows a total count of 682. If there is no difference between the 15 factors, the frequency of comments around each factor would be at 642/15, or about 42.80, for the younger group and 680/15, or about 45.33, for the middle-aged group. These values were thus used as the expected frequency for each factor during the Pearson chi-squared test for homogeneity. As a result of the Pearson chi-squared test of homogeneity, all age groups showed p-values rounded to 0.000, meaning that, for all age groups, there is a significant variability among the frequencies in which comments around the adoption factors were mentioned.

For a more detailed analysis of the frequency analysis, Table 32 lists the adoption factors ordered by the frequencies in which related responses were collected. In Table 32, the numbers in parentheses indicate the observed frequencies summed from the three stages.

**Table 32. Comparison between frequencies for the adoption factors: age comparison**

| Age group | Younger (20~39) | Middle-aged (40~59) | Older (60 and up) |
|---|---|---|---|
| Expected frequency | 45.47 | 45.33 | 42.80 |
| Adoption factor rankings | Value (166)<br>Social support (71)<br>Experience (61)<br>Usability (59)<br>Affordability (53)<br>Lifestyle fit (48)<br>Accessibility (45)<br>Emotion (45)<br>Independence (24)<br>Interoperability (21)<br>System reliability (18)<br>Service trust (17)<br>Technical support (10)<br>Confidence (4)<br>Conceptual fit (0) | Value (150)<br>Affordability (79)<br>Usability (74)<br>Social support (71)<br>Lifestyle fit (66)<br>Experience (52)<br>Emotion (49)<br>Accessibility (30)<br>Service trust (27)<br>Interoperability (25)<br>System reliability (21)<br>Independence (18)<br>Technical support (13)<br>Confidence (5)<br>Conceptual fit (0) | Value (168)<br>Experience (87)<br>Lifestyle fit (70)<br>Social support (74)<br>Emotion (62)<br>Usability (51)<br>Affordability (49)<br>Service trust (27)<br>Accessibility (25)<br>Technical support (22)<br>Interoperability (19)<br>Independence (15)<br>Confidence (9)<br>System reliability (7)<br>Conceptual fit (0) |

Between-factor score differences were significant at α=0.01 for all three age groups.

For all three age groups, large variability was found between the frequencies in which related comments were gathered. The result may indicate that people may weigh the adoption factors differently when they are making decisions along the stages of technology adoption and use, rather than weighing all factors equally. Alternatively, because the responses relied on people's memories, the result may also indicate that considerations around some factors are more consciously done or easily recalled, while thoughts around other factors are more unconsciously done or easily forgotten.

With regards to the relative importance of the adoption factors as suggested by the frequency analysis, some commonalities can be found between the age groups. In all three age groups, comments and discussions related to value were most frequently mentioned, while responses around confidence were less frequently mentioned. On the other hand, age differences were observed for some factors as summarized in Table 32. For example, affordability was ranked at different points in different age groups. In the order presented in Table 32, affordability was the placed at fifth among the younger group, second among the initial group, and seventh in the older group, in terms of the frequency in the open-ended response data. Few factors, such as lifestyle fit and emotion were more frequently mentioned, compared to other factors, among the older respondents.

While the result from the open-ended responses cannot be directly compared with the mean comparison shown in Table 31 due to the lack of consistency in data formats and the nature of the question contents, some similarities and differences can be observed. Some findings can be discussed to be common across the two types. For example, value and affordability were ranked high among all ages for both the average scores and the number of related comments. Also, technical support was ranked slightly higher among older adults compared to the younger and middle-aged group according to the average scores for its perceived importance, and the result of the frequency analysis based on the open-ended responses showed a similar pattern. On the other hand, several factors were found to show different patterns between the multiple-choice scores and open-ended responses as they are compared between age groups. For example, confidence was ranked around the middle when analyzed based on the average scores from the multiple-choice responses, it was ranked much lower based on the frequency analysis based on the open-ended responses. Also, while the ranks for emotion were lower among the older group compared to the younger groups according to the average scores on its perceived importance, it was ranked higher among the older group when analyzed based on the open-ended responses. However, both parts of the data confirmed that the variability between perceptions toward the adoption factors is statistically significant for all ages.

In addition to age, the differences between averages scores for the perceived importance of the adoption factors were statistically tested for other respondent groups categorized by individual characteristics. For all respondent groups distinguished by living situation variables as shown in Appendix 8, the variability between average scores for the adoption factors were found to be statistically significant at a confidence level of 0.01, suggesting that people of various characteristics all weighed the individual adoption factors differently during stages of adoption and use. The range of the average scores, or the overall variability, was smaller in a few groups, including people who live with young children 12 years of age or younger and people who have a family member in school, while it was slightly wider for other groups, including people who live alone or live with parent(s) 65 years of age or older. The differences between average scores for the adoption factors were also found to be statistically significant for both male and female respondents, and the ranges of scores, as well as the individual averages scores, were similar in the two genders as shown earlier in Table 28.

#### 4.4.3.3. Comparison between decision stages

In addition to the comparative analysis between respondents age and other individual characteristics, the variability among average scores for the perceived importance of adoption factors were compared between the three decision stages – purchase, initial use, and continued use. The comparison between stages was carried out to investigate if the relative importance of the individual adoption factors and the overall variability among the average scores differ between the stages of adoption and use. The statistical significance of the differences between the adoption factors was tested using ANOVA for all three decision stages. Table 33 summarizes the result with the ranks for the adoption factors for the three decision stages, assigned in order of descending average scores, and shows the result from the mean comparison analysis. The numbers in parentheses indicate the actual average scores.

**Table 33. Comparison between perceived importance scores for the adoption factors: decision stage comparison**

| Decision stage | Purchase | Initial use | Continued use |
|---|---|---|---|
| Between-factor variability | 356.73 | 338.89 | 327.31 |
| Adoption factor rankings | Affordability (6.39)<br>Service trust (6.30)<br>Usability (6.29)<br>Value (6.23)<br>System reliability (6.12)<br>Lifestyle fit (6.06)<br>Confidence (5.95)<br>Technical support (5.91)<br>Interoperability (5.74)<br>Experience (5.71)<br>Emotion (5.58)<br>Accessibility (5.57)<br>Conceptual fit (5.40)<br>Social support (4.54)<br>Independence (3.49) | Service trust (6.17)<br>Usability (6.14)<br>Value (6.13)<br>Affordability (5.99)<br>System reliability (5.95)<br>Lifestyle fit (5.88)<br>Technical support (5.86)<br>Confidence (5.82)<br>Interoperability (5.61)<br>Experience (5.48)<br>Emotion (5.45)<br>Conceptual fit (5.36)<br>Accessibility (5.09)<br>Social support (4.31)<br>Independence (3.47) | Service trust (5.97)<br>Usability (5.83)<br>System reliability (5.83)<br>Value (5.82)<br>Affordability (5.71)<br>Confidence (5.65)<br>Lifestyle fit (5.56)<br>Technical support (5.56)<br>Interoperability (5.42)<br>Emotion (5.26)<br>Experience (5.16)<br>Conceptual fit (5.15)<br>Accessibility (4.76)<br>Social support (3.93)<br>Independence (3.39) |

Between-factor score differences were significant at $\alpha$=0.01 for all three decision stages.

The differences in the average scores for the perceived importance of the adoption factors were found to be statistically significant at all three decision stages. Little difference was found in the degree of the variability in the average scores between the decision stages. The values for the mean square of treatments, which is shown in Table 33 as between-factor variability, were the smallest for the continued use stage and the biggest for the purchase stage. While the variability was significant for all stages, the values suggest that the range of average scores for the adoption factors may be slightly larger during purchase compared to the following stages of adoption and use.

The rankings in Table 33 show that people have similar perceptions around the relative importance of the adoption factors throughout the decision stages. Several factors, such as affordability, service trust, usability, and value, were ranked high on the scale for all decision stages. Other factors, including independence, social support, conceptual fit, and accessibility, were constantly ranked low for all decision stages. Small differences were found between the three decision stages. Affordability was ranked relatively higher for the purchase stage and lower for the continued stage. System reliability, on the other hand, was ranked relatively higher for the continued use stage, although the actual score decreased from the purchase stage to the continued use stage.

The data coded from the open-ended responses were also analyzed to compare the relative importance or weights of the adoption factors between the three decision stages. Similar to the previous analyses as shown in sections 4.4.3.1 and 4.4.3.2, the actual frequencies, or the number of times in which comments related to the adoption factors were mentioned, were compared with the expected frequencies. Based on an examination of the data, it was found that the total count for the factor frequency summed to 921, which was the highest of the three stages. The total number was 633 for the initial use stage, and 450 for the continued use stage. More comments were gathered around the adoption factors during the early stage of adoption and use compared to the later stage. Assuming that there is no difference between the 15 factors, the frequency of comments around each factor would be at 921/15, or about 61.40, for the purchase stage. Similarly, the expected frequencies would be 633/15, or about 42.20, for the initial use stage, and 450/15, or 30, for the continued use stage. The Pearson chi-squared test for homogeneity was conducted to statistically compare the actual frequencies against these expected values for all three stages. As a result of the Pearson chi-squared test, it was found that the variability between the frequencies for the individual factors were significant at all three stages.

In all three stages of technology adoption and use, the number of related comments varied greatly between the factors. The result suggests that, throughout the decision stages, people weigh the adoption factors, or decision criteria, differently rather than equally. Also, as discussed in the previous section, the result may alternatively suggest that some factors are more consciously considered or easily recalled, while other factors may be easily forgotten or considered at a more unconscious level.

For a more detailed analysis of the frequency analysis, Table 34 lists the adoption factors ordered by the frequencies in which related responses were collected. In Table 34, the numbers in parentheses indicate the observed frequencies summed from the three stages.

**Table 34. Comparison between frequencies for the adoption factors: decision stage comparison**

| Decision stage | Purchase | Initial use | Continued use |
|---|---|---|---|
| Expected frequency | 61.40 | 42.20 | 30.00 |
| Adoption factor rankings | Value (225)<br>Affordability (134)<br>Social support (102)<br>Lifestyle fit (83)<br>Usability (69)<br>Accessibility (60)<br>Emotion (57)<br>Experience (55)<br>Service trust (47)<br>Interoperability (36)<br>Independence (33)<br>System reliability (12)<br>Technical support (8)<br>Confidence (0)<br>Conceptual fit (0) | Value (114)<br>Experience (112)<br>Social support (92)<br>Usability (72)<br>Emotion (41)<br>Accessibility (40)<br>Lifestyle fit (36)<br>Technical support (33)<br>Affordability (30)<br>Interoperability (19)<br>Independence (14)<br>Confidence (13)<br>Service trust (12)<br>System reliability (5)<br>Conceptual fit (0) | Value (145)<br>Lifestyle fit (65)<br>Emotion (58)<br>Usability (43)<br>Experience (33)<br>System reliability (29)<br>Social support (22)<br>Affordability (17)<br>Interoperability (10)<br>Independence (10)<br>Service trust (9)<br>Confidence (5)<br>Technical support (4)<br>Accessibility (0)<br>Conceptual fit (0) |

Between-factor score differences were significant at $\alpha=0.01$ for all three age groups.

The result shown in Table 34 shows some commonalities, in terms of the range of frequencies describing the number of comments around the adoption factors, between the decision stages. In all three stages, comments and discussions related to value were most frequently mentioned. Also, in the purchase stage and the continued use stage, comments around value were mentioned far more frequently that the factors that ranked behind value. Conceptual fit, which was not brought up in any of the comments across all stages, and confidence, which was only mentioned in several comments for initial use and continued use, constantly ranked low. In all three stages, usability was constantly ranked at a mid-to-high position, with the actual number of comments not much different between stages.

Some differences between the three stages can be observed from the result shown in Table 34 as well. The overall range of the frequencies for the adoption factors were found to be much larger in the purchase stage, compared to the other two stages. The range between the most frequently mentioned factor, value, and the least frequently mentioned factor, conceptual fit, was 225 for the purchase stage, while it was 114 for the initial use stage and 145 for the continued use stage. In addition to the overall range, the range between the most frequently mentioned factor, value, and the factor that ranked at second were different between the stages. In the initial use stage, the frequency gap between value, the first factor in rank, and experience, the second in the order of frequency, was only 2. On the other hand, in the continued use stage, the frequency of comments related to value was more than twice the frequency of the second-ranked factor, which was lifestyle fit. Table 34 also shows how the relative importance, which can be inferred from the number of related comments, varied by decision stages for some factors. For example, emotion was found to have ranked higher, compared to other factors, in the continued use stage than in the earlier stages. Technical support was mentioned in only several comments during discussions around the purchase and continued use stage, but it was ranked higher in the initial use stage.

As discussed earlier, the results from the average scores found from the multiple-choice questions on perceived importance and frequencies found from the open-ended questions cannot be compared directly due to differences in data formats and the contents entailed in the original questions. However, some similarities and differences in the overall patterns can still be identified. In both types of data, significant variances among the relative importance or weights for the factors were found with statistical analyses. That is, to both types of questions, respondents indicated that they consider the individual adoption factors to varied degrees when they make decisions around the adoption and use of technology at various points, rather than weighing them all equally. The relative importance of individual factors showed some differences between the two types of the data. In some cases, factors that ranked very high based on one type of data were found to rank much lower when analyzed with the other type of data. Such discrepancy may suggest that the frequencies of the related responses gathered from the open-ended questions may not be an accurate proxy for assessment of perceived importance, but that they may be actually artifacts of memory biases, as discussed earlier. The gap can also indicate that the ways in which questions were stated and worded in the multiple-choice section may have been understood incorrectly by the respondents of did not properly explain the concepts entailed in the adoption factors.

### 4.4.4. Associations among technology adoption factors

The last research question posed for the survey research concerns the possible associations and relationships between the adoption factors. As discussed previously in section 3.4, the literature review and user interviews on descriptions of the technology adoption factors have suggested the presence of some correlations and underlying structure among the factors. To further study the associations, the answers to the multiple-choice questions on the perceived importance of the adoption factors were used, along with the open-ended questions around technology use experiences, to analyze the correlations and co-occurrences for determining the underlying structure among the adoption factors.

Factor analysis was used as the primary method of analysis for exploring and describing the factor associations based on the averages scores for the adoption factors. The responses from the older respondents 60 years of age or older were first investigated using factor analysis to assess the possible associations between adoption factors based on their perceived importance. Additionally, factor analysis was conducted for the other age groups and repeated for various respondent groups to compare any differences between factor relationships that may be associated with individual characteristics. The process was then repeated for a comparison between the three decision stages.

For extraction of factors, a common factor analysis, or principal axis extraction, was used instead of a component analysis method as the objective was to underlying dimensions rather than to reduce the amount of data or the size of the variable set.[17] The common factor analysis generates factors as linear combinations of variables that are orthogonal to each other. During factor analysis, an eigenvalue, which indicates the amount of sample variance captured by the linear combination, is calculated for each factor. Using a latent root criterion, factors having eigenvalues greater than 1 were selected for discussion in this section[18]. The partial correlations between the adoption factors were also calculated for a more detailed analysis of their relationships.

For the analysis of the open-ended responses, association rules was used for analyzing how various factors were mentioned together. Each response was coded to show the related adoption factors it mentions or discusses. For an analysis of factor relationships, the coded data were analyzed to investigate patterns in which factors are mentioned or discussed together.

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[17] Component analysis and common factor analysis are two key methods used for factor extraction in a factor analysis process. Component analysis considers the total variance in data, which includes three types – common variance, specific variance, and error variance. Common variance, or communality, is based on a variable's correlations with all other variables. Specific variance, or unique variance, is associated with a single variable and does not explain its relationships with other variables. Lastly, error variance represents variability in data that may be caused by randomness or unreliability in data collection or measurement. On the other hand, common factor analysis, or principal axis extraction, considers only the common or shared variance. It is used when the specific variance and error variance are assumed to be not of interest in defining the structure of the variables. In practice, component analysis is most appropriate when data reduction is the main concern, while it is better to use common factor analysis when the objective is to identify the underlying dimensions (Hair et al., 2009).

[18] Latent root criterion is a technique for determining the number of factors to extract. When using the latent root criterion, the decision is based on selecting factors that account for variances larger than that of a single variable. Since the eigenvalue represents the amount of variance explained by a factor, it is used for determining if a factor should be extracted. Thus, using the latent root criterion, only the factors with eigenvalues greater than 1 are considered significant, and those with eigenvalues less than 1 are disregarded (Hair et al., 2009).

#### 4.4.4.1. Assessment of factor relationships among older adults

In order to explore and define the underlying structure among the adoption factors based on the perceptions of the older group, factor analysis was conducted on data combined from all three decision stages. Table 35 summarizes the result of factor analysis, including the extracted factors that were determined as significant with eigenvalues greater than 1 and the amount of variance they explain. In Table 35, the extracted factors are ordered by the size of eigenvalue, or the amount of variance explained by each. The variables, or individual adoption factors, included in a single extracted factor are closely correlated with others in the same factors, while significantly less correlated with variables in other factors.

**Table 35. Association between adoption factors: the older group (ages 60 and up)**

| Factor | Included variables[19] | Eigenvalue (initial) | Eigenvalue (rotated) | % of variance | Cumulative % |
|---|---|---|---|---|---|
| 1 | Accessibility (P, I, C), experience (P, I, C) | 14.520 | 3.607 | 8.015 | 8.015 |
| 2 | Independence (P, I, C) | 4.473 | 3.329 | 7.397 | 15.413 |
| 3 | Emotion (P, I, C), lifestyle fit (P, I, C) | 3.114 | 2.887 | 6.415 | 21.827 |
| 4 | Value (P, I, C) | 2.658 | 2.874 | 6.387 | 28.214 |
| 5 | Usability (P, I, C), confidence (P, I, C) | 2.047 | 2.851 | 6.336 | 34.550 |
| 6 | Affordability (P, I, C) | 1.895 | 2.807 | 6.238 | 40.788 |
| 7 | Social support (P, I, C) | 1.688 | 2.792 | 6.204 | 46.992 |
| 8 | Technical support (P, I, C) | 1.392 | 2.650 | 5.889 | 52.882 |
| 9 | System reliability (P, I, C) | 1.358 | 2.510 | 5.578 | 58.460 |
| 10 | Conceptual fit (P, I, C) | 1.257 | 2.492 | 5.538 | 63.997 |
| 11 | Service trust (P, I, C) | 1.197 | 2.478 | 5.507 | 69.504 |
| 12 | Interoperability (P, I, C) | 1.054 | 2.396 | 5.324 | 74.829 |

As shown in Table 35, the 15 adoption factors at three decision stages were grouped into 12 factors. The 12 factors were found to explain a total of about 74.83% of the total variance in the data. The key finding from the result shown in Table 35 is that the individual adoption factors at the three stages were grouped together based on the factor descriptions, rather than the stages in which the data referred to. In all 12 factors, the individual factors at the three stages were grouped together. This suggests that the scores for the perceived importance of a particular adoption factor at one stage are closely correlated with the scores for the perceived importance of the same factor at other decision stages. Another key result that can be observed from Table 35 is the association between some of the factors. According to the factor analysis result, the perceived importance of accessibility at all stages and experience at all stages were found to be

[19] The variables are not listed in a particular order.

associated. Similar relationships were found between emotion and lifestyle fit, and between usability and confidence.

For a more detailed analysis on the relationships among the adoption factors, factor analysis was conducted separately on the data for the three decision stages. Table 36 shows the results on the associations between the adoption factors at the three decision stages.

**Table 36. Association between adoption factors at different decision stages: the older group (ages 60 and up)**

| Decision stage | Factor no. | Included variables[20] | Eigenvalue (initial) | Eigenvalue (rotated) | % of variance | Cumulative % |
|---|---|---|---|---|---|---|
| Purchase | 1 | Service trust, technical support, lifestyle fit, interoperability, system reliability | 5.139 | 2.154 | 14.363 | 14.363 |
| | 2 | Affordability, usability, confidence, value, accessibility | 1.649 | 2.106 | 14.042 | 28.405 |
| | 3 | Independence, emotion, social support, experience | 1.211 | 1.692 | 11.277 | 39.682 |
| | 4 | Conceptual fit | 1.026 | 0.909 | 6.058 | 45.740 |
| Initial use | 1 | Affordability, accessibility, usability, value, service trust, confidence, experience | 5.035 | 2.587 | 17.249 | 17.249 |
| | 2 | Independence, emotion, social support | 1.631 | 1.845 | 12.298 | 29.546 |
| | 3 | Technical support, interoperability, lifestyle fit, system reliability, conceptual fit | 1.217 | 1.706 | 11.373 | 40.919 |
| Continued use | 1 | Usability, accessibility, affordability, experience, confidence, lifestyle fit, value | 6.277 | 3.115 | 20.765 | 20.765 |
| | 2 | System reliability, technical support, service trust, conceptual fit, interoperability | 1.442 | 2.518 | 16.786 | 37.551 |
| | 3 | Independence, social support, emotion | 1.144 | 1.784 | 11.896 | 49.448 |

According to the result shown in Table 36, the adoption factors were grouped into 3 to 4 factors at each decision stage. The amount of variance explained from these factors ranged from about 40 to 50 percent, which is lower than when the three stages were analyzed in combination as shown in Table 36. Across

[20] The variables are ordered in the order of association with the respective factor. The variable that has the highest association with the factor is listed first.

stages, some associations between the adoption factors were found to be consistent. For example, affordability, usability, accessibility, and value were grouped into the same factor at all three stages, suggesting a consistent relationship among them as older adults perceive their importance throughout stages of technology adoption and use. Similarly, interoperability, technical support, and system reliability were grouped together at all stages. Independence, emotion, and social support also showed a consistent tie among them across stages.

For a more detailed analysis on the relationship between the adoption factors, correlation analysis was conducted to find the bivariate correlations between paired combinations among the individual adoption factors. The result of the correlation analysis, with the Spearman's rank correlation coefficient for all pairs among the adoption factors, can be found in Appendix 9. From the result, it can be seen that the adoption factors that are grouped together as shown in Table 36 are more strongly correlated with one another than with adoption factors that were separated into other factor groups. For example, at all three decision stages, independence was more correlated with social support and emotion compared to other factors. While the correlation coefficient was not always larger among factors in the same group, the trend can be observed in general for other groups as well.

A different method was used for analyzing associations between the adoption factors using the open-ended responses. Since the data coded from the open-ended responses were recorded in a binary format instead of a numerical scale, association rules analysis was used to analyze co-occurrences of the adoption factors in the responses gathered. The association rules method generates rules that describe common patterns in data.[21] That is, the rules describe items or variables that co-occur often in individual observations. For the analysis, Sipina, a data mining software, was used as an add-on application to analyze data tabulated in Microsoft Excel. Table 37 summarizes the result from the association rules analysis conducted on the responses from the older group. In Table 37, the identified association rules are ordered by the lift ratio.

A few conclusions can be made from the result from the association rules shown in Table 37. Similar to the result from the factor analysis on the multiple-choice responses shown earlier in Table 37, social support and emotion were found to be associated at various stages, especially during the purchase stage and the initial use stage. Independence, which was grouped with social support and emotion based on the

[21] Association rules analysis generates patterns in an {antecedent → consequent} format. This rule format can be interpreted as "if (antecedent), then (consequent)" patterns. However, since the objective for this part of study is to describe relationships rather than to explain causality, the rules summarized in Table 37 do not distinguish antecedents and consequents in them. Instead, the antecedents and consequents are listed together. In cases where both {A → B} and {B → A} for items or adoption factors A and B, they were represented as {A and B} in Table 37.

factor analysis, was not found to be strongly associated with other factors according to the association rules. This may have been because independence was not frequently mentioned in the open-ended responses, whereas social support and emotion were talked about more frequently. It can also be seen from Table 37 that value was highly associated with many other factors, including emotion, lifestyle fit, social support, and experience. When analyzed across stages, it was found that respondents who commented on value at one stage were likely to talk about it in their descriptions around other stages as well. This suggests that the perception of value at various stages of technology adoption and use may be highly associated with how they see the emotional benefits, how their peers and family support the use, and how they see a technology fitting into their life patterns.

**Table 37. Co-occurrence patterns among adoption factors in open responses: the older group (ages 60 and up)**

| Decision stage | Association rule | Support[22] | Lift[23] |
|---|---|---|---|
| All stages[24] | {Social support (I) and emotion (I)} | 0.054 | 4.278 |
| | {Value (C) and emotion (C)} | 0.069 | 2.749 |
| | {Social support (P) and emotion (P)} | 0.054 | 2.671 |
| | {Social support (P) and social support (I)} | 0.064 | 2.395 |
| | {Value (P), lifestyle fit (P) and value (C)} | 0.054 | 2.279 |
| | {Value (P) and emotion (P)} | 0.084 | 1.824 |
| | {Experience (I) and value (C)} | 0.074 | 1.620 |
| | {Lifestyle fit (P) and value (C)} | 0.064 | 1.604 |
| | {Lifestyle fit (P) and value (P)} | 0.108 | 1.484 |
| | {Value (P) and value (C)} | 0.138 | 1.406 |
| Purchase | {Social support and emotion} | 0.054 | 2.671 |
| | {Value and emotion} | 0.084 | 1.824 |
| | {Value and lifestyle fit} | 0.108 | 1.484 |
| | {Value and social support} | 0.089 | 1.118 |
| Initial use | {Social support and emotion} | 0.054 | 4.278 |
| Continued use | {Value and emotion} | 0.069 | 2.749 |

22 Support is a measure of a rule's "interestingness" that reflects the frequency in which the rule occurs within a dataset. For example, a support of 0.05 indicates that the rule can be found in 5% of the observations in the data (Han et al., 2012).

23 Lift is a measure of correlation that reflects the dependence among the items in a rule. If the lift value for a rule is less than 1, then the item sets are negatively correlated, meaning that the occurrence of one item likely leads to the absence of the other item. If the lift is found to be 1, it means that the items in a rule are independent of each other. On the other hand, a lift value greater than 1 indicates that the items in a rule are positively associated with each other, meaning that the occurrence of one item implies the presence of the other. A higher lift value indicates a higher positive association (Han et al., 2012).

24 The letters in the parentheses refer to the decision stage, where P stands for the purchase stages, I represents the initial use stage, and C stands for the continued use stage. For example, emotion (P) refers to comments related to emotion being mentioned around the continued use stage.

#### 4.4.4.2. Comparison based on age and other individual characteristics

Analysis on associations and relationships between the adoption factors was extended to other age groups for comparison. The underlying structure among the adoption factors at the three decision stages – purchase, initial use and continued use – were investigated with factor analysis on responses from respondents in the younger and middle-aged group. Table 38 summarizes the result of factor analysis, including the extracted factors that were determined as significant with eigenvalues greater than 1 and the amount of variance they explain. In Table 38, the extracted factors are ordered by the size of eigenvalue, or the amount of variance explained by each.

From the results of factor analysis on the responses on all decision stages from the younger and middle-aged groups Table 38, some similarities and difference between age groups can be found. It can be seen that, across ages, the adoption factors at various stages are often grouped together. For example, in the younger group, interoperability at all three decision stages were grouped into the same factor. In the younger group, the same pattern was observed for lifestyle fit, system reliability, independence, social support, technical support, emotion, and conceptual fit as well. Among the middle-aged group, the same pattern was found for independence, system reliability, experience, conceptual fit, interoperability, social support, and lifestyle fit, in that these factors at all three stages were grouped together. As shown earlier in Table 38, the pattern held for all 15 adoption factors. Another finding that was shown to be consistent across ages is that usability and confidence were often grouped together, although not at all stages. Based on the responses from the younger group, usability, and confidence at the purchase and initial use stages were grouped together into the same factor. For the middle-aged group, usability and confidence at the purchase and initial use stages were grouped together, while the two factors at the continued use stages were also grouped together, along with other factors, into the same variable group.

A key age difference in the results from the factor analysis is that more cross-factor associations were found among the younger and middle-aged groups. As shown earlier in Table 35, the result from the older group's responses showed that only the same factors at different stages were grouped together, while different factors were separated into different variable groups. On the other hand, in the younger and middle-aged groups, different factors were often grouped together while some factors were separated by the stages they describe. For example, in the first variable group found from the younger group's responses, interoperability, lifestyle fit, system reliability, and service trust were shown to be associated.

**Table 38. Association between adoption factors across three decision stages: younger and middle-aged groups**

| Age group | Factor number | Included variables[25] | Eigenvalue (initial) | Eigenvalue (rotated) | % of variance | Cumulative % |
|---|---|---|---|---|---|---|
| Younger (20~39) | 1 | Interoperability (P, I, C), lifestyle fit (P, I, C), system reliability (P, I, C), service trust (I, C) | 16.786 | 5.946 | 13.213 | 13.213 |
| | 2 | Experience (C), independence (P, I, C), social support (P, I, C) | 4.574 | 5.432 | 12.071 | 25.284 |
| | 3 | Value (P, I), affordability (P, I), accessibility (P), experience (P, I), service trust (P) | 2.197 | 3.169 | 7.041 | 32.325 |
| | 4 | Technical support (P, I, C) | 1.829 | 3.012 | 6.693 | 39.018 |
| | 5 | Usability (P, I), confidence (P, I) | 1.631 | 3.008 | 6.685 | 45.703 |
| | 6 | Value (C), accessibility (I, C) | 1.510 | 2.673 | 5.941 | 51.643 |
| | 7 | Emotion (P, I, C) | 1.337 | 2.626 | 5.836 | 57.479 |
| | 8 | Conceptual fit (P, I, C) | 1.246 | 1.884 | 4.187 | 61.666 |
| | 9 | Usability (C), affordability (C) | 1.021 | 1.407 | 3.126 | 64.793 |
| Middle-aged (40~59) | 1 | Value (C), usability (I, C), affordability (I, C), accessibility (I, C), confidence (C), technical support (C) | 18.671 | 6.581 | 14.625 | 14.625 |
| | 2 | Value (P, I), usability (P), affordability (P), accessibility (P), confidence (P, I), technical support (P, I), service trust (P) | 3.644 | 5.203 | 11.563 | 26.188 |
| | 3 | Independence (P, I, C) | 2.947 | 3.896 | 8.658 | 34.846 |
| | 4 | System reliability (P, I, C), service trust (I, C) | 2.131 | 3.371 | 7.491 | 42.337 |
| | 5 | Experience (P, I, C) | 1.675 | 2.711 | 6.025 | 48.362 |
| | 6 | Conceptual fit (P, I, C) | 1.562 | 2.687 | 5.972 | 54.334 |
| | 7 | Interoperability (P, I, C) | 1.421 | 2.381 | 5.292 | 59.626 |
| | 8 | Social support (P, I, C) | 1.274 | 2.374 | 5.275 | 64.900 |
| | 9 | Emotion (P, I, C) | 1.240 | 2.295 | 5.099 | 69.999 |
| | 10 | Lifestyle fit (P, I, C) | 1.099 | 1.779 | 3.954 | 73.954 |

[25] The letters in the parentheses refer to the decision stage, where P stands for the purchase stages, I represents the initial use stage, and C stands for the continued use stage. For example, emotion (P) refers to comments related to emotion being mentioned around the continued use stage. The variables are not listed in a particular order.

**Table 39. Association between adoption factors at different decision stages: younger and middle-aged groups**

| Decision stage | Age group | Factor number | Included variables[26] | Eigenvalue (initial) | Eigenvalue (rotated) | % of variance | Cumul-ative % |
|---|---|---|---|---|---|---|---|
| Purchase | Younger (20~39) | 1 | Lifestyle fit, usability, system reliability, confidence, service trust, value, technical support, interoperability, affordability, experience, emotion | 5.515 | 3.481 | 23.206 | 23.206 |
| | | 2 | Independence, conceptual fit, social support | 1.763 | 2.066 | 13.772 | 36.978 |
| | | 3 | Accessibility | 1.088 | 1.376 | 9.172 | 46.150 |
| | Middle-aged (40~59) | 1 | Service trust, affordability, value, usability, interoperability, technical support, accessibility, lifestyle fit, confidence, system reliability, experience, conceptual fit | 6.595 | 5.025 | 33.497 | 33.497 |
| | | 2 | Independence, social support, emotion | 1.408 | 1.919 | 12.792 | 46.289 |
| Initial use | Younger (20~39) | 1 | Service trust, lifestyle fit, system reliability, interoperability, technical support, usability | 6.176 | 3.330 | 22.202 | 22.202 |
| | | 2 | Social support, independence, conceptual fit, emotion | 1.695 | 2.171 | 14.472 | 36.674 |
| | | 3 | Experience, affordability, value, accessibility, confidence | 1.024 | 1.935 | 12.901 | 49.575 |
| | Middle-aged (40~59) | 1 | Technical support, lifestyle fit, confidence, service trust, interoperability, system reliability, conceptual fit, experience, emotion | 7.073 | 3.760 | 25.069 | 25.069 |
| | | 2 | Affordability, usability, value, accessibility | 1.278 | 2.533 | 16.888 | 41.957 |
| | | 3 | Social support, independence | 1.110 | 1.797 | 11.977 | 53.934 |
| Continued use | Younger (20~39) | 1 | Service trust, system reliability, lifestyle fit, interoperability, technical support, usability, confidence, value, emotion, conceptual fit, affordability | 6.853 | 4.586 | 30.572 | 30.572 |
| | | 2 | Social support, independence, experience, accessibility | 1.536 | 2.883 | 19.217 | 49.789 |
| | Middle-aged (40~59) | 1 | Service trust, lifestyle fit, system reliability, confidence, interoperability, technical support, conceptual fit, emotion, experience | 7.914 | 4.174 | 27.825 | 27.825 |
| | | 2 | Usability, affordability, value, accessibility | 1.298 | 2.843 | 18.951 | 46.776 |
| | | 3 | Independence, social support | 1.014 | 2.067 | 13.779 | 60.555 |

[26] The letters in the parentheses refer to the decision stage, where P stands for the purchase stages, I represents the initial use stage, and C stands for the continued use stage. For example, emotion (P) refers to comments related to emotion being mentioned around the continued use stage. The variables are ordered in the order of association with the respective factor. The variable that has the highest association with the factor is listed first.

Factor analysis was repeated on the responses for the three different stages from the younger and the middle-aged groups for a more detailed analysis on the relationships among the adoption factors. The results are summarized in Table 39. The results in Table 39 can be compared with the result from the older group, shown earlier in Table 36, for a more detailed discussion on similarities and differences. It can be seen from Table 38 and 39 that affordability and usability were grouped together in most cases, except for the younger group at the initial use stage. Across ages, affordability and usability were found to be highly associated at all stages. Furthermore, in the older group and the middle-aged group, affordability and usability were also grouped together with value and accessibility at all stages. On the other hand, the tie with value and acceptability was not commonly observed for the younger group. This suggests that the perceived ease of use and considerations around costs may be more related to perceptions around potential benefits and knowledge of availability among people who are middle-aged or older, compared to younger people. Another finding that is common across ages is the association between independence and social support. For all age groups, the result of the factor analysis showed that independence and social support were grouped together at all three decision stages. However, while the two factors were also grouped with emotion for the older group as shown in Table 36, the association with emotion was not consistently observed for the younger and the middle-aged group. The result suggests that the perceived importance of emotional benefits may be highly tied with social support and independence among older adults compared to younger people.

In addition to the numerical responses to the multiple-choice questions on the perceived importance of adoption factors, the open-ended responses on technology experience were also analyzed using association rules analysis to find relationships among adoption factors. Table 40 summarizes the result from the association rules analysis conducted on the responses from the younger and middle-aged group. In Table 40, the identified association rules are ordered by the lift ratio.

Based on the results of association rules analysis on the responses from the younger and the middle-aged groups shown in Table 40, it can be seen that value and lifestyle fit were mentioned together often in comments around most stages from both groups. This is consistent with the result from the older group, as a strong tie was found between value and lifestyle fit across stages as shown in Table 37. However, while the younger and the middle-aged groups consider value and lifestyle fit during various stages from purchase to continued use, the older group mentioned them together more for the purchase stage. This suggests that as people adopt and use technology, younger and middle-aged people continue to consider the benefits provided by the technology and the degree to which it fits into their life patterns, while older adults think about them together during early stages but consider other associated factors such as emotion more during the later stages. A comparison between the result from the older group, shown earlier in

Table 37, and the other age groups showed that more rules were generated from the responses provided by the older group, under the same analysis conditions. This finding suggests that older adults may consider various adoption factors in associations, while younger people may think about various factors rather in isolation.

**Table 40. Co-occurrence patterns among adoption factors in open responses: younger and middle-aged groups**

| Decision stage | Age group | Association rule | Support | Lift |
|---|---|---|---|---|
| All stages[27] | Younger (20~39) | {Social support (P) and social support (I)} | 0.055 | 2.170 |
| | | {Value (I) and value (C)} | 0.074 | 1.671 |
| | | {Value (P) and value (C)} | 0.139 | 1.443 |
| | | {Value (P) and value (I)} | 0.104 | 1.433 |
| | | {Value (P) and lifestyle fit (P)} | 0.059 | 1.377 |
| | | {Value (C) and affordability (P)} | 0.069 | 1.312 |
| | Middle-aged (40~59) | {Emotion (P) and social support (P)} | 0.059 | 4.026 |
| | | {Lifestyle fit (I) and value (I)} | 0.054 | 3.816 |
| | | {Social support (P) and social support (I)} | 0.064 | 2.673 |
| | | {Lifestyle fit (C) and value (C)} | 0.078 | 2.562 |
| | | {Lifestyle fit (C) and experience (I)} | 0.054 | 2.466 |
| | | {Social support (P) and value (I)} | 0.059 | 1.821 |
| | | {Affordability (P) and usability (P)} | 0.074 | 1.819 |
| | | {Experience (I) and value (C)} | 0.064 | 1.546 |
| | | {Affordability (P) and usability (I)} | 0.059 | 1.455 |
| | | {Value (P) and usability (I)} | 0.059 | 1.431 |
| Purchase | Younger | {Value and lifestyle fit} | 0.059 | 1.377 |
| | | {Value and affordability} | 0.104 | 1.205 |
| | Middle-aged | {Emotion and social support} | 0.059 | 4.026 |
| | | {Affordability and usability} | 0.074 | 1.819 |
| Initial use[28] | Middle-aged | {Value and lifestyle fit} | 0.054 | 3.816 |
| Continued use | Younger | {Value and lifestyle fit} | 0.050 | 2.577 |
| | Middle-aged | {Value and lifestyle fit} | 0.078 | 2.562 |

In addition to the age comparison on associations and relationships between adoption factors, a gender comparison was carried out to investigate any differences between male and female. The result of the

[27] The letters in the parentheses refer to the decision stage, where P stands for the purchase stages, I represents the initial use stage, and C stands for the continued use stage. For example, emotion (P) refers to comments related to emotion being mentioned around the continued use stage.

[28] No association rules with a lift ratio over 1 were generated for the younger group at the initial use stage.

factor analysis on numerical responses to the multiple-choice questions on perceived importance of the factors, separated by gender and decision stage, is presented in Table 41. The result based on the open-ended responses, generated using association rules analysis, is summarized in Table 42.

The factor analysis showed that the associations between adoption factors were generally similar between male and female. From Table 41, it can be seen that value, affordability, usability, and accessibility are closely associated at all stages for both male and female. Also according to the result from the factor analysis, independence and social support were shown to be associated, as they were grouped together at all stages for both male and female. A small difference can be observed in that while value, affordability, usability, and accessibility were formed into a group with no other variables for the initial use and continued use stages among females, they were found to be also associated with other variables such as experience and confidence among male respondents.

According to the result from the association rules analysis, the rules generated based on responses from males and females were consistent in that value was associated with other factors. However, while value was only significantly tied with lifestyle fit at all stages for males, it was mentioned together with a few other factors including emotion and social support among female respondents. Also, while male respondents often mentioned affordability and usability together for the purchase stage, the association was not found among females. Instead, based on the responses from female participants, emotion and social support was found to be often mentioned together.

The findings around associations among the adoption factors suggest that the ways in which the adoption factors are related with one another as people think about them during adoption and use of technology only differ by a small degree between different demographic groups. The underlying structure among adoption factors found from factor analysis and the co-occurrence patterns found from association rules suggest that age and gender only accounted for small differences.[29]

[29] Other individual variables, including income, education, and the living situation variables, showed similar results in which individual differences only accounted for small differences.

**Table 41. Association between adoption factors at different decision stages: gender comparison**

| Decision stage | Gender | Factor no. | Included variables | Eigenvalue (initial) | Eigenvalue (rotated) | % of variance | Cumulative % |
|---|---|---|---|---|---|---|---|
| Purchase | Male | 1 | Affordability, value, accessibility, experience, usability, confidence | 5.362 | 2.213 | 14.756 | 14.756 |
| | | 2 | Independence, social support, conceptual fit, emotion | 1.661 | 2.176 | 14.506 | 29.263 |
| | | 3 | Service trust, system reliability, technical support, lifestyle fit, interoperability | 1.177 | 2.164 | 14.430 | 43.692 |
| | Female | 1 | Service trust, affordability, technical support, lifestyle fit, usability, confidence, accessibility, value, system reliability, experience, interoperability, emotion, conceptual fit | 6.126 | 4.778 | 31.852 | 31.852 |
| | | 2 | Independence, social support | 1.516 | 1.755 | 11.703 | 43.555 |
| Initial use | Male | 1 | Service trust, technical support, lifestyle fit, system reliability, interoperability, conceptual fit | 5.838 | 2.429 | 16.196 | 16.196 |
| | | 2 | Accessibility, affordability, experience, value, confidence, usability | 1.660 | 2.309 | 15.393 | 31.589 |
| | | 3 | Independence, social support, emotion | 1.073 | 2.268 | 15.118 | 46.707 |
| | Female | 1 | Technical support, lifestyle fit, service trust, system reliability, interoperability, confidence, conceptual fit, emotion, experience | 6.412 | 3.330 | 22.203 | 22.203 |
| | | 2 | Affordability, usability, value, accessibility | 1.345 | 2.362 | 15.748 | 37.950 |
| | | 3 | Social support, independence | 1.073 | 1.634 | 10.892 | 48.842 |
| Continued use | Male | 1 | Service trust, lifestyle fit, usability, interoperability, confidence, technical support, system reliability, accessibility, value, affordability, experience, emotion, conceptual fit | 6.917 | 5.052 | 33.681 | 33.681 |
| | | 2 | Independence, social support | 1.457 | 2.447 | 16.310 | 49.991 |
| | Female | 1 | Service trust, system reliability, technical support, conceptual fit, lifestyle fit, interoperability, confidence, emotion | 7.297 | 3.625 | 24.167 | 24.167 |
| | | 2 | Usability, affordability, value, accessibility | 1.327 | 2.838 | 18.918 | 43.085 |
| | | 3 | Independence, social support, experience | 1.057 | 1.935 | 12.901 | 55.986 |

**Table 42. Co-occurrence patterns among adoption factors in open responses: gender comparison**

| Decision stage | Gender | Association rule | Support | Lift |
|---|---|---|---|---|
| Purchase | Male | {Affordability and usability} | 0.056 | 2.375 |
| | | {Value and lifestyle fit} | 0.059 | 1.309 |
| | Female | {Emotion and social support} | 0.069 | 2.956 |
| | | {Value and emotion} | 0.072 | 1.821 |
| | | {Value and lifestyle fit} | 0.086 | 1.581 |
| | | {Value and social support} | 0.072 | 1.093 |
| Initial use[30] | Male | {Value and lifestyle fit} | 0.059 | 4.071 |
| Continued use | Male | {Value and lifestyle fit} | 0.082 | 2.353 |
| | Female | {Value and emotion} | 0.059 | 2.400 |

#### 4.4.4.3. Comparison between decision stages

The associations among the adoption factors were also compared between the three decision stages – purchase, initial use, and continued use. The comparison was conducted to investigate if the underlying structure or the co-occurrence factors among the adoption factors differ between the different stages of adoption and use. Table 43 summarizes the result of factor analysis conducted on responses around the perceived importance of the adoption factors at the three decision stages. For this part of analysis, respondents were not separated into different groups.

**Table 43. Association between adoption factors at different decision stages: all age groups combined**

| Decision stage | Factor no. | Included variables[31] | Eigenvalue (initial) | Eigenvalue (rotated) | % of variance | Cumul-ative % |
|---|---|---|---|---|---|---|
| Purchase | 1 | Service trust, technical support, affordability, lifestyle fit, usability, value, confidence, accessibility, system reliability, interoperability, experience | 5.695 | 4.151 | 27.671 | 27.671 |
| | 2 | Independence, social support, emotion, conceptual fit | 1.582 | 2.008 | 13.384 | 41.056 |
| Initial use | 1 | Service trust, technical support, lifestyle fit, interoperability, system reliability, conceptual fit, confidence | 6.107 | 2.977 | 19.850 | 19.850 |
| | 2 | Affordability, usability, accessibility, value, experience | 1.493 | 2.185 | 14.567 | 34.417 |
| | 3 | Independence, social support, emotion | 1.043 | 1.936 | 12.904 | 47.321 |

[30] No association rules with a lift ratio over 1 were generated for the female respondents at the initial use stage.

[31] The variables are ordered in the order of association with the respective factor. The variable that has the highest association with the factor is listed first.

| | | | | | | |
|---|---|---|---|---|---|---|
| Continued use | 1 | Service trust, system reliability, technical support, lifestyle fit, interoperability, conceptual fit, confidence, emotion | 7.092 | 3.369 | 22.458 | 22.458 |
| | 2 | Usability, affordability, accessibility, value | 1.396 | 2.769 | 18.457 | 40.914 |
| | 3 | Independence, social support, experience | 1.011 | 2.059 | 13.727 | 54.642 |

According to the result of the factor analysis summarized in Table 43, it can be seen that the associations between the adoption factors did not differ largely between the three decision stages. At all three stages, usability, affordability, accessibility, and value were grouped together. Similarly, independence and social support were grouped together at all stages. Only small differences were found between the three stages. While independence and social support were also associated with emotion during the first two stages, they were tied instead with experience at the continued use stage. Also, during the purchase stage, most of the adoption factors were tied together in multiple ways rather than separated into smaller variable groups.

The responses to the open-ended questions around thoughts and experiences at the three decision stages were analyzed using association rules analysis. Table 44 summarizes the result of association rules analysis for the three decision stages. Respondents were not separated into different groups.

**Table 44. Co-occurrence patterns among adoption factors in open responses: all age groups combined**

| Decision stage | Association rule | Support | Lift |
|---|---|---|---|
| Purchase | {Social support and emotion} | 0.0458 | 2.9426 |
| | {Usability and affordability} | 0.0475 | 1.9164 |
| Initial use | {Value and lifestyle fit} | 0.0393 | 3.5731 |
| | {Social support and emotion} | 0.0327 | 3.2397 |
| | {Value and emotion} | 0.0327 | 2.6145 |
| Continued use | {Value and lifestyle fit} | 0.0589 | 2.3338 |
| | {Value and emotion} | 0.0442 | 1.9616 |

As shown in Table 44, only few rules were generated for the three different stages. Also, the support values for the rules were low, mostly below 0.05, meaning that the rules were only found in a handful of responses. While the rules summarized in Table 44 were not widely found in the dataset, few findings can be discussed. When compared between the three stages, it can be seen that the associations between the adoption factors were similar between the initial use stage and the continued use stage, while more different at the purchase stage. In both the initial use stage and the continued use stage, comments around value were often mentioned together with stories around emotional benefits or lifestyle compatibility. On the other hand, for the purchase stage, no significant rules were found around value. The rules generated for the purchase stage found that social support and emotion were mentioned together often, while comments around usability were often tied with thoughts around affordability.

### 4.4.5. Interaction effects

In the previous sections, the results have been compared between responses from participants of various individual characteristics, including age, gender, income, prior experiences of technology use, and other descriptions of living situation. The results from the comparative analyses suggest possible interaction effects between the individual characteristics. In section 4.4.1, the negative correlations between age and experiences with various types of technology have been found. The interaction effect between age and prior experience is likely to have contributed to the positive correlations between perceived importance of many adoption factors and experience. Also, age may have also affected the differences in the perceived importance of the adoption factors between respondents who have recently made a new technology acquisition and those who have not.

In addition to experience, many variables that describe people's living situations and life events can be described as closely associated with the age of the respondents. For example, as shown in Appendix 8, it was found that whether people live with children under the age of 13 accounted for differences in the perceived importance of many adoption factors. However, it is unlikely that the difference is solely due to the household composition but rather affected by age, as the majority of respondents who have young children belonged to the younger age group. Age may have interaction effects with other variables as well. Out of 159 respondents who reported themselves as living alone, 73 were 60 years of age or older. In other words, about half of those who contributed to results describing perceptions and thoughts of people living alone were older adults. Also, of the 210 respondents who identified themselves as currently employed, only 37 were 60 years of age or older, while the majority of the group belonged to the younger or middle-aged groups.

Based on such observations, one can intuitively suggest that possible associations between age, experience, and living situations contribute partly to the difference in perceived importance of the adoption factors. In order to analyze whether the living situation variables and the age of respondents are statistically associated with each other, Pearson's chi-squared test was conducted. Table 45 summarizes the result of the Pearson's chi-square test.

**Table 45. Frequency analysis for interaction effects between age, recent adoption experience and living situation variables**

| Living situation | | Younger (20~39) | Middle (40~59) | Older (60+) | p-value |
|---|---|---|---|---|---|
| Recently bought or started using a technology* | Yes | 140 | 107 | 64 | 0.000 |
| | No | 46 | 91 | 129 | |
| Live alone* | Yes | 39 | 47 | 73 | 0.000 |
| | No | 163 | 157 | 130 | |
| Live with spouse/partner | Yes | 99 | 117 | 107 | 0.241 |
| | No | 103 | 87 | 96 | |
| Live with friend(s)/roommates(s)* | Yes | 18 | 7 | 7 | 0.017 |
| | No | 184 | 197 | 196 | |
| Live with child(ren) 12 years of age or younger* | Yes | 62 | 24 | 3 | 0.000 |
| | No | 140 | 180 | 200 | |
| Live with child(ren) between ages 13~18* | Yes | 16 | 46 | 3 | 0.000 |
| | No | 186 | 158 | 200 | |
| Live with child(ren) 19 years of age or older* | Yes | 0 | 29 | 24 | 0.000 |
| | No | 202 | 175 | 179 | |
| Live with parent(s) 64 years of age or younger | Yes | 35 | 1 | 1 | 0.000 |
| | No | 167 | 203 | 202 | |
| Live with my parent(s) 65 years of age or older* | Yes | 7 | 14 | 2 | 0.008 |
| | No | 195 | 190 | 201 | |
| Employed (part-time or full-time)* | Yes | 89 | 84 | 37 | 0.000 |
| | No | 113 | 120 | 166 | |
| Retired* | Yes | 0 | 22 | 132 | 0.000 |
| | No | 202 | 182 | 71 | |
| Have regular income* | Yes | 88 | 107 | 137 | 0.000 |
| | No | 114 | 97 | 66 | |
| In school (part-time or full-time) * | Yes | 34 | 12 | 1 | 0.000 |
| | No | 168 | 192 | 202 | |
| Have a child or family member in school* | Yes | 44 | 44 | 14 | 0.000 |
| | No | 158 | 160 | 189 | |
| Have moved during the last 3 years* | Yes | 66 | 29 | 26 | 0.000 |
| | No | 136 | 175 | 177 | |
| Plan to move during the next 3 years* | Yes | 58 | 33 | 28 | 0.000 |
| | No | 144 | 171 | 175 | |
| Had a change in family over the last 3 years | Yes | 41 | 32 | 28 | 0.194 |
| | No | 161 | 172 | 175 | |
| Expect a change in family over the next 3 years* | Yes | 38 | 22 | 17 | 0.004 |
| | No | 164 | 182 | 186 | |

*: Hypothesis on independence of two variables – age and living situation – rejected at α=0.05

From the test of independence, it was found that various variables that describe one's living situation and life events – including living alone, living with a child or children under the age of 13 and between ages of 13 and 18, having a family member in school, being employed, and having a regular source of income – were significantly associated with the age group in which the respondents belonged to. The number of people who had recently bought or started using a new technology also differed significantly between the three age groups. While the direction of any causal effect between age and living situations cannot be stated from the data, it can be suggested that differences in perceptions around various adoption factors may not be solely due to one's age or living situations, but rather affected by a combination of the two. Alternatively, it can also be suggested that people's age and living situations may have mediating roles, rather than having direct effects on technology experience and adoption decisions.

### 4.4.6. Close-ended vs. open-ended responses

In most parts, big differences were found between the results found from analysis of closed-ended responses to the multiple-choice questions and the findings generated from investigation of open-ended responses around thoughts and experiences related to technology adoption and use. From the analysis on the overall and relative importance of the adoption factors, the results on the most important or influential factors differed between the responses from the multiple-choice questions and the open-ended questions. The mean comparison analysis on the responses to the multiple-choice questions found value, affordability, usability, and service trust to be perceived as more important compared to other factors, and identified that social support, independence, and emotion were rated as unimportant. However, the frequency analysis on the data coded from the open-ended responses found that social support and emotion were mentioned more often than many other factors as participants talked about their experiences. The results from the analysis on the associations between factors also differed between the numerical and open-ended responses to some degree. Based on the factor analysis on the close-ended responses, it was found that usability, affordability, accessibility, and value may be closely related, while independence, social support and experience are associated. On the other hand, the association rules analysis on the data coded from the open-ended responses found the following pairs of adoption factors to be frequently mentioned together – value and lifestyle, usability and affordability, and emotion and social support. Also, based on the open responses, value was found to be associated more closely with lifestyle fit, emotion, and social support rather than usability or accessibility.

There are several possible causes that could explain the differences between results generated from the two types of data. First, the differences may have been due to the differences between the question boundaries and frames. During the multiple-choice questions, respondents were asked to answer them based on their thoughts and experiences related to technologies in general. On the other hand, during the open-ended section of the questionnaire, respondents were asked to pick a specific technology and write about their thoughts and experiences. It is possible that respondents may be thought about different domains and types of technology as they answered the two different types of questions. This explanation also suggests that the relative importance of the adoption factors and their associations may differ across various types of technology.

Another possible reason for the differences can be identified as differences in wording and phrasing of the questions. In the multiple-choice section, question statements for emotion, independence, and social support were written as "if using a technology would make me happier," "how I would look to others if they see me using a technology," and "the things that people around me say about a technology," respectively. While the statements have been revised through the cognitive interviews and the pilot field study, it is possible that the statements still do not accurately describe the respective factors. For emotion, the word "happier" may have not correctly captured the breadth of related feelings, which can include enjoyment, comfort, social belonging, entertainment, and more. For the factors independence and social support, the respondents may have perceived the question statements as negative or something that they are not willing to admit. That is, the combined effects of inappropriate wording and respondent attitudes may have contributed to the low scores found for these factors, while they were actually mentioned quite frequently among the open-ended responses.

Lastly, the differences between the results generated from the two types of data may have come about from patterns in which people remember and forget past experiences. The average scores calculated from the answers to the multiple-choice questions on perceived importance were significantly higher than the neutral point for service trust, conceptual fit, system reliability, confidence, interoperability, technical support, and accessibility. However, these factors were less frequently mentioned, in comparison to other factors, among the open-ended responses. A possible explanation is that the thoughts and experiences people had around these factors may be more difficult to recall or more easily forgotten. Also, it may be the case that these factors are considered less consciously than other factors including value, affordability, and social support, which may be more explicit. Possible differences between the adoption factors in terms of the related cognitive processes and memory effect can be suggested as a topic to be investigated in future research.

Possible advantages and usefulness of using open-ended questions in surveys, along with the characteristics in which they differ from close-ended questions, have been discussed in existing literature as discussed previously in section 4.2.1. It has been suggested in the literature that open-ended questions may be able to capture a broader or a more appropriate set of possible answers, as well as the related reasoning and narratives (Fowler, 1995; Shuman and Presser, 1996). In this survey, only a few comments were found to mention factors that were not included in the original set of 15 adoption factors identified based on literature review and user interviews. In these comments, respondents have mentioned that their thoughts and experiences around adoption and use of technology at various stages were affected also by curiosity, style, and the perceived degree of innovativeness. However, the frequencies of comments around these factors were very low. Also, it has been suggested that open-ended questions may be less affected by social desirability or biases compared to close-ended questions (Converse and Presser, 1986). In this study, a possible effect of social desirability have caused the low average scores for the perceived importance of independence and social support that were gathered from the multiple-choice questions. The large numbers of comments around these two factors gathered from the open-ended questions may suggest that the difference may have come about from the effect of social desirability.

Collecting survey data using only closed-ended questions or solely relying on open-ended questions may not be sufficient for generating results that are accurate and complete. As shown by the discrepancies between results found from the closed-ended and open-ended responses, it may be useful to employ multiple measures and questions around the topics of interest. In short, the results of this survey study confirm the suggested differences between closed and open approaches to gathering responses and point out a methodological implication around the advantages of using both types of questions for a more comprehensive understanding around possible responses and results.

## 4.5. Summary of the survey study

In this chapter, quantitative and qualitative data from a large-scale survey were analyzed to describe the importance and roles of the 15 technology adoption factors identified earlier in chapter 3. An online survey was conducted with a questionnaire that was designed to gather responses on technology experience and knowledge, demographics, living situations and perceived importance of adoption factors. The questionnaire was evaluated and revised based on two rounds of pre-testing that included cognitive interviews and a pilot field study prior to the full launch. During the full launch of the national survey, responses were collected from a total of 609 adults in the United States, evenly distributed in terms of age, gender, income level, and geographic location.

The survey sought to answer three main research questions around older adults' perceptions, attitudes, and behaviors around adoption and use of technology. A main objective was to assess the overall importance of the adoption factors and to empirically test their validity. The next research question concerned the relative importance of the adoption factors. Lastly, the survey also aimed at describing the underlying structure among the adoption factors with an analysis of their relationships. The related questions were asked with reference to three decision stages of technology adoption and use – purchase, initial use, and continued use.

In the first part, older adults' responses to the multiple-choice questions on the perceived importance of the adoption factors were analyzed using a t-test procedure. As a result, it was found that the average scores for most of the factors, except for independence and social support, were rated to be significant above the neutral point. In the open-ended responses, however, comments related to independence and social support were found more frequently than a few other factors, including confidence, system reliability, and conceptual fit, which were given higher average scores for the multiple-choice questions. While the result from the multiple-choice responses suggested that not all factors may be important in older adults' decisions throughout adoption and use of technology, the open-ended responses confirmed that the factors with low average scores still have major influence on their decisions and experiences.

In the second part of analysis, the scores for the perceive importance was compared between the 15 individual adoption factors using ANOVA. As a result, affordability, service trust, usability, value, and system reliability were constantly found to be perceived by the older group as the most important factors throughout the decision stages. On the other hand, social support and independence were ranked as least important, compared to the other factors, at all stages. The open-ended responses were analyzed based on their relative frequency using Pearson's chi-square test of homogeneity. Contrary to the result from the multiple-choice responses, social support was identified as one of the most frequently mentioned factors, along with value, experience and lifestyle fit. In the open-ended responses, fewer comments were mentioned around service trust and system reliability.

Lastly, the associations among the variables were investigated based on the relationships of the scores for the perceived importance of the adoption factors and the frequencies in which multiple factors were mentioned together. Based on the factor analysis conducted on the closed-ended responses from the older group, three main variables groups were identified: (affordability, usability, accessibility, and value), (interoperability, technical support, and system reliability), and (independence, emotion, and social support). From the association rules analysis on the open-ended responses, emotion and social support were found to be frequently mentioned together. However, the analysis of co-occurrence patterns among the open-ended responses showed that value was closely tied with lifestyle fit, emotion, and social support rather than affordability, usability, or accessibility.

Additionally, results were compared between answers from respondents of different individual characteristics. The results from the older group were compared against the younger and the middle-aged group. Similar analyses were also carried out for comparing results between respondent groups separated by gender, income, technology experience, and various characteristics of living situations. While gender and income level were found to account for only slight differences in the results, age, technology experience, and living situations were found to be associated with significant differences on many adoption factors. Table 46 summarizes the individual characteristics that were found to be associated with higher or lower average scores for the adoption factors. It should be noted, however, that the summary in Table 46 is based on a general observation of the overall trend rather than statistical significance, and that it may not hold for all of the adoption factors. Also, as discussed in section 4.4.5, it was found that the variables listed in Table 46 are highly interrelated, which suggests that people's perceptions and attitudes around decisions related to technology adoption may be affected by a combined effect of the related individual characteristics rather than influenced by a sole factor in isolation. Also, in many cases, the score differences were bigger when compared between groups of different living situations and degree of related experiences, while age differences were mostly very small. Thus, it can alternatively suggest that the effect of age may be strongly mediated by other related characteristics as it influences decisions related to technology adoption and use.

**Table 46. Relationships between individual characteristics and average score differences**

| Characteristics related to higher importance scores | Characteristics related to lower importance scores |
|---|---|
| – Higher degree of technology experience and knowledge<br>– Having recently bought or started using a technology<br>– Living with children under 19 years of age<br>– Being employed<br>– Having a regular source of income<br>– Having a family member in school<br>– Planning to move in the near future | – Lower degree of technology experience and knowledge<br>– Not having recently bought or started using a technology<br>– Living alone<br>– Living with parents 65 years of age or older<br>– Being older (not for usability, affordability, accessibility and service trust) |

The results were also compared between the three stages of adoption and use – purchase, initial use, and continued use. Based on an ANOVA for comparison of the average scores, all adoption factors were found to be perceived most important during the purchase stage and least important during continued use. However, when analyzed based on the number of related open-ended responses, it was found that some factors were mentioned more frequently around the initial use stage or the continued use stage, suggesting that the relative importance of the adoption factors may differ depending on the types and timeframe of decisions that people are involved in. Also, while only small differences were found between the decision stages when analyzed for the association between the adoption factors, it was suggested that various factors may be interrelated in more complex ways during the purchase stage compared to the following decision timeframes.

While this study sought to comprehensively analyze the importance and roles of the adoption factors with a large sample using a set of pre-tested measures, several issues around internal and external validity can still be identified. First, one may question the measurement validity of the questionnaire. Measurement validity is concerned with the alignment between the observations and the concepts originally intended to be covered (Adcock and Collier, 2001). More specifically, the degree to which the indicators and questions represent the concepts being measured, or content validity, can be an area of concern. As discussed earlier in section 4.4.5, the question statements for emotion may not have sufficiently described the breadth of the entailed concepts. The results can be also questioned on its contextual specificity in that the interpretation of the same score may be different if they it was generated in different contexts (Adcock and Collier, 2001). More specifically, the results may be interpreted differently if they were based on responses collected from an offline sample, or if the sample was collected from a specific group of people who have experience with a particular type of technology. Furthermore, the results generated from the data are prone to multiple sources of selection bias that may limit the external validity. First, the survey was administered online. According to a recent report, it was found that 15% of American adults do not use the Internet at all. The percentage of those who are not online was higher among the older population, with 44% of older adults 65 years of age or older not using the Internet or e-mail (Zickuhr, 2013). Because the survey was administered online, the result only reflect the perceptions, attitudes and experiences of people who are online, and may not be generalizable to the thoughts and behaviors of people who do not go online. Another significant source of selection bias is that the survey answered by people who are included in the Qualtrics Panel. The sample includes people who have volunteered to be included in the panel and have decided to participate in the survey. Thus, there are layers of self-selection that may limit the generalizability of the findings.

Several practical implications can be discussed based on the results of the survey study. First, it can be seen that the discrepancies between age groups, in terms of the importance and roles of the adoption factors, are very small. While traditional beliefs described older adults as a unique population with special needs and expectations, this study found that their perceptions and thoughts around various characteristics and qualities of technology actually don’t differ much from younger people. As suggested by Panagos (2003), older users and consumers sometimes have unique needs, but not as many as one might assume, as they tend to follow purchase patterns established in their 20’s and 30’s. Another managerial implication can be discussed based on the effects of various individual characteristics on the score differences. It was found that differences in perceptions around the adoption factors may be more strongly associated with people's experiences with technology and characteristics of living arrangements. This conclusion suggests that it may be more effective to define and describe the target market and user characteristics based on lifestyle characteristics and related experiences or knowledge rather than demographics when designing, developing, and distributing technology-enabled products or services to older (and younger) adults. Lastly, it was suggested, mainly from the open-ended responses, that people may base their decisions on different adoption factors or technology qualities at different stages of adoption and use. The related results can inform practitioners for planning and designing effective distribution strategies, pricing structures, and service models. For example, the average score for the importance of affordability was much higher for the purchase stage compared to the later stages, while service trust and usability emerged as the most importance factors for the initial use and continued use stages. Such result can inform businesses to potentially alleviate consumer burden of high initial costs by introducing a subscription pricing or by offering financing plans, and to emphasize the reliability or related services after purchase throughout continued use.

In addition to the managerial implications, several research implications can be discussed. First, it was found that respondents, especially the older group, were less experienced with health management technologies, home security systems, and transportation technologies compared to other types. Thus, respondents may have answered the questionnaire based on their experiences and knowledge around technologies that they are familiar with. In other words, it may be the case that the responses better describe people's perceptions and attitudes toward mobile devices, social networking services, and office technology, rather than covering a wider breadth of technology systems that are available. For the results to be more generalizable, the survey method and the questionnaire can be replicated for various types of technology. Future research on a comparison of the results between different technology types or domains can be expected to generate findings that can directly inform various industries with implications specifically tailored to them. On a related note, it was found that older adults on average have little to no experience with health management systems, which may suggest a need for more research on current practices around design and distribution of the technology type to identify areas of improvement and to discuss general design implications. Also, as discussed earlier in section 4.4.6, the large differences between results from the closed-ended and open-ended responses suggest a need for employing multiple measurements and approaches when collecting survey data around subjective perceptions and attitudes. Rather than relying on a single type of data, an integration of results gathered from multiple approaches can be less susceptible to social biases and more effective for a comprehensive understanding.

# 5. Phase 3: Analysis of technology adoption factors based on industry and research practices

The effects of various factors on the perceptions and behaviors around technology adoption have mainly been studied with a focus on the consumer and user side. While the issues around technology adoption have important implications for the design, development, and delivery of technology-enabled products and systems, the development practices have been considered as a separate research topic.

As discussed earlier, the factors that influence consumer decisions around technology adoption can be understood as a set of design goals or product qualities. That is, the findings around the adoption factors need to be transferred to and integrated with an understanding of the practices with which technologies are designed and developed. However, research around the process of product design and development has been limited in that the rate and patterns of adoption by the consumers and users have not been fully considered together.

Furthermore, the existing frameworks and process models are usually built around the cases in which products are made for the general population. That is, the processes and activities described in existing frameworks may be more appropriate when the target groups are easily accessible or relatable. It can be argued that the established models may not be readily applicable for technology-enabled products and systems targeted at older adults. Thus, the issues around the applicability and adaptability of the existing frameworks also need to be considered.

In order to address the research gaps, a set of case have been studied. During the case study, a research example and two industry cases were surveyed to understand and describe the main design activities, the decisions around the adoption factors, and the ways in which older adults were involved during the development processes. This chapter presents a detailed description of the selected cases and the methods of data collection. Also, the main findings, including an outline of the overall design processes and the mapping of the adoption factors, and implications are discussed.

## 5.1. Questions and objectives

Case study is a research method that consists of a detailed investigation of phenomena within their context (Hartley, 2004). It can be used for generating implications for research and practice based on an examination of the processes, methods, dynamics, and decisions involved in an event, an organization, a project, or a system. It can serve as a learning tool where real stories are analyzed for general insights (Flyvbjerg, 2006).

In this study, real-world cases were studied to understand how existing technologies are designed, developed, and distributed to older adults in practice. The descriptions of the adoption factors and the related discussion around implications, presented earlier in chapter 3, suggested the need for a detailed analysis on the decisions and activities with which technologies for older adults are designed and delivered. Based on the descriptions summarized from the literature review and user interviews, section 3.4 has discussed a few implications for practice and suggested a research agenda around an investigation of current practices in relation to the adoption factors.

The case study sought to identify and describe how the adoption factors are considered in practice. It was discussed earlier that the adoption factors can act as design goals and a set of actions for development, and that they should be fully considered during design processes to make technologies more valuable and appealing. Thus, the case study aimed at identifying when, or during which design stages, the various adoption factors are consciously or unknowingly considered. Also, a related goal was to describe the ways or methods in which the adoption factors are addressed in practice.

A main conclusion that was made from the descriptions for the adoption factors was the importance of user involvement. The findings suggested the need for involving older adults deeply throughout the design processes, rather than simply asking questions or relying on assumptions. Thus, the case studies aimed at identifying and describing the methods which practitioners use to collect inputs from older adults and to address the findings in design. Since continuous user involvement throughout various stages of design was emphasized, the case study also sought to describe when, or during which design stage, the potential older users are involved.

The overall objective of the case study was to describe the key decisions around the adoption factors and activities of user involvement that are carried out during design, development, and delivery of technologies targeted at older adults. With a survey of selected cases, this study sought to model a process framework that describe the design stages, main decision points, and important activities from planning and concept development to production and post-purchase activities. Also, the current practices were asssessed to identify adoption factors and design qualities that are not fully considered and to discuss potential areas for improvement.

## 5.2. Case selection

A total of three cases were surveyed to describe the design activities and processes, and to understand how the adoption factors are considered in practice. This section describes the criteria in which the case selection was based on. Also, the three cases – e-Home for Seniors project by the MIT AgeLab, MISTY by Parental Health, and PARO by AIST – are described with their main technical features and service characteristics.

### 5.2.1. Selection criteria

Strategies for selection of cases can largely be categorized into two types – random selection and information-oriented selection. Random selection is often used when it is important to avoid systematic biases by collecting a statistically representative sample. On the other hand, information-oriented selection is used when the objective is to achieve the greatest possible amount of information on a given problem or phenomenon (Flyvbjerg, 2006). In this study, cases were selected with an information-oriented selection strategy rather than a random selection approach to maximize the utility of information from a small sample. Decisions around case selection were carried out based on the information contents the cases are expected to contain. Several requirements were outlined as criteria for selection of cases.

A major requirement for the case selection was to include technology-enabled products that aim at fulfilling essential needs of the older population. It has been discussed that one of the most prominent needs of older adults is captured in the idea of aging-in-place. As described earlier in section 2.2.2, technology-enabled solutions developed to enable and help older adults age in place have three common characteristics. First, they aim to serve assistive roles, mainly in managing health, wellness, and daily activities. Second, many aging-in-place technologies are designed as product-service systems, with the service and value creation emphasized rather than focusing solely on the physical product. Lastly, they are mostly designed for use in the home environment, which is where older adults' activities mostly take place as they age in place. Following these key characteristics identified in literature, the case selection aimed at finding technologies for older adults that serve assistive purposes at the home environment with a focus on providing benefits with a service component.

More specifically, among various types of assistive technologies for older adults, those that support compliance in health management or promote personal wellness were selected. As discussed in Dishman (2004), aging-in-place technologies that provide assistance in maintaining wellness and independence were suggested to be effective and sustainable, but less known compared to clinic-oriented technologies for reacting to crisis or treating diseases. Also, as presented earlier in section 4.4.4, it was found from the survey that older adults are not familiar with health management and assistive technologies. While many consumer technologies for health are developed for older population, the level of experience and knowledge was significantly lower among the target population compared to younger generations. Also, in the open-ended portion of the survey, participants who chose to talk about health technologies discussed their thoughts and experiences around basic, clinical systems such as glucose meters, and fitness applications. No discussions were formed around medication management systems, emergency response systems, or behavior monitoring technologies, although they have been studied in related fields extensively. Thus, an additional criterion was defined as technology-enabled wellness support systems targeted at older adults, as this was identified as an area that presents a significant gap that needs to be better understood.

Another requirement around selection of cases was to include both hardware systems and software systems. In a study that involved a comparison between hardware and software development, the two were found to differ in various dimensions including manufacturing practices, managerial imperatives, critical roles of the design teams, techniques and methods for design, and measures of effectiveness for evaluating design processes and outcomes (Hauptman, 1990). Due to the possible differences in design activities and managerial decisions, it was decided that studying only hardware or software would not be sufficient for gathering a complete understanding around development practices.

### 5.2.2. Description of selected cases

A multiple-cases approach was chosen over a single-case approach for its robustness and analytical power, as suggested by Yin (2009). Also, it was chosen as a single-case study design is appropriate when a phenomenon represents a critical, extreme, or revelatory case, while a multiple-case design allows cross-case analysis and investigation to strengthen research findings (Darke et al., 1998).

Based on the criteria and requirements described in the previous section, three systems were selected for the case study. This section provides detailed descriptions for the three cases, including the product characteristics and technical features. Table 47 shows a summary of the descriptions.

**Table 47. Characteristics of selected cases**

| Product | Company/organization | Main component | Specific application domains |
|---|---|---|---|
| e-Home for Seniors | MIT AgeLab | Hardware and software | − Medication management<br>− Online social communications<br>− Informal caregiving |

| | | | |
|---|---|---|---|
| PARO | AIST (National Institute of Advanced Industrial Science and Technology in Japan) | Hardware | − Dementia care and management<br>− Emotional support and therapy<br>− Formal and informal caregiving |
| MISTY | Parental Health | Software | − Health and medication management<br>− Connection with family and community<br>− Formal and informal caregiving<br>− Management of daily activities |

### 5.2.2.1. Case 1: e-Home for Seniors

The e-Home system is a research project that was carried out by the MIT AgeLab in collaboration with NTT (Nippon Telegraph and Telephone) Corporation. In the e-Home project, the two organizations partnered to find opportunities with which they can combine expertise, skills, and available technologies to create a useful application. The MIT AgeLab, established in 1999, conducts studies that involve translating new ideas and technologies to the design of practical solutions that promote health, wellness, activities, and productivity throughout the lifespan. In the MIT AgeLab, research projects are conducted with various methods including human experiments, social science methods, and field studies around topics related to older adults' living and working environments. NTT is a telecommunications company headquartered in Tokyo, Japan. It is the largest telecommunications company in the world in terms of revenue[32], and its assets were valued at a total of about 19.389 trillion yen as of 2012. The NTT Corporation and its subsidiaries provide services around telephone communications, internet, digital television, data and information security, and system integration. The company is also involved in various research activities around creating new communication services, developing infrastructure for network technologies, and creating concepts for future innovations[33]. In the e-Home project, the Service Evolution Laboratories of the Service Innovation Laboratory Group at NTT, which aims at creating innovative services with information and communications technologies, was mainly involved[34].

The e-Home system includes a hardware device and a software component. The software operates on any PCs with a Microsoft Windows operating system, and includes applications for scheduling medications, tracking compliance, exchanging notes with family, and videoconferencing. The hardware component detects medications and measures the amount of pills taken. The hardware part is made of an RFID

[32] Nippon Telegraph and Telephone, http://en.wikipedia.org/wiki/NTT

[33] R&D organizations at NTT, http://www.ntt.co.jp//RD/OFIS/organization/lab_en.html

[34] NTT Service Innovation Laboratory Group, http://www.ntt.co.jp/svlab/e/about/

tracking system and a scale, and works with the software component with a PC connection that uses USB cables. The e-Home system is shown in Figure 22.

**Figure 22. e-Home system**


The e-Home for Seniors study is an example of designing, prototyping, and evaluating products targeted at meeting older users' needs. The e-Home study was conducted as a process where potential users were deeply involved in generating, designing, prototyping, and evaluating an aging-in-place solution. The user participation approach was employed to minimize the gap between designers and users by better translating the user inputs into product functions and design features. The main functions of the system, which included managing medication compliance and enhancing remote communication with family, were selected and defined based on inputs from potential users. The detail design and revisions were decided with consideration of user feedback as well. The project started in April, 2010 with a planning phase, and the field evaluations ended in May, 2011. The e-Home project was completed as a research project and did not include the mass production and launch stages.

#### 5.2.2.2. Case 2: MISTY by Parental Health

Parental Health was founded in 2009 with the motivation to leverage the power of technology to address various needs of the healthcare system that arise with the aging of the population. The company is located in Nashville, Tennessee, and its leadership team is formed of people with expertise and experiences in healthcare systems, technology development, management, and sales.

MISTY (Medical Information System To You) is an integrated software platform that includes various applications for managing and supporting the needs of older adults, as well as their caregivers and family members. It includes tools that address challenges facing older adults and their caregivers, including management of chronic conditions and medication intake, monitoring daily activities, and preventing issues related to isolation. Table 48 summarizes the nine key features included in MISTY. The home screen of the MISTY software is shown in Figure 23.

**Table 48. MISTY's key features[35]**

| Feature | Description |
|---|---|
| Health monitor | Self-monitoring and management of chronic conditions using standard measurement devices |
| Pill box | Medication management and tracking |
| Personal health record | Managing personal health records and sharing them with caregivers and healthcare providers |
| Daily activities | Monitoring activities of daily living and sharing them with caregivers, family members and home health agencies |
| Emergency | Assistance in emergency situations with video-enhanced emergency calls |
| Supplies and services | Assistance in selecting and ordering medical supplies and groceries |
| Family connect | Communication tools including texting, e-mails and videoconferencing for prevention of social isolation and the associated depression |
| Family legacy | Video-based tool for recording life stories or events and sharing them with family members |
| Community connect | Links to communities important to older adults to keep them socially connected |

**Figure 23. MISTY software[36]**


[35] MISTY system benefits, http://parentalhealth.com/Benefits

[36] Image source: http://parentalhealth.com/

#### 5.2.2.3. Case 3: PARO

PARO is an interactive assistive robot developed to deliver therapeutic benefits to older adults. PARO was developed to provide effects that can be delivered with animal therapy. It has been suggested that interacting and bonding with animals and pets can bring psychological, physiological, and social benefits (Baun et al. 1984; Beck and Meyers, 1996). PARO is positioned as an alternative form of animal therapy that can bring the intended benefits while preventing possible risks and challenges related to interacting with animals, such as allergies, infections, injuries, and tasks related to taking care of a life.

PARO was designed in a form of a baby harp seal with a layer of antibacterial fur, and has the size and weight similar to those of a human baby. Its exteriors are designed to be soft and warm to touch, without any metallic feel, as shown in Figure 24. Several different types of sensors are included to enable visual, auditory, and motion-enabled interactions between PARO and its users. It also has microchips that provide computing and processing power, enabling it to learn a new name and favorable behaviors (Shibata, 2012).

**Figure 24. Therapeutic robot PARO**

The development of PARO began in 1993, and it was first commercialized in Japan in 2005. The design and technical features have evolved since it was first introduced, and the eighth version is currently being sold. PARO is also available in the United States and many European countries including Denmark, Germany, and Austria. PARO is sold as an assistive medical device, and has been approved and certified by the United States Food and Drug Administration (FDA), the European Restriction of Hazardous Substances Directive (RoHS) regulations and the Conformité Européenne (CE; European Conformity) mark (Shibata, 2012).

## 5.3. Data collection

Multiple methods of inquiry and data sources were used to collect and gather case evidence. As described in Yin (2009), common sources of case study evidence include documentation, archival records, interviews, direct observations, participant observations, and physical artifacts. Since the development of all three cases have been completed, it was not possible to employ the method of direct observation, which is suited for cases that are not purely historical and happening real-time. In this study, various methods of data collection were used to enable triangulation of evidence and to provide stronger substantiation of constructs to which potential results can be grounded upon, as suggested by Eisenhardt (1989). Interviews were used as the main source of data and evidence along with documentations. Participant observation, study of physical artifacts, and survey of archival records were also carried out when applicable and accessible.

### 5.3.1. Interviews

Interviews have been described as one of the most important and widely used method of collecting case study information. In Yin (2009), the strengths of interviews as a source of case evidence have been discussed, along with potential weaknesses. Interviews are effective in they can be targeted with questions that focus directly on the topics of interest and tailored to specific contexts or circumstances. Also, interviews can provide insights into explaining causal events based on the perceptions and memories of the informants. However, the method relies on the responses provided by the informants, therefore being subject to biases, poor recall, and inaccuracies. An additional problem that can be associated with interviews is reflexivity, which refers to situations in which an interviewee gives what the interviewer presumably wants to hear. While interviews were used as the primary source of case evidence in this study, the responses were corroborated against other sources, such as documentations, to ensure accuracy and exactness of information.

During the case studies, in-depth interviews were conducted with key informants who have been deeply involved in the design and development processes of the selected cases, and thus have knowledge of the related activities and decisions. For the e-Home for Seniors case, the research team at the MIT AgeLab, including a researcher who was originally from the NTT Service Evolution Laboratories, were interviewed in person and via electronic communications. For MISTY, the leadership team at Parental Health, including the CEO and CTO, were interviewed over the phone. For PARO, the creator was interviewed in person.

The interviews were conducted as semi-structured conversations. A number of questions around the research objective, presented earlier in 5.1, were prepared in advance as a guide to the interviews. The questions were designed to investigate the following topics related to the research objectives.

- Development timeline and stages
- Activities during concept generation and selection
- Decisions related to overall and detailed system design
- Methods of system evaluation and testing
- Distribution strategies: channels for reaching target market
- Activities related to user/customer involvement
- Reflections and thoughts about the adoption factors

The interviews included three types of questions – main questions, follow-up questions, and probes – as described in Rubin and Rubin (2012). Discussions around each separate topic began with a main question that was written out in advance. During the conversations, follow-up questions were asked to gather detailed in-depth information and to find out more about related concepts or events. While some follow-up questions were prepared in advance, many of them were asked as necessary during the interviews. Probes were used to help manage the interviews. For this purpose, simple questions and comments were used to keep the informant talking on important matters, to keep the conversation on topic, and to clarify earlier responses. The questions prepared for the interviews, including all of the main questions and some follow-up questions, are shown in Table 49.

**Table 49. Case study interview questions**

| Interview topic | Questions |
|---|---|
| System description | - Please provide an overall description of (PRODUCT).<br>- What are the key functions offered by (PRODUCT)?<br>- How do you anticipate (PRODUCT) to be used by potential users? |
| Development timeline | - How long did it take to design, develop, manufacture and launch (PRODUCT)?<br>- How would you describe the key stages of (PRODUCT)'s development process? |
| Concept selection | - How was the concept of (PRODUCT) developed? Please describe the process as you recall.<br>- Were there any alternative concepts you have considered?<br>- With what criteria did you evaluate potential concepts during the selection process |
| System design | - Please describe the overall system architecture of (PRODUCT).<br>- What are the key features of (PRODUCT)'s detailed design?<br>- How did you decide on the detailed design and product specifications? |

| | |
|---|---|
| System evaluation and testing | – During the development process, was (PRODUCT) tested before launch? If so, during what stage was the evaluation done?<br>– What methods did you use for evaluation and testing?<br>– Did the results of evaluation feedback into the design and development of (PRODUCT)? If so, how? |
| Distribution strategies | – How did you plan to reach the target customers and users?<br>– Through what channels was (PRODUCT) advertised?<br>– What are the key strategies and methods you used for distributing (PRODUCT)? |
| Customer and user involvement | – Were your potential customers and users involved in any during the design and development of (PRODUCT) before launch? If so, during what stages were they involved?<br>– Please describe the types of customers and users involved during development.<br>– What methods did you use to gather customer and user inputs?<br>– What did you find out from the customer and user involvement processes? |
| Consideration of technology adoption factors | – It has been discussed that a number of different factors affect and determine how individuals adopt and use technology. How do you see them relevant to (PRODUCT)'s development objectives? Did you consider such factors when you were deciding on the key product features?<br>– How do you see them relevant to (PRODUCT)'s design and development processes? Did you consider such factors when you were deciding on the design specifications?<br>– How do you see them relevant to the distribution and delivery of (PRODUCT)? Did you consider such factors when you were deciding on the distribution strategies and methods? |

The question outline shown in Table 49 was approved by MIT Committee on the Use of Humans as Experimental Subjects (COUHES) prior to conducting the interviews. The leadership team at Parental Health and the creator of PARO were contacted via e-mail and asked for participation. The recruitment e-mail is included in Appendix 10. Also prior to conducting the interviews, all participants were presented with a study description and information regarding disclosure or publication of responses. The details were documented in a consent form, which was also approved by MIT COUHES. All interviewees were asked to review and sign the consent form, and were given a copy to keep. The consent form is included in Appendix 11. The interviews were recorded using a voice recorder with permission of the interviewees.

### 5.3.2. Documentations

Documentations are written records of information. As a source of case evidence, documentations have several strengths. Once collected, documents remain stable and can be viewed repeatedly. They also have the advantages as they contain exact information and specific details, such as names and titles, and because they can cover a long time period and a broad set of events (Yin, 2009).

A variety of documentations were collected for the cases. The types of documentations studied during the case studies included academic publications, news articles, reports from meetings or events, memos, brochures, product or company Web pages, and other written materials. However, documentations, as a source of data, are prone to reporting biases as they are often written and edited by authors and may reflect their views or opinions (Yin, 2009). In order to prevent from producing biased results, multiple documentations from various authors were collected for each case.

### 5.3.3. Archival records

Archival records are files and records that contain information and data that may be relevant (Yin, 2009). In this study, archival records were used as an additional source of evidence for the e-Home case. For the analysis of the e-Home case, data from experiments and surveys were accessed and viewed to gather detailed information around the results of user involvement conducted during the project. Archival records were not used for the two industry cases, MISTY and PARO.

### 5.3.4. Physical artifacts

Physical artifacts are a source of evidence that take a form of a technological device, an instrument, a work of art, or some other tangible structure (Yin, 2009). Although not widely used as an information source in many case studies, physical artifacts were determined to be important in this study as the technical systems and components were central to the research questions and related discussions.

The actual systems were used for studying the e-Home case and the PARO case. In addition to the information gathered from interviews and other sources, an e-Home system and a PARO robot were used to study the actual operations and interactions. For the MISTY case, video demonstrations of the system components were reviewed as the actual software was not available.

### 5.3.5. Participant observation

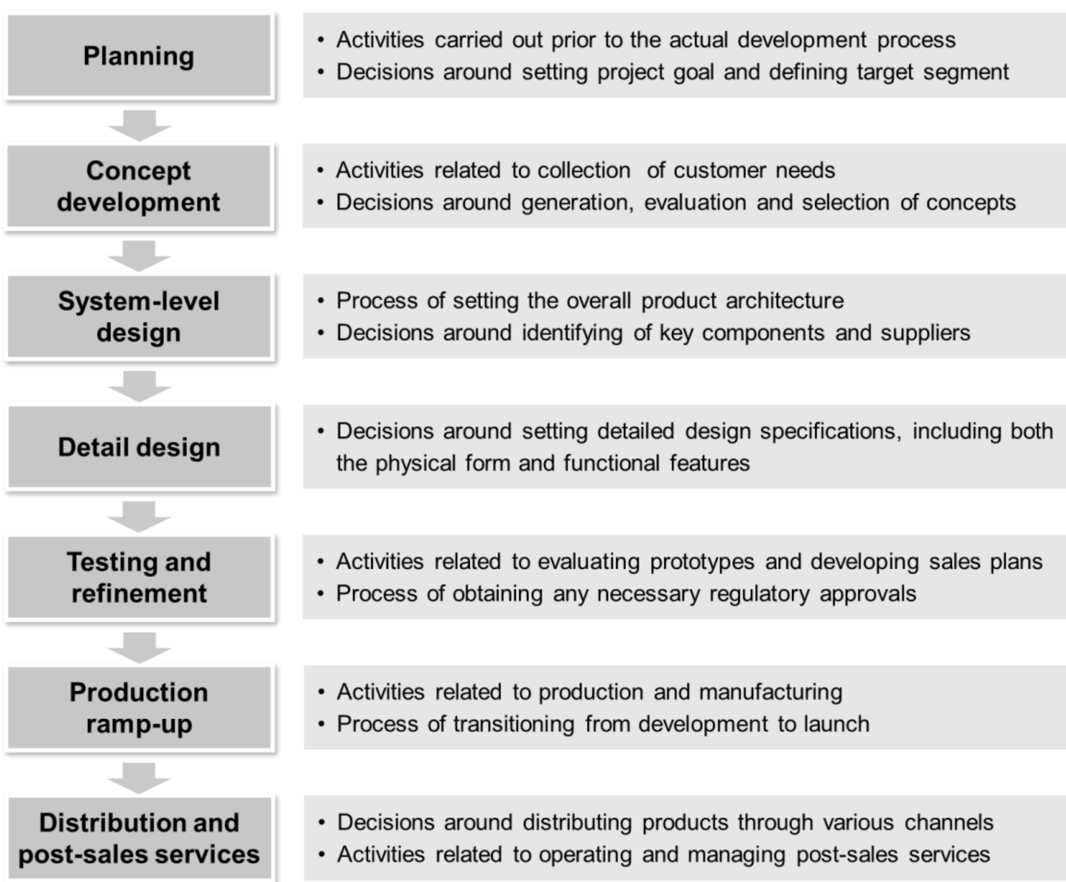
According to Yin (2009), participation observation is a special mode of observation in which the researcher assumes a variety of roles and participates within a case situation that is being study, instead of being a passive observer. Being a member of the research team at the MIT AgeLab, the participation observation technique was possible and applicable for the e-Home case. In the case of the e-Home project, participation observation was used as an additional source of evidence for gathering detailed information around events and activities.

## 5.4. Data analysis

### 5.4.1. Analysis framework

In this study, the three cases are analyzed by mapping the design activities and decisions, including those related to the adoption factors and those that involve user engagement, on to a process framework. As discussed earlier in section 2.1.1.1, various frameworks and models have been suggested to describe the processes of product design and development. While the specific stages and detailed descriptions differ between the frameworks, they commonly include activities around project planning, concept selection, product realization, evaluation, and manufacturing. For the analysis of the three cases, the generic framework suggested by Ulrich and Eppinger (2004), shown in Figure 25, was used as it includes the key elements described in most frameworks, and because it is designed for a general application.

**Figure 25. Process framework for case analysis (modified from Ulrich and Eppinger, 2004)**



The analysis framework also included a distribution and post-sales stage added to the original model by Ulrich and Eppinger (2004). It was discussed in the literature, summarized in chapter 3, and in the comments from the survey, summarized in chapter 4, that activities carried out after production, such as distributing products through various channels and providing technical assistance, are also essential to the discussion around older adults' adoption and use of technology. Thus, the analysis framework was extended to include an additional stage to describe any activities and decisions that took place after production or manufacturing.

### 5.4.2. Content analysis

The analysis of case study is rarely done with any fixed formulas or standard techniques, but often relies on the types of data collected and the styles in which individual investigators conduct research (Yin, 2009). However, while a variety of processes are employed by different researchers, several common features and characteristics can be identified. Previous discussions have described that case study analysis usually begins with getting familiarized with individual cases by developing write-ups, preparing transcripts, and examining the contents of collected data (Eisenhardt, 1989; Yin, 2009). The preliminary step can be followed by activities for organizing data, which may involve tabulating data into different arrays, grouping evidence into meaningful categories, or ordering information using a temporal scheme (Miles and Huberman, 1994). The organized data are then usually analyzed by pattern matching, explanation building, time-series-analysis, logic models, or cross-case synthesis (Yin, 2009).

The examination and organization of case evidence, especially those from interviews or documentations, often follow the techniques and procedures described in a method termed content analysis. As described by Hsieh and Shannon (2005), content analysis is a class of quantitative and qualitative approaches that are used for analyzing and interpreting text data, which may be based on verbal communications, observations, or printed narratives. In practice, content analysis usually involves collecting and recording evidence, operationalizing concepts meaningful to the phenomenon being studies, coding various forms data, and identifying patterns or developing descriptions (Krippendorff, 2004; Hsieh and Shannon, 2005). Furthermore, content analysis aims to make inferences from data and identify implications rather than analyzing only the information manifest in the collected evidence (Mayring, 2000).

The data collected for the three cases were analyzed by following the approaches and techniques described around analysis of case evidence and text data. First, the interviews were transcribed into a readable text format to enable and facilitate further analysis. Then all pieces of text data, including the interview transcripts and other documents, were examined and categorized. The categorization process included coding individual quotes and sentences according to two dimensions – development stage and activity type. The development stage dimension was defined as the modified process development framework shown earlier in Figure 25. The contents of the interview transcripts and documents were categorized according to the specific stage they concern. The other dimension concerned the types of activities or decisions described by the data. The activity types were divided into three categories – user involvement activities, decisions and thoughts related to the adoption factors, and other design activities. In addition to the stages they concern, the contents of the text data were also coded based on the type of activities or decisions they are related to. Contents included in other types of data, including those gathered from archival records, observation of physical artifacts, and participant observation, were also tabulated along these two dimensions when applicable.

After categorization and tabulation have been finished, a full description was developed for each case. The descriptions followed the sequential framework illustrated in Figure 25, along with contents around the related activities and decisions. The development of the single-case descriptions were then followed by a cross-cases analysis. The similarities and differences were compared between the three cases at each development stage and for each type of activities. Any differences were additionally analyzed with development contexts, team characteristics, or technical features that may be related.

## 5.5. Case study results

This section presents the results of the case study, including the overall description of each case, discussion of implications proposed by each case, and a summary and consolidation of the three cases. Each case description is organized by the design stages in the following order - planning, concept development, system-level design, detail design, testing and evaluation, production, and distribution and post-sales activities. For each stage, the main activities and decisions around design, user involvement and the adoption factors are described with evidence from data collected through various sources. Lastly, the cross-cases summary reviews the similarities and differences found between the three cases and discusses insights and implications.

### 5.5.1. Case 1: e-Home for Seniors by MIT AgeLab

The e-Home for Seniors project began with an identification of multiple issues related to aging-in-place. Then, based on interactions with potential users, the concept of a home technology system with medication management and remote communication was selected. The system architecture and detailed features were designed through several iterations that involved evaluation of various technologies and alternative architectures. After prototyping the concept, the system was extensively tested in the laboratory and in the field with potential users. During the long-term field testing, multiple user studies methods were employed for a comprehensive analysis of interactions. User-centered design principles and various related methods were employed early in the development process from the planning and concept development phase, as well as later during the iterative testing phase. This section describes these design and development activities in more detail, along with a discussion on the considerations around the adoption factors. The production ramp-up stage and the post-sales services stage are excluded in this section as the e-Home case was a research project aimed at building and evaluating a prototype rather than a marketable system.

#### 5.5.1.1. Planning

The project started with an examination of the user segment. At this stage, the assessment of general needs and expectations involved a careful survey of prior work. Based on a review of literature and existing research projects, it was found that a considerable amount of work has been conducted in the domain to investigate the possibilities of developing solutions to improve the life of older adults. A variety of existing products and services emerged during the review, including emergency calling, electronic pill cases, and fall monitoring systems. Related studies and products are reviewed from three perspectives – technical, process-oriented, and social. The technical perspective looks that the specific component technologies and their capabilities in existing systems. On the other hand, the process perspective focused on design and development processes and practices. The process-oriented review found that only few studies were based on real users' voices, and that most of the existing systems are only tested in the laboratory environments instead of being tested in realistic settings. Also, it was found that existing systems focused mostly on the technical features and that the social implications and settings were not fully considered. In summary, two main issues were identified with respect to prior work. First, products designed to contribute to satisfaction of older adults have not been particularly successful in the market. Second, products and services proposed as useful in this area have not typically been reviewed to see if they contribute to adding to quality of life in an integrated way. That is, products or processes, in most cases, were proposed and evaluated in isolation while different needs and requirements may be closely related.

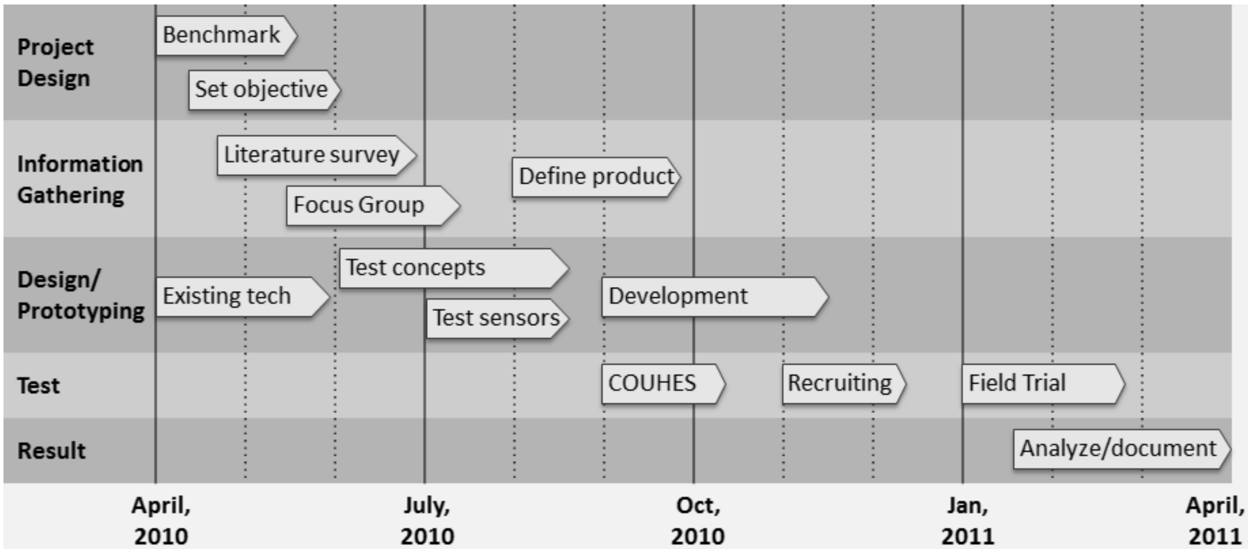
In many cases, older adults have reported consistently that they would prefer to age in place, that is, reside in own homes as long as possible without having to relocate. The ideal way to age in place has been described as living longer confidently, comfortably, and independently in locations and with people that they are familiar with. However, as they are often left alone to deal with life tasks on their own, they often face issues and problems related to isolation, mobility, hygiene, finances, health management, home management, safety, and nutrition. It was also discovered that these issues are often interrelated and interconnected. For example, problems with mobility can potentially worsen isolation issue as not being free to move around can cause older adults to only stay in their homes with less human contact. Also, failing to properly manage diet and nutrition can lead to various health issues, and problems experienced around home management and housework can lead to safety issues such as fall risks in the home environment. However, it was identified that, because previous studies focused on isolated point solutions, the breadth and complexity of aging-in-place issues have not been properly addressed.

The planning stage also involved an assessment of available technologies. An aim of the project was to create capabilities and develop useful features with an integration of accessible sophisticated technologies that are readily available. Since the project was run in collaboration with NTT, the team had access to various telecommunications applications that could be readily implemented. In addition to the telecommunications technologies, a variety of different sensors and identification technologies were surveyed as well, based on the premise that context awareness, as well as capabilities to monitor and manage activities, can provide benefits to aging in place. Through this process, the research team found a variety of off-the-shelf sensor technologies that were available at reasonable costs, such as RFID systems and motion sensors.

Based upon the preliminary research around current issues and available technologies, the objectives of the project were outlined. The main objective was to design and develop a solution that can assist in dealing with issues and challenges related to aging-in-place. Based on the discussion that older adults' activities mostly take place in the home environment, the system was outlined as a home solution so that it would easily fit into their daily lives. In order to address the limitations of existing systems and projects, it was decided that multiple related issues would be addressed. An objective was also stated around the involvement of older adults during the design process for a correct and comprehensive understanding, as the shortcomings of current system was discussed to have come from a lack of proper knowledge around user needs and expectations. Also, for a quick and inexpensive prototyping, the team sought to make use of component technologies that are readily available. In summary, the project aimed at developing a system that would quickly deliver value while keeping the costs at a minimum so that the end product would be affordable if it were to be further developed and distributed in the market.

In addition to the research activities, planning around project management was carried out in parallel and a rough schedule was outlined. The overall development was planned over one year, and a simple Gantt chart was first created to include major activities such as technology alternatives search, system design, detailed design, prototyping and testing in the unit of months. This early version of the project scheduling chart is shown in Figure 26.

**Figure 26. Initial Gantt chart for the e-Home case**

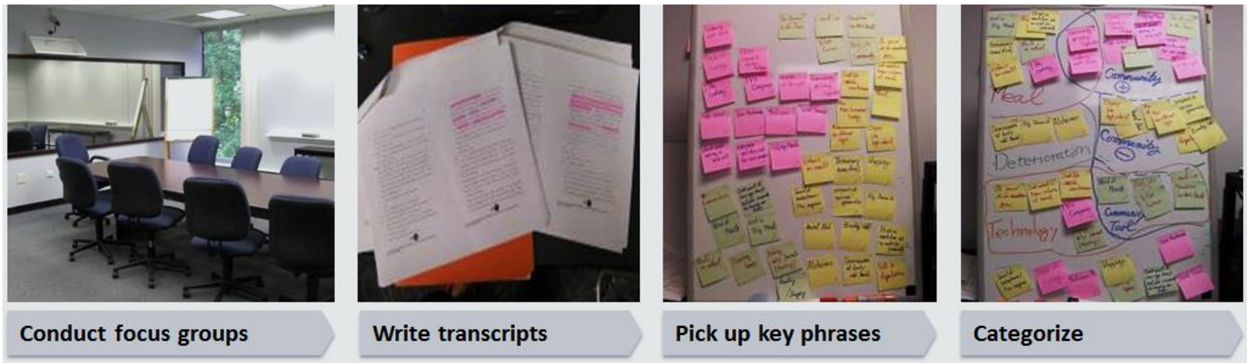



The project team was formed with members with multidisciplinary skills and expertise in mechanical engineering, electrical engineering, computer science, psychology, and social sciences. The team included a researcher from NTT Service Evolution Laboratory. An experienced project manager and a usability engineer were also added as the project was found to involve multiple issues and methods.

### 5.5.1.2. Concept development

Preliminary qualitative research done at the MIT AgeLab on older adults' decisions on where to live has shown that a strong criterion was the ability to support social communication among family members and within a community. During concept generation, two focus group discussions were carried out with older adults from age 55 and up. Both focus groups were conducted in Massachusetts – one in Braintree and the other in Framingham – with older adults living in active senior communities. The first one was carried out with 9 females and 3 males, aged from 57 to 77, and the second one included 6 females and 6 males in a similar age range. The focus groups were transcribed, summarized, and categorized to extract key information, as illustrated in Figure 27. From the focus groups, it was revealed that they greatly value a connected lifestyle with rich social connections and being in a community with people around, as in the following comments and terms – "… people, it's like a gift!", "camaraderie", "high school", "everyone watch out for one another", and "that reason (friends) was an extra bonus for me."

**Figure 27. e-Home focus groups**

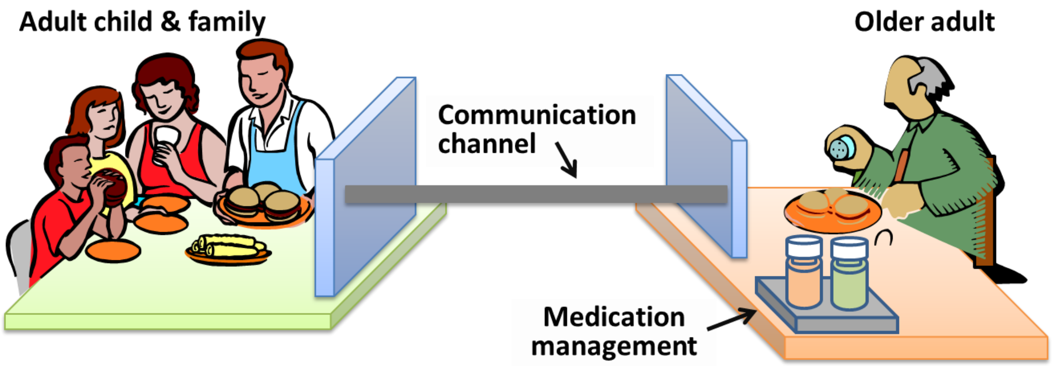



Continued discussions with the target users revealed that older adults often have negative feelings toward monitoring technologies ("no need to be monitored now", "don't want to know calories of meals", and "don't like outside interference"). This led the research team to create ideas around using informal and friendly communications, which was the primary need identified from user inputs, to improve other situations and issues that may arise at home and to alleviate the potential threat that arise from possible monitoring. Various ideas were generated, ranging from remote caregiving and talking to family during meal time to even making sure that a wastebasket is being emptied properly and checking if an older adult is making coffee at a regular time.

As the concept of family communication system started to emerge, the research teams started looking at the other half of the user population – older adults' children. A previous MIT AgeLab survey research had identified that adult children, who are often the informal caregivers, are very interested in knowing how their parents manage health, such as consuming and refilling medication (Coughlin et al., 2009). The importance of the medication compliance issue was confirmed with a literature review, as studies found non-compliance to be an extremely risky and costly, yet common, problem among older adults (Lee et al., 2011; Asai et al., 2011).

The strong user input and background information were used to prioritize and direct the goals of the e-Home project. The team wanted the system to clearly demonstrate improved communication, while providing solution to another issue that could be related. As a way to facilitate the communication and assist remote caregiving, the team decided on incorporating medication consumption management into the system. Thus, the final concept was defined as a home technology system for proactive medication management and enhanced communication. A basic illustration was developed to visually describe the selected concept, as shown in Figure 28.

**Figure 28. e-Home system concept illustration**



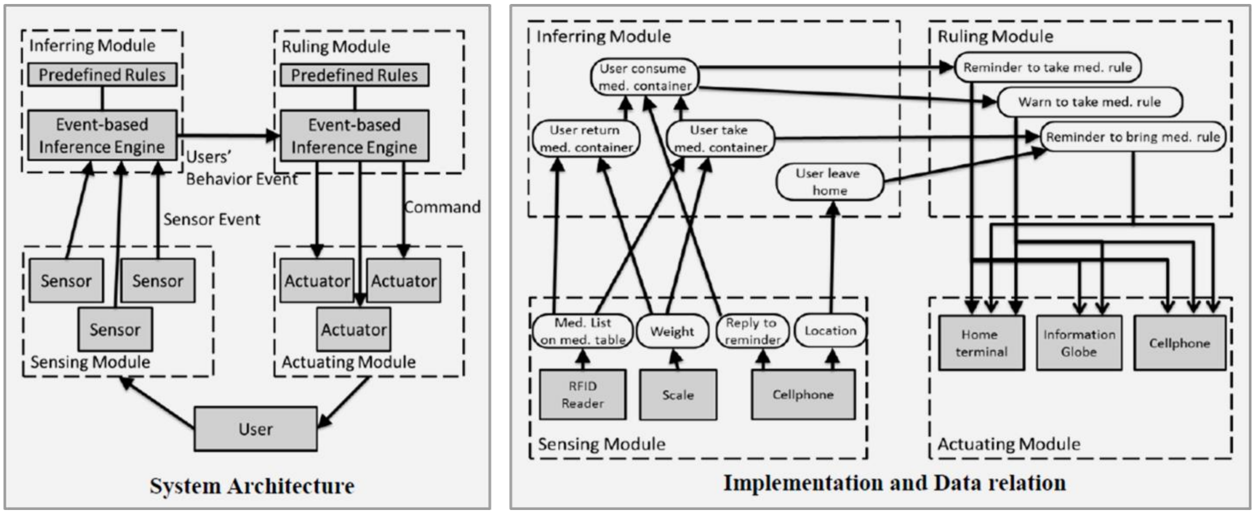

The user studies had made it very clear that a parallel goal to that of communication was that of ease of use. Based on the user comments and literature, it was clear to the research team that the selected concept had to be developed in such a way that it is pleasant to use, straightforward to learn, easy to install and manage, accurate, and reliable. Lastly, a decision was made around the need to ensure that issues related to privacy, which was also raised during the focus groups, were recognized and addressed, as older users may be uncomfortable with the monitoring function.

#### 5.5.1.3. System-level design

The system-level design was driven by the requirements identified in the earlier stages of the project. An additional goal was to provide an architecture that provided flexibility to deal with any new requirements that came from issues related to implementation or from initial user testing. As it was conducted as a research project that sought to answer questions around how technology can enhance older adults' quality of life and how such technology would work in realistic settings, one important aspect of the architecture was the need to collect data on system usage as part of the research environment. Related issues were also identified, including the need to require minimum demands on the users' network capability when used and to maintain guaranteed privacy in the communications.

The system was designed with two main parts - medication management and remote communication - as stated in the concept description. At a functional level, four components - sensing, inferring, ruling, and actuating - were defined as illustrated in Figure 29. The sensing module was designed as the interface to the real world and the sensors required. The inferring module was defined as storage that collects data from the sensors and contains rules that define user events. The inferring module was also designed to continuously match incoming events against the rules to identify system events. The ruling module was set to analyze user events and identify actions for users based on a set of rules. The actuating module was designed as an output interface with the various components visible to the users. Throughout the process of setting functional goals and defining system modules, the team decided that the system would include both hardware components and software interfaces.

**Figure 29. e-Home system components (Asai et al., 2011)**



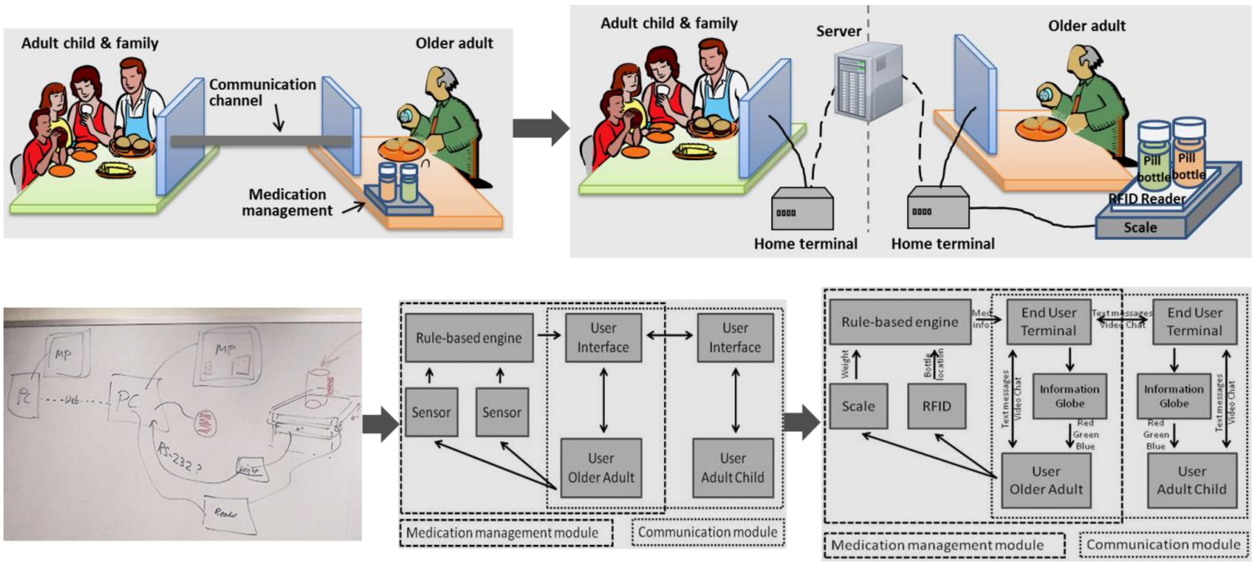

Based on a preliminary assessment of applicable component technologies for the medication management module, RFID technology and motion sensors were selected as candidates. The two were tested for performance, accuracy, and reliability in the laboratory to determine if they could be effectively used in a realistic setting. The RFID technology was selected as a result of simple experiments. As the system also needed to detect if pills were actually consumed, a precision scale was added to the system.

Discussions were carried out to discuss the modes of communications that could be implemented in the system to provide benefits to the older users and their family counterparts. As a result, the team decided on including a videoconferencing feature and an instant messaging function that could be operated with simple interactions. For the videoconferencing part, the team decided on using NTT's Meeting Plaza, which can operate as a one-click videoconferencing program. While the Meeting Plaza was included for face-to-face, real-time communication, the instant messaging was included for delayed communication for situations in which either side has something to say that does not need immediate attention.

The RFID-enabled medication tracking hardware and the communication and user interface software were decided to be designed as a universal tool that could be connected to various PCs. For prototyping and testing, however, the team decided to use a regular all-in-one touchscreen PC for its flexibility, interoperability, and usability. An information globe was added to the overall design based on a use cases analysis, since users may want a quick-glance understanding of system status when they are not close to the screen or when they have the screen turned off for privacy or cost reasons.

In short, the system-level design started from a simple structure as shown on the left side of Figure 30. With a use cases analysis based on the user inputs from earlier stages, and with technology assessment and testing, the overall system design was specified as shown on the right side of Figure 30.

**Figure 30. System-level design evolution in the e-Home case (adapted from Lee et al., 2011)**




### 5.5.1.4. Detail design

After defining the overall system architecture, the process was followed by part selection, hardware integration, software development, industrial design, and interface design. The detail design activities were carried out in the aim to meet the following requirements identified from the user studies in the concept development phase.

- The system should be easy to use: intuitive design, minimum user effort
- The system should be accurate: time keeping, medicine identification, weight measurement
- The system should be reliable: use of reliable Internet service, stable hardware connections
- The system should be easy to install: easy user manual, step-by-step wizard, USB connection

These requirements generally apply to any systems that involve user interactions. However, they were found to be especially important for this system as it was revealed from user studies and literature that failure to meet these requirements can lead to critical outcomes as it was designed to serve vital roles. Also, the requirements were emphasized for the target population as they are less likely to have various means of network connection and often less experienced with operating new hardware and computer applications.

The detail design of hardware, software engine, and user interfaces were run in parallel. In order to facilitate efficient exchange of ideas, streamlined development, and seamless integration, researchers who were mainly involved in design and development held daily informal meetings in addition to the regular meetings that were already scheduled and held weekly. As specific tasks were defined, the overall project schedule was specified expanded to include detailed tasks, and was also redesigned with days and weeks as the unit of scheduling timeline.

Through a market research and a technology assessment, several specific models were selected as candidate hardware components. They were evaluated on several dimensions including price, performance, and features. One important principle during part selection, and the following design improvements, was the need to consider the performance of the integrated product rather than optimizing at the part level (Utterback et al., 2006). For example, the RFID parts were selected not in terms of the best detection power, but how they can be put together for the desired overall system behavior. Because the RFID system was to be used for short-range medication detection, the team specifically looked for an inexpensive and accurate short-range system, rather than high-performance systems that enabled distant detection. Based on such criteria, candidate models were tested and selected for system integration. This process of setting selection criteria and evaluating candidate parts were repeated for the precision scale and the computer as well.

After selecting the parts, alternative hardware configurations were generated and tested. The evaluation of candidate configurations aimed at meeting the key requirements generated from user inputs, as described earlier, and was informed by results from experiments, a task analysis, a failure modes analysis, a cognitive walkthrough, and a digital observation of user behaviors. Various configurations of the RFID reader, antenna, and tags were tested for performance in detection of individual medications. Based on experiments, the team decided to use an RFID system where the reader and the antenna are set in a perpendicular angle. The task analysis was done to develop detailed description of potential user interactions, while the failure modes analysis and the cognitive walkthrough were conducted to identify problem areas and possible paths that may lead to errors or system failure. The digital user observation was conducted as a photo collection process, during which a large sample of older adults were contacted to use an online form to submit photographs showing where and how they store and manage their medications.

Based on the results of the task analysis, cognitive walkthrough, and digital observation, it was outlined that when people consume medication, they usually go through the process of reaching a medication container from the place, opening the container, picking pill(s) out from the container, consume the pill(s), closing the lid, and returning the medication container to the original space. Thus, it was decided that the system should be able to track these behaviors and give users related feedback. The conclusion was translated and organized into a set of functional requirements that included adding and deleting medication to and from the database, detection and recording of medication bottle movements, detection and recording of bottle weight changes, keeping track of time, generating reminders, and showing warning messages at scheduled times. Also, it was found from the digital observation that people store medications in various forms of storages or containers - on shelves, in cabinets, on countertops, or in boxes (Lee et al., 2013a). Due to the wide variations, it was decided that an open and accessible design would be more usable and favored compared to designs that involve extra tasks of closing containers, arranging medications, or covering contents.

For the development of the underlying engine and the software application, sharing messages, and making calls through Meeting Plaza. The functional requirements were then organized and mapped onto a rough software component structure, which was then refined through iteration with unified modeling language (UML) and construction of system diagrams. After deciding on the detailed structure and flow, researchers with expertise in computer programming got involved in the detailed software development and coding. Several languages and tools were used, based in part on libraries that were available as interfaces to the hardware components that had been selected. Data transfers between the clients and server were encrypted to ensure privacy.

Making the system easy to understand and use was the biggest concern during the detailed design of the user interfaces. Through an examination of design metaphors, the team settled on a corkboard interface. That is, the screen would show a virtual corkboard with reminders and notes pinned onto it. The corkboard metaphor was selected because it made the interactions natural and intuitive. It was also attractive because it could easily use touch as a user interface mechanism, as the need to support touch interactions was folded into the specifications during part selection. With the interface, users were able to simply touch a note icon with a finger to generate a note, touch and drag to move an existing note, and touch and drag the thumbtack image to remove a note. The information globe, which was added as an additional display component, had to easily show the system status even when the users are not close enough to the screen to read messages. With a consideration of human factors and general mental models, the globe was designed to alternate between colors red, green, and blue according to system status. The colors corresponded to the colors displayed on the screen, and also to the common sense where red usually is used for warning.

The physical hardware, underlying engine, and software application were then quickly integrated into a functional system. An efficient integration was possible as the team continuously communicated at every stage of detail design. The interfaces among components were defined using simple mechanisms. For example, most of the hardware components were connected using USB cables, and the software application was packaged as a general Windows application. The external components with the highest data communication requirements were connected to USB connectors on the computer that were processed with the highest priority. The detail design specification of the prototype system is shown in Figure 31 and also summarized in Table 50.

**Figure 31. Detailed design of e-Home hardware and software**[37]


Medication table — Graphical user interface with corkboard interface — Information globe

**Table 50. e-Home requirements and design decisions**

| System component | Requirements | Selected part |
|---|---|---|
| Precision scale | – Accurate measurement ability: need to detect 1g (for detection of small pills)<br>– Capacity: ability to hold multiple pill bottles<br>– USB connectivity | – Ohaus Scout Pro |
| RFID reader, antenna and tags | – Ability to read multiple tags<br>– Ability to read tags at a short distance<br>– Tag size: small enough to fit on a pill bottle<br>– Tag detection: ability to be detected at different angles<br>– USB connectivity | – Reader: Skyetek's SR70<br>– Antenna: Mobile Mark's PN6-915RCP<br>– Tags: Avery AD-814 |

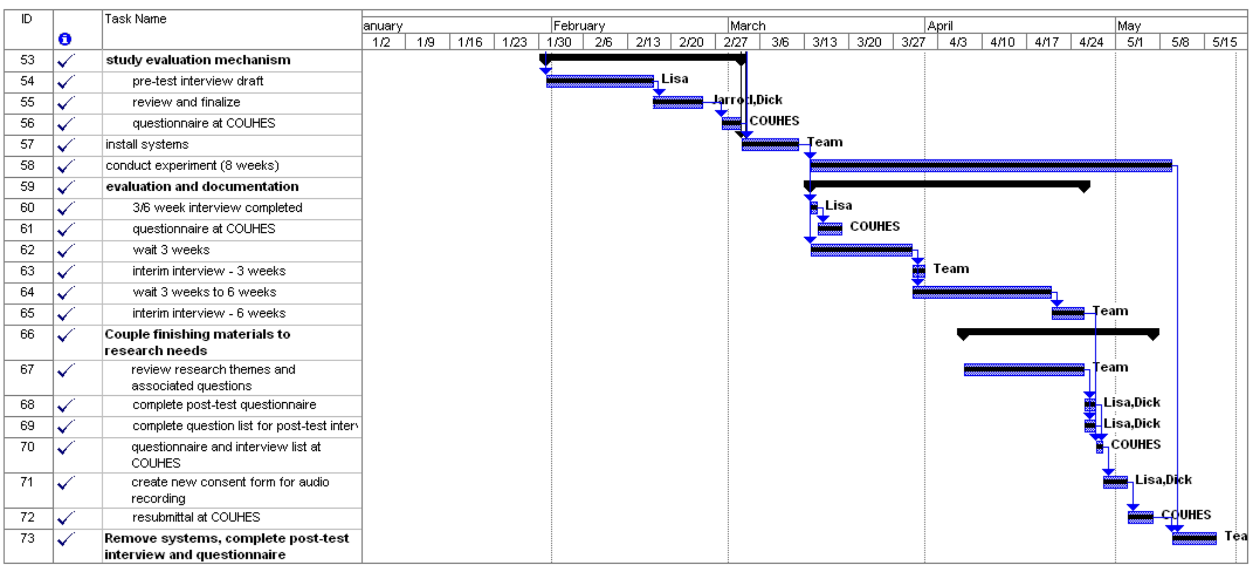
[37] The medication table includes the RFID reader, antenna, tags to be attached to medication bottles, and the precision scale. The corkboard interface shows four types of notes - yellow notes are posted to self, blue notes are instant messages shared between older adult and adult child, green notes are medication reminders that show up when a medication is due, and red notes are warning messages that pop up when a medication is overdue. The green and red notes disappear automatically when the corresponding medication has been taken. The phone icon initiates a Meeting Plaza video call when clicked or touched. The wheel icon on the lower right opens up a setting tool for adding or deleting medications from the system. The information globe is normally green, but changes to red when there is a warning message, and changes to blue when there is an incoming video call.

| | | |
|---|---|---|
| Information globe | – Ability to transmit light and change color according to system status<br>– USB connectivity | – Arduino Duemilanove microcontroller board<br>– Small LED bulbs |
| Video-conferencing | – Simple interactions<br>– Connection stability | – NTT Meeting Plaza |
| Software display | – Intuitive interactions<br>– Ability to support touch interactions | – Corkboard interface with colored notes |
| PC terminal | – Ability to support touch interactions<br>– Microsoft Windows operation<br>– Multiple USB ports | – Asus Eee all-in-one PC |

#### 5.5.1.5. Testing and refinement

Prior to rounds of testing and evaluation, the Gantt chart for project scheduling was elaborated with detailed activities and related information such as dates, task interdependencies and names of people in charge. The chart was constantly updated with any additional tasks or progress. A part of the detailed chart is shown in Figure 32.

**Figure 32. Updated project schedule for e-Home**




With the integrated prototype, a thorough laboratory testing was conducted to evaluate the system's functionality, reliability, and usability under various use cases. Two systems were installed in an MIT AgeLab laboratory space to simulate an older adult and adult child pair. First, researchers used the system in a typical setting where the older adult would take medication a few times a day, and the both sides would occasionally exchanges calls or notes. This was done to see if the system was able to function as it was designed to. Then, based on prior interactions with potential users, a large number (over 30) of use cases were enumerated to describe the various purposes, components, and processes with which users may use the system. Use cases related to possible failure modes were also described to test the reliability under different conditions such as unstable network connection. The researchers then tried the various situations described in the use cases to see if any design changes were necessary. A bug list was kept to record detailed results, which was circulated among the team.

The system was taken out for a short pilot field testing after incorporating the design changes identified from laboratory testing. The pilot testing was conducted with one older adult and her adult child in the Greater Boston area for a week in February 2011. During the week, the participants kept a diary to record any notes about their interactions, problems experienced, and ideas for improvement. The pilot study identified several important suggestions, such as providing a one-page summary user manual and the incorporation of audible announcement rings associated with notes and communication requests. In general, the system was able to perform with no major problem in the field setting, and was well received by the two participants, as well as other family members at the adult child side.

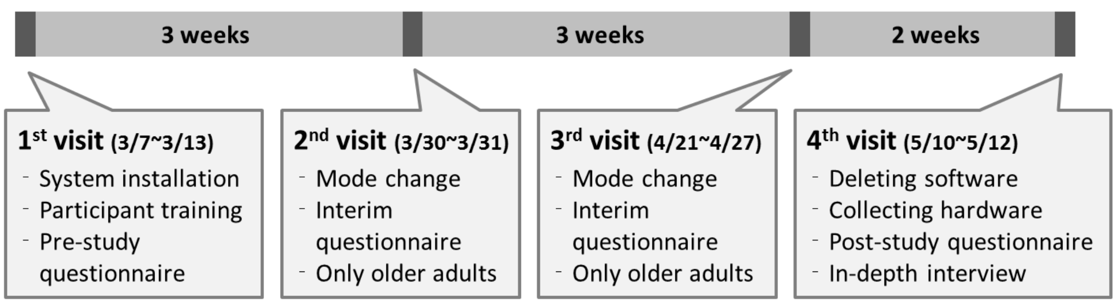
The system architecture proved to be very flexible, and was able to easily incorporate inputs and comments received from users that arrived after the pilot implementation. After incorporating the design changes identified from the pilot study and testing the refined system for its performance and reliability in the laboratory, the system was put into the field. For the field testing, four older adult and adult child pairs were recruited through a screening process including an initial questionnaire and a phone interview. The older adult was required to be at least 60 years old and living alone without any home healthcare services. Both male and female participants were selected. To ensure that they use both modules of the system, an older adult and his or her adult child was required to be at least 25 miles or 40 minutes apart by driving distance. This was based on the reasoning that if they lived closer, they would be likely to communicate in person rather than use the system during the testing period. Also, the older adults were selected after screening out the candidates who were not on any medication on a daily basis and thus wouldn’t use the medication module. Table 51 shows a summary of the participant profile.

A long-term schedule of eight weeks was planned for understanding real-life usage rather than just getting results based on initial impressions. Over the course of eight weeks from mid-March to mid-May in 2011, the e-Home research team made four scheduled visits to each older adult home, and two scheduled visits to each adult child home as illustrated in Figure 33. The interim visits were not made to the adult child homes as the mode change only required system alteration from the older adult side. The interim questionnaires from the adult children were collected electronically, while they were collected in person from older adults. The visits were made for system installation, participant training, and collection of data. Visits were scheduled frequently and as evenly as possible to maintain a close contact with the participants and to collect survey data at appropriate times. Additional visits were made for system repairs or additional training as requested. Participants also made contacts by phone or email to ask questions, report unexpected system behaviors, and to talk about any related matters.

**Table 51. e-Home field evaluation participant profile**

| ID | Side | Age[38] | Gender | Medication | Location | Distance |
|---|---|---|---|---|---|---|
| 1 | Older adult | 68 | Female | 1 at 8am and 3 at 6pm | Winthrop, MA | 38.3 mi. |
| | Adult child | 50 | Female | n/a | Dracut, MA | |
| 2 | Older adult | 65 | Male | 3 at 12pm | Chelsea, MA | 35.3 mi. |
| | Adult child | 31 | Male | n/a | Haverhill, MA | |
| 3 | Older adult | 67 | Female | 1 at 8am | Dedham, MA | 29.0 mi. |
| | Adult child | 40 | Female | n/a | Marlborough, MA | |
| 4 | Older adult | 76 | Female | 3 at 11am and 1 at 8pm | Medford, MA | 33.4 mi. |
| | Adult child | 35 | Male | n/a | Windham, NH | |

**Figure 33. Field visits during the e-Home project**




During the eight-week period, the system alternated between two modes of operation. The two modes differed in the amount of information shared and the level of privacy that the older adults had. In the shared mode, all system information including the medication notes were fully accessible to both older adult and adult child sides. In the local mode with added privacy, however, the monitoring feature was suppressed and only the older adult was able to view the medication notes. The communication notes and videoconferencing remained fully functional in the local mode. At the beginning, two pairs were randomly selected to start using the system in the shared mode, and the other two were given the system

[38] Age at time of recruitment (February 2011).

in the local mode. They switched modes after the first three weeks, and all pairs were asked to choose a favored mode for the last two weeks.

Various topics were investigated with the field test. The topics, as listed below, concern the system's performance in real-life setting, potential user perceptions and attitudes, and ideas for future systems.

- Patterns of user interactions and any temporal changes
- Differences between older adult side and the adult child side, and between shared and local modes in terms of their interactions with the system
- Perception of benefits from the two main modules – medication and communication
- Interplay between the two main modules (medication and communication) in the real-life setting
- Problems areas in the system in terms of performance and/or usability
- Potential ideas for the next generation of the system

To investigate these issues in depth, several user studies methods were employed at various times during the field testing. Multiple methods were used to collect both subjective and objective information, as well as both quantitative and qualitative data.

Questionnaires were filled out by the during four scheduled visits at the start of the study, after three weeks, after another three weeks, and at the end of the eight-week period. The first questionnaire asked about the participants' expectations about the system, experiences with technologies, relationship and communications with study partner, current health status, and general state of mind. The two interim questionnaires collected information on system usage, perception of system features, and relationship and communications with study partner specifically for the mode that they were using the system in. The post-study questionnaire referred to the whole study period, and asked questions about their experiences with the system and the study program. In addition, the final questionnaire included questions regarding the participants' willingness to pay if such system was available in order to understand user perceptions related to cost issues.

Information related to system usage was collected into a database throughout the study, including RFID detections, weight changes, and time and initiator of notes and video chats. The specific contents of conversations were not recorded.

At the last visits, interviews were conducted to gather detailed feedback on system features and the perceived effect on medication management and communication. Each interview lasted about 30 minutes. In addition, all participants kept a diary throughout the eight-week period to write about their experiences, any minor problems that came up, and suggestions and ideas they had about system improvements (Lee et al., 2011). The methods of data collection used during the field evaluation are summarized in Table 52.

**Table 52. e-Home field study data collection methods**

| Method | Time of collection | Data collected |
|---|---|---|
| Questionnaire | Four times, one at each scheduled visit | – Information on system usage<br>– User perception of the system<br>– Perceived effect on medication compliance and communication |
| System log (remote observation) | Throughout the eight-week period | – Detailed usage of notes and video chat<br>– Medication consumption information (time and errors)<br>– Automatic daily transfer upon encryption |
| Interview | At the last visit for about 30 minutes each | – Feedback on system features<br>– Perceived effect on medication compliance and communication<br>– Ideas for future systems |
| Usage diary | Throughout the eight-week period | – System usage and errors<br>– Ideas for improvement |

The data collected from with the various methods of user studies were analyzed to investigate and answer research questions listed earlier. Table 53 summarizes the specific research questions and evaluation topics, the analysis approaches, and the types of data that were analyzed.

**Table 53. e-Home field study research questions and analysis approaches[39]**

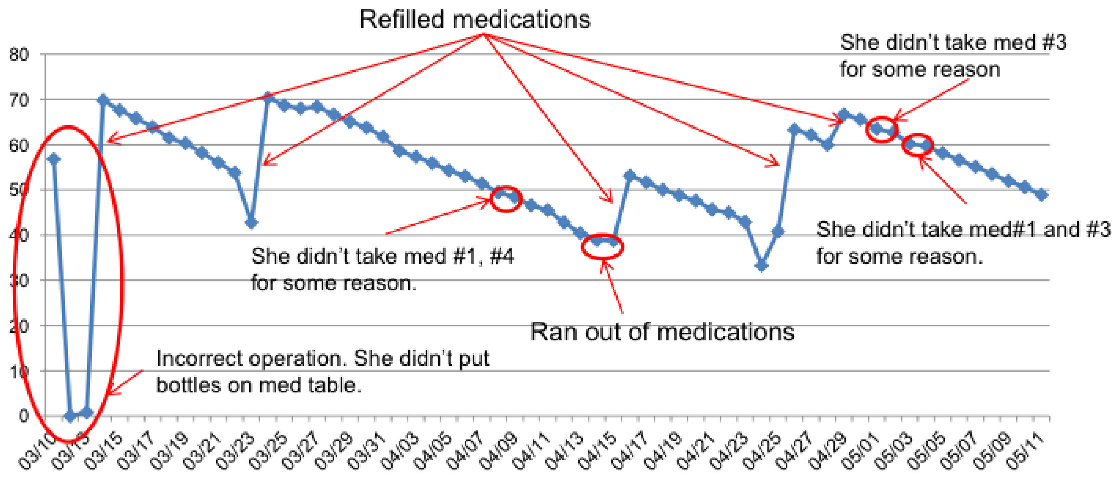
| Research topic | Analysis approach | Types of data |
|---|---|---|
| How do users interact with the system? Do their interactions change over time? | – Plotting data on against time<br>– Analysis of user reports and perceptions | – Log data<br>– Questionnaire and interview results |
| Do interaction patterns differ between the older adult side and the adult child side, and between shared and local modes? | – Data comparison in terms of frequency, error rate and perceptions | – Log data<br>– Questionnaire and interview results |
| How do users benefit from the two main modules – medication and communication? | – Plotting data on against time<br>– Analysis of error rate<br>– Analysis of user perceptions | – Log data<br>– Questionnaire and interview results |
| How do the two main modules interplay in the real-life setting? | – Data comparison in terms of frequency, error rate and perceptions | – Log data<br>– Questionnaire and interview results |

[39] Detailed results and reports of the findings can be found in Lee et al. (2011), Asai et al. (2012), Lee et al. (2013b), and Asai et al. (2013).

| | | |
|---|---|---|
| What problems do users experience with the system's performance and/or usability? | – Usability analysis<br>– System error rate | – Log data<br>– Questionnaire and interview results<br>– Usage diary |
| What are potential ideas for the next generation of the system? | – Analysis of user suggestions<br>– Identification of existing problems | – Interview results<br>– Usage diary |

The system log data on RFID detection and weight changes were plotted for each older adult participant for a better illustration of information on the participants' medication compliance during the trial. As an example, the data on changes in bottle weight from one of the older adults are summarized in Figure 34.

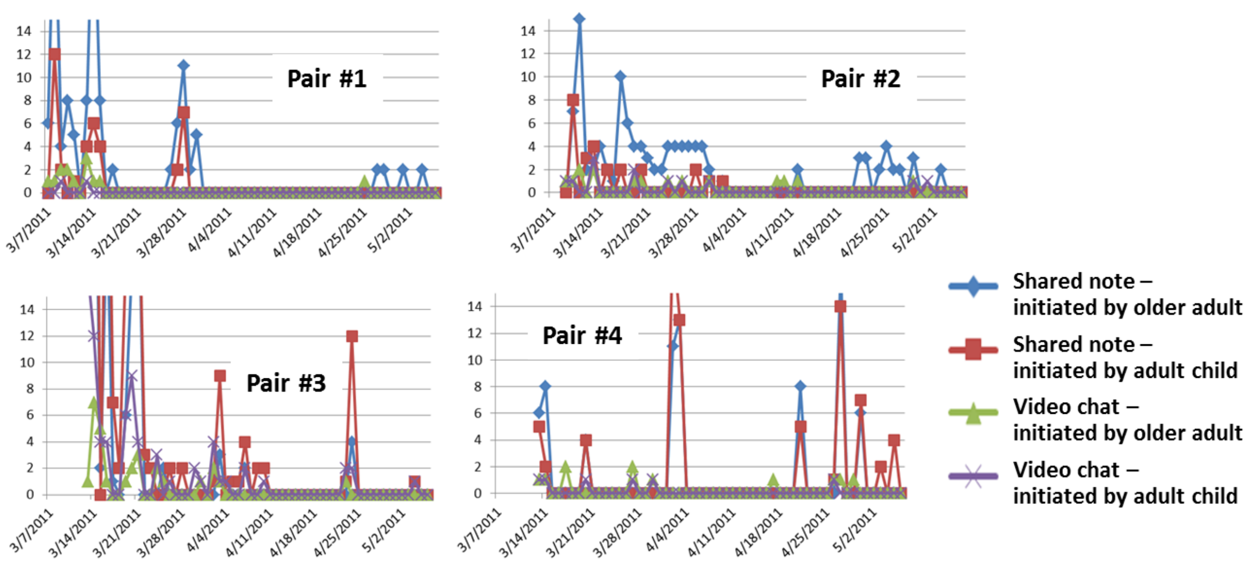
**Figure 34. Medication consumption data from e-Home field study (Lee et al., 2011)**




Data from all four older adults showed that all reminders were removed by correct medication consumption or voluntary removal. While some participants did not take one or two medications a few times for some reason, they were aware of the situation and no reminders went unnoticed. Thus, according to the log data, the system seems to have been effective in assisting older adults in managing their medications. Also, from the questionnaires, it was found that all participants, especially older adults, perceived the medication components of the system as useful. The average scores for the usefulness of the overall system were 4.5 from the older adult participants and 3.5 for the adult children, on a scale from 1 (much less useful than expected) and 5 (much more useful than expected). While the small sample did not allow discussion on statistical significance, the score difference suggested that older adults found the system to be effective in assisting medication compliance and family communication, even though they may have had privacy concerns or were unsure about using online connections. This result concurred with what participants said during the in-depth interviews, such as "the reminders were great, because I tend to forget things sometimes," "my pill taking was erratic, and this stabilized it," "I took definitely at the proper time unless I was out, and that only happened twice," "sometimes I forget and don't know whether to take it or not, but with this, that won't happen," and "it was a good tool to keep track of what was going on with my mom and if she was taking her medications or not."

Patterns of user interactions and system effects on communications were also analyzed using data from the system log, questionnaires and interviews. From the questionnaires, it was found that all participants, especially older adults, perceived the communication components of the system – the blue instant messaging notes and Meeting Plaza videoconferencing program – as useful. Positive comments were collected during the interviews as well, including "I think this gave us a connection like we could touch each other at any time" and "it was a great way for us to keep in touch … because we don't see each other that often." The system log data were used to analyze patterns in usage of the communication features based on frequency and intensity. For example, Figure 35 shows information on the number of notes exchanged and the frequency of videoconferencing for the four pairs. It can be seen that, while there is some variation, the frequency of using e-Home as a communication channel decreased over time. This finding suggested that there was a novelty effect during the beginning, but that the participants' use of the system quickly stabilized to be compatible with how they normally communicate with each other. Another observation that can be made from Figure 35 is that, even though the frequency has decreased overall, the participants still used the system as a way of communicating throughout the study period. This suggests the possibility that the Internet-based communication methods such as instant messaging and videoconferencing could be effective replacements for more traditional methods.

**Figure 35. Communication frequency data from e-Home field study**



Based on a comparison between the shared mode and the local mode, it was found that sharing medication information had a positive effect on relationship and communications, and vice versa. In the questionnaire, older adults' responses showed that they generally perceived the system to be more useful in shared mode, in which all medication information was shared with their adult children. Although the shared mode required the older adults to sacrifice their privacy to some degree, the participants reported that the sharing medication information made communication more frequent and richer. The adult children also felt that the shared mode as more helpful, confirming the effectiveness of targeting interrelated issues together. The following comments show the adult children's perception of the interplay between the two components – "when I was getting alerts for her medication, if I didn't get one, I would start to get concerned. So I would always make sure that I Skyped (used Meeting Plaza) her or sent her a note" and "because the thing is, it's giving you a basis to talk about other things. So if you're calling about the pills, you'll also start talking about something else. So I think it's just spurred general conversation."

The two components were found to have a synergistic effect, where the medication information triggered more communication while the presence of the adult children motivated older adults to adhere to the medication regimen. Around the sixth week, the research team asked all participants to choose the system mode they would like to use for the last two weeks of the study. All four pairs chose to use the system in the shared mode, further confirming the strong preference. At both sides, the older adults and the adult children, participants felt that the medication monitoring provided useful information, which contributed to increased likelihood, frequency, and quality of communication. Based on the findings, the researchers were able to conclude that it would be useful to demonstrate clear benefits, such as contributing to and enhancing social communications with family and close acquaintances, would be an effective way to make them more comfortable with monitoring functions, as well as with technology in general.

The user comments and feedback from the interviews and usage diaries allowed the research team to identify several directions in which the system could be improved or extended. Several issues were raised around detail design and technical performance, such as "can you make the text larger?" "the orb is too bright," "it wasn't sensitive enough for my light pills," and "it needs to be speeded up." Participants also shared their ideas on additional features that could be added to the system to improve their experiences, such as "it would be nice to have a clock on the screen," "that would be awesome if something yelled at me and said - don't you eat that fattening thing!" and "one thing I was thinking about is diet and exercise." Lastly, a few participants provided suggestions for making the software available for various operating platforms and devices, as in "it would be a good system to go onto a phone or regular computers" and "being integrated into existing applications or existing devices, so it's not a stand-alone system." While these comments reflect their misunderstanding that arose from being constrained to use the software only on the PC that was given to them, the research team found these comments useful in that they provide an insight for future design requirements around interoperability.

#### 5.5.1.6. Summary and implications

In this section, a case description was developed to trace the process and activities involved in the e-Home for Seniors project. The e-Home project was conceived from the beginning to identify, understand, and address a major need of an aging population and their caregivers. Several processes were employed from the early stages to gather and prioritize user needs. Methods of user studies included direct contact with the target population, as well as indirect methods such as literature search and study archives.

The importance of continuously involving user inputs and gathering feedback was emphasized throughout the design specification and development processes in order to select the design alternatives that are best aligned with user needs and expectations. As ease of use was identified as a primary requirement, special emphasis was put on making the system inviting and easy to use. The architecture of the hardware and software was selected to allow changes in the system to be easily incorporated as the emerging system was reviewed with users. User inputs were also used create use cases, which then compiled into test plans to ensure that the product was reliable in the areas of most common use.

The functionality, usability, and reliability of the product were checked repeatedly through laboratory tests, a pilot field installation, and a long-term field study. From the laboratory tests and the pilot study, the changes and improvements that were identified were quickly incorporated and evaluated. When necessary, formal project management techniques were used to monitor and coordinate changes. The resulting product was enthusiastically received by a sample of potential users, used without difficulty by older adults often unfamiliar with technology, and was viewed as a contribution to their lives and communication with family members. Several quantitative and qualitative mechanisms were utilized to gather more detailed comments and responses from users, which have successfully allowed a range of information to be collected for further work. Table 54 shows a summary of the key activities and decisions throughout the e-Home project described in this case.

**Table 54. Summary of the e-Home case description**

| Design stage | Key activities and decisions | Implementation of user involvement | Adoption factors considered |
|---|---|---|---|
| Planning | − Assessment of general needs<br>− Survey of prior work<br>− Assessment of available technologies<br>− Outlining project objectives<br>− Scheduling and team formation | − n/a | − Value<br>− Affordability<br>− Lifestyle fit<br>− Independence |

| | | | |
|---|---|---|---|
| Concept development | − Idea and concept generation<br>− Collection of user needs<br>− Prioritization of objectives<br>− Final concept definition<br>− Setting overall product requirements and qualities | − Focus groups with older adults<br>− Prior survey conducted at MIT AgeLab (indirect) | − Usability<br>− Reliability<br>− Emotion<br>− Social support |
| System-level design | − Definition of system requirements<br>− Finalizing product architecture (main modules and interfaces)<br>− Selection of component technologies | − n/a | − Reliability<br>− Value<br>− Usability<br>− Lifestyle fit<br>− Social support<br>− Emotion<br>− Interoperability<br>− Affordability |
| Detail design | − Definition of specific design requirements<br>− Detail design and development of hardware, software and user interfaces<br>− Part selection<br>− Evaluation and selection of hardware configurations<br>− Analysis of use cases and failure modes<br>− Integration of system components | − Digital user observation with collection of photographs showing user behaviors | − Value<br>− Usability<br>− Affordability<br>− Experience<br>− Confidence<br>− Conceptual fit<br>− Emotion<br>− Social support<br>− Reliability<br>− Technical support |
| Testing and refinement | − Detailed scheduling<br>− System evaluation in the laboratory and in the field | − Short pilot field testing<br>− Long-term extensive field study | − Usability<br>− Value<br>− Affordability<br>− Emotion<br>− Social support<br>− Technical support<br>− Interoperability<br>− Reliability |

From Table 54, it can be seen that various methods of user studies and user involvement were employed at various stages including concept development, detail design, and testing and evaluation. During the planning stage, the research team referred to prior research for consideration of user needs, but no method of direct user involvement was used. Similarly, while the design of the overall system architecture was based on a use case analysis, the system design stage was not based on direct user inputs. Many of the adoption factors were considered and addressed in the design and evaluation of the system, except for accessibility and service trust. However, most of the factors were considered at the later stages. It can be discussed that considering more factors from the early stages may be helpful for making the system easier to use and more valuable. For example, while the potential users' prior experiences with related technologies were not considered until the detail design stage, it may help to address the experience factor earlier to inform the selection of component technologies and the design of information flow to minimize problems and difficulties during initial use, as few participants reported usage errors for the first few days before they were fully familiarized with the system.

The e-Home study has several key implications and suggestions for the design and development of future systems and further research in the domain of technology-enabled home solutions for aging-in-place.

- Make the system resilient: The needs and issues related to the older population are often complex, not clearly understood, and can rapidly change especially when health issues are involved. Developers and designers can often face unexpected feedback or problems that may require significant design changes. Thus, it is important to start with a flexible architecture that is resilient to changes in individual situations and needs.
- Leverage existing systems: It would be better to design products to be easily installed or added onto existing products, such as PCs or mobile phones which most of older adults already own, rather than building a separate system. This way, they can be made cheaper and more accessible.
- Examine relationships between needs as products are developed: It was found from the field study that the communication and medication issues were deeply related in usage, creating a synergy effect. Sharing medication information acted as a trigger for communication, and communication played a role in motivating older adults to adhere to regimen. Such relationship may be found between other needs as well, and should be considered for system design as emergent behaviors can affect user experience.

The case study also has insights for product development in general. The key lessons and implications can be identified and highlighted as listed below.

- Iterate quickly and often: Many design iterations took place within a phase, and even across different phases, such as between testing and detail design. The e-Home team found the iterative process to be helpful in improving system quality, functionality, and usability in a short period of time.
- Make prototypes: It was described by the research team that they found it much easier to work with tangible prototypes rather than concepts and thoughts, especially since it is more difficult to conceptually analyze from older adults' perspectives due to inevitable gaps in understanding and experience.
- Get ideas from users: Rather than starting with a concept that the team thought as important, they reached out to the potential users to learn what they really wanted. This helped to have the system

developed around previously neglected desire to communicate, rather than based on stereotypes of older adults.

- Maintain close contacts with users: From recruitment to wrap-up, field testing participants were in close and regular contact with the researchers for about four months. Having them familiarized to the researchers was helpful as it made them feel the process as less intrusive. This also facilitated in-depth conversations to close the knowledge and experience gaps.
- Have a flexible team: Rather than having a fixed set of roles, the team found it much more effective to have an interdisciplinary team who assumed flexible responsibilities, because they were able to react quickly to different design problems and effectively manage user contacts.
- Keep shared documentations: During design and testing, several documents - bug lists, meeting notes, field notes, and a schedule chart - were kept and shared among the team members. They found that the documents served as an effective way of communication.

### 5.5.2. Case 2: MISTY by Parental Health

The ideas around features and services included in MISTY were conceived based on personal experiences of the leadership team at Parental Health. The personal need for a better technology intervention in health management and family connections for older adults and their caregivers was conceptualized into an integrated technology solution and developed as a software application that is now serving people of various ages. The design and development of MISTY were based on an extensive research that involved older adults, patients, family caregivers, and clinicians. While MISTY has been commercially available for a few years, the system is constantly being improved based on inputs from distribution partners and findings from observation of user behaviors. This section describes the activities and decisions that took place in the design, development, and distribution of MISTY. The process and results of user and stakeholder involvement throughout the design stages are also described, along with a discussion of the adoption factors that were considered.

#### 5.5.2.1. Planning

The need for a user-friendly system that integrates health monitoring and family connections for the older population was recognized by Scotte Hudsmith, now the Chief Executive Officer of Parental Health, and his business partner Darin Moore, who later joined Parental Health as the Chief Technology Officer. In 2009, Mr. Hudsmith observed, as a family caregiver for his father who was then in his mid-80s, that family engagement and continued conversations played a vital role in maintaining emotional well-being and managing stress for older adults living independently. It also became clear to him that proper technical assistance would be necessary, as older adults often do not how to solve technical problems and communicate the need for troubleshooting services due to the lack of relevant prior experiences. With the need for a way to enable continued family communications, as well as management of health and well-being, Mr. Hudsmith looked for technology-enabled solutions, but couldn't find any system that met the requirements.

In November 2009, Mr. Hudsmith and Mr. Moore started sketching out their ideas which later became developed as MISTY, an integrated software solution for older adults and their caregivers. They understood that, while it is more common in other cultures for older adults to move in with children who take care of them, older adults in the United States often choose to stay independent or to age in place. Thus, the project goal was stated to address older adults' need to stay healthy, independent, and connected, and caregivers' need for more effective and efficient caregiving and communication with older adults who don't reside with them. In other words, the ideas were centered around "the approach of digitally moving an elderly person back into the home" and "connecting generations."

The development objective was set on delivering value and providing benefits to its users, and they considered the novelty of technical platform and components to be of less importance. Based on their observation of current practices, what they saw is that developers are often unnecessarily focused on making "cool apps" connecting them to the newest devices by using the most up-to-date methods and programming languages. However, their understanding of the target population's expectations toward a technology were about the benefit they can from it, rather than the technical details, as explained in the following quote from Mr. Hudsmith – "What they care about is - they're connected to their family, and there's reminders to help them take their meds, or do whatever they need to do to keep their doctor happy. The rest of it, they don't really care about." In short, MISTY was decided to be created as a value-centric solution from the beginning, rather than a gadget driven by technological capabilities.

The primary user segment was defined to include older adults who live independently, as well as their healthcare providers. In addition to professional clinicians, family caregivers were also included as the primary user population as they assume the role of a direct caregiver, as well as "the bridge between a patient and a clinician." A secondary population was also defined as with people who would potential benefit from the use of MISTY. The secondary user segment included a broader set of individuals, such as people with developmental disabilities and behavioral health issues. The secondary market was defined due to the similarities in their needs and requirements with the older population – "It's the same problem of trying to manage their overall health regardless of whether they are 85 or if they are 18, as long as they have an issue that needs to be managed."

#### 5.5.2.2. Concept development

MISTY was positioned to fill a gap in the healthcare technologies industry, as the team was not able to find an available platform that connects an older adult with family members and professional caregivers together in real-time to help ease the caregiver burden, to assist the management of chronic conditions and other life activities, and to facilitate the communication of related data to inform the clinical care regimen.

In order to inform their decisions around the specific features and detailed design configurations of MISTY, the team conducted interviews with a large number – about 1000 – of potential users, including older adults, patients, family caregivers, and clinicians involved in the caregiving situation. Surveys and facilitated discussions, or focus groups, were also conducted to explore how people would use the system and what they would do with it. Detailed topics around system requirements were discussed during the user studies as well. The discussion topics included the specific functionalities they expect to see, the information they would want to share, and the price points that they would perceive as reasonable.

Based on the user studies, the team was able to collect the needs and requirements of the target segment. It was clear that the system would have to be easy to use and affordable. The system also needed to include monitoring components that enable management of health status. Social connectivity and the ability to facilitate communications were identified as an important component as well. It was expressed from the potential users that social connections would be necessary to help with depression that is often related to isolation among older adults. This capability of providing a technology-enabled communication channel was thought to provide an added benefit of “generation-skipping connectivity” where the grandchildren, who may not think it “cool” to talk to their grandparents, can be motivated to stay connected. In addition to the emotional benefits, it was discovered that being closely connected with family would also help with health management, such as improving medication compliance.

The final concept of MISTY was thus defined as “a platform that would be able to help with biometric monitoring, medication adherence, daily activities, information about their health records, and also the social connectivity components.” In order for the system to be capable of alleviating the caregiver burden, medical histories, nutrition management, and medical supplies and services components were also included in the concept. The social connectivity component was described to involve texting, videoconferencing, and e-mail to enable the family caregivers and other family members to use their current methods of telecommunication, while giving the older adult an integrated channel that combines the various features. While the individual features were widely available in the market, the main objective of the integrated concept “was to have it all in one central place.” Based on the main functions and features described by the concept definition, the first prototype, which was a rapid prototype, was developed in early 2010.

#### 5.5.2.3. System-level design

Before the full-scale development and detailed coding, detailed user stories were written and analyzed to inform how the system features needed to be operated. The user stories were basically written as usage scenarios based on personas that described the primary users including older adults, family caregivers, and clinicians. The results from the user interviews during the previous stage, as well as the development team's personal experiences of either being a caregiver or a person with chronic conditions, informed the characterization of the personas and detailed description of the scenarios. The personas included description of the potential user's roles as well as individual characteristics such as age. The descriptions included possible interactions with the system and the contexts in which the interactions may occur. For example, in a medication adherence scenario, the team reviewed the practical and realistic ways with which a prescription gets refilled, a medication is used in a daily time window, and how system features such as alert and alarms would inform users of different roles.

The detailed user stories and the inputs from user interviews served as the bases for outlining the key requirements and channels of information flow. For instance, the main system activities and information flow for managing and sharing health information between family members were outlined to include the following events – 1) older adult and family caregiver agrees on information to be shared, 2) events agreed upon between the older adult and family are recognized by the system, 3) events are triggered based on inputs to the system, 4) notices are sent to the family caregiver via a text or an e-mail, and 5) the family caregiver logs into a secure encrypted site to see what's happening and determines how to engage in necessary actions.

With the functional descriptions and process outlines, the team was able to key design requirements and qualities that would inform the following stages of detail design and software programming. On the older adult and family caregiver sides, the process descriptions confirmed the importance of providing clear value rather than just presenting novel technologies, which they had outlined earlier during project planning. While they reviewed multiple technology options, they finally decided that the software platform would need to run on any Windows device and that the information portal would need to be accessible on any browser. They considered other devices newer and more mobile than Windows PCs, such as iPads, as described in Mr. Moore's comment, "we had lengthy discussions with elderly users of iPads about their abilities to swipe and handle the iPads, and what they could do and how they could do it." However, the key requirements around ease of use and connectivity with multiple components, such as biometric devices, informed the team to finally decide on the Windows platform. The development team's thoughts, discussions and decisions are described by the following comment - "There is a lot of things you have to think about when things are coming in through a platform. It can't just be the coolest, neatest, newest, best thing that's there. Often, that's what happens in a development cycle, but you've got to be true to the process, not go down that path and get caught up in what's cool and fun."

Design requirements were identified for the other type of users, the clinicians and professional healthcare providers, as well. For the clinician side, a big difference was that they already had "rules and roles" in which they communicated information within their organizational structures. Thus, the team decided that the system shouldn't be overly intrusive, but that "it needed to be easily integrated into their workflow," as the system would push system information and notices during their regular work and business activities.

#### 5.5.2.4. Detail design

Having defined the major information flows and key requirements for users of different roles, the team moved on to detailed interface design and software development. The detail design activities focused on the realization of the following requirements identified from the previous decisions based on various methods of user studies.

- The system should be operated with minimum user effort and simple interactions: readable interfaces, intuitive yes-or-no operations
- The system should not require physical dexterity or fine motor skills: big buttons for touchscreen operations, color schemes with appropriate degree of contrast
- The system should be reliable and robust: use of reliable online data storage, ability to run key features without Internet connection
- The system should enable real-time information sharing between users of different roles

The first two requirements around the usability of the system were informed by the understanding around the target users' characteristics, capabilities, and experiences. As they knew that MISTY would serve people who "are not the most technology-savvy", they decided that it would be important to minimize the number of steps and options, or have "the least number of clicks and buttons", required for necessary interactions. While there may be "a lot of stuff behind the system that's complex", the team made it clear that "it has to be simple for the users." In order to further assist its users to interact with MISTY without any usability problems, the software comes with an online help, which its users can look up and refer to if they have any technical problems. The online help is built into the software for a straightforward access.

The third requirement around system reliability and robustness was emphasized as MISTY was defined to serve vital functions, such as medication reminders, with which failures can lead to further complications. Thus, the design requirement specified that the older adult users would still get their medication reminders and be able to user check on their biometric information, such as glucose level and blood pressure, even when the system is not connected to the internet.

The last requirement specifies that the users of different roles at various locations should be able to observe changes in information and system activities simultaneously. For example, based on a premise that a particular older adult user agreed to share medical information, any updates from the older adult user on his or her medication intake, blood pressure or glucose level would be stored in a secure space that can be accessed by family caregivers and clinicians at the time of the event. In order to enable the real-time data sync and sharing, the team decided to run the back end of the system in Amazon Cloud.

The actual programming of the MISTY software was outsourced to developers who worked closely with the project team at Parental Health. The system development stage included frequent and extensive communications between the managers, designers, and developers involved in the project. The team at Parental Health developed detailed descriptions that included user stories and design requirements and sent them to the developers. When they needed to cover an original use case for the first time, the project team at Parental Health and the developers met in person to go over the scenarios together. After an initial meeting, the communications and information exchanges were done through various channels including e-mails, phone calls, and videoconferences. As they received the necessary design requirements and outlines, the developers proposed recommendations about additional ideas or design changes, which the team at Parental Health then reviewed to either approve or disapprove. When all requirements for a feature were finally set, the developers quickly programmed the design requirements into functional software prototypes. The prototypes were then tested at Parental Health through user interactions. The findings and feedback from the user interactions were incorporated into the user stories and design requirements, which were then sent again to the developers and addressed with revised prototypes. The team members held regular meetings and scheduled checkpoints, but also had occasional ad hoc meetings whenever there were issues to discuss or decisions that needed to be made quickly.

The MISTY software was written in .NET Framework using SQL server on the back end. It was packaged as a small program that could be installed on Windows operating PCs. The home screen of MISTY included large buttons that linked the users to various features, such as the MISTY Now Web site for exchanging and communicating information, a faith Web site, and an exercise Web site. The selection of button icons and symbols were aimed at neutrality and universality, in addition to intuitive understanding and clear visibility.

#### 5.5.2.5. Testing and refinement

A beta version of MISTY was released in the first quarter of 2011. Since idea generation, which took place in late 2009, the development took about 18 months. The beta version was a complete software that included all of the features that were outlined as the system requirements. It was distributed through organizations that were planned as the channels with which MISTY would be fully launched.

Feedback on MISTY's functions, operational characteristics and design quality were collected through the distributors, from end users, from market evaluations, and from the general public who may belong in the potential user population. User evaluations, which mostly came through the organizations that distribute MISTY and provide the services to the end users, enabled the team to make changes to refine the design and improve the system functionality. The feedback and suggestions for design changes were evaluated and prioritized based on their importance and overall impact. Only those that would be able to sufficiently enhance the user experience were implemented. For example, while one of the organizations reported that few of its end users were experiencing problems seeing a certain shade of green on the MISTY screen, the team passed on changing the color schemes as it was found to affect only a very small number of the user population. When a potential change in the system was evaluated to have a significant positive impact, the change was quickly implemented. For example, while the original system included emergency response functionality through which older adults could touch the button on the MISTY screen to call for help, the field evaluation revealed that it was not being used although it was place right on the center of the screen. The team decided that it was "taking up real estate on the screen" while it was not being used, and replaced it with wellness components. Aside from the replacement of the emergency response feature, only small changes were made to MISTY since its original beta release.

Parental Health also looks at market data and industry rankings to evaluate how they are doing at various aspects of the system. The market data usually includes evaluations on MISTY's performance and qualities, such as ease of use, based on comments from customers who are involved in purchase decisions. The customer feedback, which entails comments around why they choose MISTY versus its competitors, has continued to confirm that MISTY is one of the most user-friendly products in its domain.

The feedback and reactions from the general population are collected through various events such as health fairs. For example, the team set up MISTY on a couple of computers at an event for people to try.

Then they observed and watched people interacting with MISTY without intervening in their experiences to “see what they would do without being guided and without someone leading them through the process.”

### 5.5.2.6. Production and post-sales activities

The full production and distribution of MISTY basically followed the same process as that of the beta release. As a software platform, MISTY started with the beta version and was constantly refined and upgraded throughout its broader distribution. Mr. Hudsmith, the CEO, led the sales and marketing team during the early releases. Later, as MISTY grew larger, David Gamble joined in as the VP of sales.

MISTY was distributed to the end users through organizations and companies including “large payers, self-insured employers, assisted living facilities, behavioral health entities, and workers’ compensation,” and is not sold directly to individual consumers. While the key functionalities of MISTY were common across the organizations, some features were configured and customized for each organization’s needs. For example, if an organization needed its end users to connect to a certain application or Web site they use, the links provided with MISTY were configured to enable such connection.

The end-user costs for using MISTY varies by the size of the user base associated with each organization or company. On a per-user basis, MISTY is priced up to $49 per month in small-scale rollouts, but can be below $1 per month when rolled out to a larger scale. Because the software cost diminishes when spread across users on a per-member, per-month basis, the price itself hadn’t been a big issue.

One area with which they have experienced problems with is the costs related to internet connectivity. They have found that if a user is in a home setting, having an internet connection may be more expensive than having the MISTY software or a piece of hardware to run the program on. Thus, the team has identified connectivity as a challenge that has slowed down broader adoption of the product. However, they are working to solve this issue through a couple of different ways. For example, they are partnering with internet service providers and services, such as Comcast’s Internet Essentials Program, to provide the users with broader access.

In addition to the primary users that include older adults and their caregivers, MISTY has also been successfully distributed to the secondary target market including those with behavioral health issues or people in rehabilitation centers. During the initial distribution of MISTY, the ages of its users were mostly between 75 and 85. Since the early releases of MISTY, its user base has broadened to include people of various ages – “Over time, we have migrated to managing overall chronic conditions, and now have people that vary in age across the spectrum.” As MISTY grew more popular in drug and alcohol rehabilitation facilities and behavioral health, the average age of its users has gone down considerably.

The team continues to seek feedback from its users from across the age spectrum. Overall, the feedback has been positive as they "all seem to like interacting with it and using it." Also, based on the perception from users of various ages, MISTY is "definitely not viewed as something that is granny-specific," but something that can appeal more universally.

Parental Health is now thinking about the future of MISTY, which was built as a platform that can evolve and be reconfigured. The team has identified several features – health risk assessments, health education, smoking cessation, and video coaching – that could provide benefit to the users with a more effective management of health and wellness. They are also exploring different platforms – including mobile devices – with which some features of MISTY can operate on.

#### 5.5.2.7. Summary and implications

This section presented a case description for Parental Health's MISTY with the processes, activities, and decisions throughout the design, development, and distribution. MISTY started with a personal need that is experienced by many older adults, family caregivers, and clinicians, as well as people of all generations who deal with issues related to management of health conditions. Providing benefits and meeting vital needs were the key objectives for the value-centric project. Also, MISTY was designed to ensure ease of use, system connectivity, and work flow integration, which were defined as the key design requirements based on an analysis of the needs and lifestyles of users with different roles.

The initial idea for was further confirmed and elaborated with interviews and focus groups with potential users including older adults, family caregivers, and clinicians involved in professional care of older patients. The user inputs were used to create user stories and scenarios with personas describing users of different roles in a caregiving situation. The system features and design requirements were defined based on an analysis of the user stories. Throughout the initial release and full distribution, user feedback is collected both directly and through organizations and market evaluations to inform design changes and directions for future improvements.

The key activities and decisions that took place during the making of MISTY are summarized in Table 55. As shown in Table 55, direct and indirect collection of user feedback was carried out during all stages of design, development, and distribution. During the early phases, the development team directly interacted with potential users to gather needs and requirements to identify functional applications and design characteristics that would effectively deliver the intended benefits. On the other hand, during the later stages, user feedback was gathered through various channels, mostly through their distributors but also by direct observation, to understand user experiences and to find ways in which the system could be improved. It can be seen that, while user feedback played a central role in the early stages and the post-design phases, user interactions were somewhat limited during the actual design processes. It can be discussed that expanding the user interactions for prototype testing during the detail design stages may help to detect potential design problems prior to market release and to understand behaviors of users with various characteristics. Also, during the system-level design, the user stories and scenarios can be made into a more user-driven process where potential users get involved in the writing, analysis, and evaluation of the stories to directly communicate needs and expectations of the system.

**Table 55. Summary of the MISTY case description**

| Design stage | Key activities and decisions | Implementation of user involvement | Consideration on the adoption factors |
|---|---|---|---|
| Planning | − Overall needs assessment<br>− Outlining project objectives<br>− Defining target markets (primary and secondary) | − Personal experience and observation | − Usability<br>− Value<br>− Technical support<br>− Confidence<br>− Emotion<br>− Social support<br>− Independence<br>− Experience |
| Concept development | − Collection and assessment of user needs<br>− Concept selection<br>− Defining key system components and features<br>− Rapid prototyping | − Interviews and focus groups with potential users (older adults, family caregivers, and clinicians) | − Usability<br>− Value<br>− Emotion<br>− Social support<br>− Lifestyle fit<br>− Affordability |
| System-level design | − Development and analysis of use cases and scenarios<br>− Outlining main operations<br>− Defining overall design requirements for users of various roles | − User stories (indirect, based on interview results) | − Value<br>− Interoperability<br>− Usability<br>− Experience<br>− Lifestyle fit |
| Detail design | − Defining specific design requirements<br>− Detailed user interface design and software development<br>− Outsourcing<br>− Prototype development and testing | − Interactions with users for prototype testing | − Value<br>− Usability<br>− System reliability<br>− Technical support<br>− Experience<br>− Emotion<br>− Interoperability |
| Testing and refinement | − Initial release of beta version through existing organizations<br>− Prioritization of suggested changes<br>− Implementation of design changes | − Collection of user feedback (through organizations, market evaluations, and direct observation) | − Accessibility<br>− Service trust<br>− Value<br>− Usability<br>− Confidence |

| | | | |
|---|---|---|---|
| Production, distribution, and post-sales activities | – Full-scale distribution through organizations<br>– System configuration and customization | – Collection of user feedback (through organizations, market evaluations, and direct observation) | – Accessibility<br>– Service trust<br>– Value<br>– Usability<br>– Affordability<br>– Interoperability<br>– Lifestyle fit<br>– Independence |

While some factors were more emphasized than others, the MISTY project was successful in that it addressed a complete set of the adoption factors. Some factors were considered from the planning stage as part of the project objectives. These factors include value, usability, emotion, technical support, social support, and independence. Other factors such as lifestyle fit and interoperability were incorporated into the design and development decisions as they emerged through user studies during the concept development phase. Although not discussed explicitly, accessibility and service trust can be discussed to have accounted for the decision to distribute MISTY through existing organizations rather than selling it directly to individual consumers.

Several design implications and suggestions, as listed below, can be identified and discussed from the description of the MISTY project to inform future technology-enabled systems that aim to address issues around aging-in-place, formal and informal caregiving, and management of chronic conditions.

- Collectively consider the needs of the stakeholders: While older adults are at the center of the caregiving situation, the user segment is likely to include other players such as family members, professional caregivers, and healthcare providers in clinical settings. If a system is designed to have multiple players and stakeholders come together, it needs to be designed in a way that fits the varied needs of the users with different roles.
- Ensure system connectivity and service alignment: Technology-enabled systems for caregiving and health management are likely to touch upon the work flow and organizational practices that are already established. Thus, it is important to ensure that a system can fit into the existing settings and contexts without causing interference. In addition to the process connectivity, the physical and technical connectivity also needs to be ensured. It would be better to have systems built for operation on platforms that are readily accessible, usable, and equipped with channels of connection, rather than building on a novel platform.
- Consider relationships between needs: MISTY was planned and developed around the close connection between emotional needs and health-related requirements. Systems that aim to address

such issues would also need to be built with consideration on other issues and needs that may be closely connected.

The MISTY case description points out a few insights and directions for product development in general as listed below. These implications can apply to products of various types across domains. It can be seen that the implications are similar to those generated from the e-Home case.

- Iterate quickly and often throughout various stages: The design and development of MISTY involved numerous iterations from the concept development stages to the detail design phase and finally throughout post-sales activities. The iterative process can help to detect problems, identify areas of improvement, and continuously enhance system quality.
- Make prototypes: The development of PARO involved rapid prototyping from the concept development stage. More prototypes were developed as the requirements were specified. The functional prototypes enabled the team to understand user experiences and to quickly identify necessary design changes.
- Focus on the main goal: At various stages, the team consciously made an effort to stay the course and work on meeting project goals. It is easy to divert from the main objective when various technical components and numerous decision points are involved. However, it is important to keep the focus on realizing intended purposes and meeting the main objectives to develop a system that effectively address the user needs.
- Talk to the users: The user stories and scenarios that guided the overall design of MISTY were largely based on the results and findings from user interviews. User feedback helped the team throughout detail design and post-sales evaluation by enabling effective verification of prototype performance and identification of necessary design changes.
- Maintain close communications among the development team: During detail design, Parental Health and the software developers communicated frequently through regular meetings, ad hoc meetings, phone calls, and online channels. While it may be more important for project like MISTY where parts of the development processes are outsourced, ensuring frequent communication among team members is essential in the design of any systems as it is likely to involve multiple people with different roles.

### 5.5.3. Case 3: PARO by AIST

The therapeutic robot PARO was developed to address issues and shortcomings in existing methods and practice of caregiving. The ideas around the design of PARO were developed with multiple design iterations and prototype testing. Prototypes were made and tested from the early concept development stage, and multiple generations were built before PARO was commercialized. From one generation to the next, the design of PARO was changed and improved with feedback from potential users and results from clinical trials. As a commercial product as well as a research project, PARO is constantly being tested to study its clinical efficacy and user satisfaction. This section presents a case description to trace how PARO was designed, developed, distributed, and evaluated. The methods of user involvement in the design and evaluation stages are described along with the activities and decisions that took place during development.

#### 5.5.3.1. Planning

The ideas around the basic features that later became to be developed as PARO were first conceived in 1993 by Dr. Takanori Shibata, then a research scientist at the National Institute of Advanced Science and Technology (AIST) in Tsukuba, Japan. While studying the techniques and applications of robotics and artificial intelligence, he discovered that caregiving and disease management would be new areas of opportunity where robots would be able to deliver value.

Based on a review of existing means of caregiving, Dr. Shibata found that the use of a robot would be helpful in several ways. Mainly, an opportunity was identified as an assistive tool for providing and managing long-term care of chronic conditions and diseases such as dementia. While there is no permanent cure for dementia, there has been evidence suggesting that providing positive emotional stimulations can help better manage behavioral and psychiatric disturbances to prevent further development of related conditions (Shibata, 2012). More specifically, it was thought that a therapeutic robot could be preferred over animal therapy. If designed appropriately, a therapeutic robot would be able to deliver the key benefits of animal therapy, including improvements in psychological, physiological, and social conditions, while not requiring the caretakers to have the burden of having to take care of a living thing or be open to risks of possible injuries or infestations. Dr. Shibata also pictured that a therapeutic robot would be fit for use in nursing homes and other care facilities to help patients with managing stress and emotions.

Alternative opportunities and application areas were identified as well. While the primary target for a therapeutic robot was defined as older adults in need for a long-term care of chronic conditions, it was also thought to be useful for children and people of other ages with behavioral impairments or developmental disabilities, and also for older adults who live alone and could benefit from increased communication and companionship.

#### 5.5.3.2. Concept development

One of the objectives of the project was to provide a better option for people who could benefit from animal therapy but could also be vulnerable to related risks. While the objective was described as a purpose statement, the potential for being a substitute for animal therapy and pets also informed the decisions around the overall physical form. That is, to be able to provide benefits similar to those of animal therapy, PARO needed to look and behave like a friendly animal, in addition to delivering its therapeutic effects. Also, PARO needed to look and feel like a pet rather than a robot so that people would be attracted and drawn to interact with it rather than feeling intimidated or skeptical.

Multiple alternatives were generated as candidates for the shape of the robot. One alternative was to make it so that it looks like a familiar animal - such as a dog or a cat - that people commonly have as their pets. Another option was to resemble the shape of a less familiar animal that most people have minimal knowledge of. Lastly, a possibility was to base the shape of the robot on an imaginary animal or fictional character.

Based on a consideration of acceptability, possible subjective interpretations and user perceptions, it was decided that PARO would take the form of a baby harp seal. The option of taking the form of a familiar animal was avoided because most people have existing knowledge and experiences that can cause its users to expect too much from PARO. It was decided that using the shape of an unfamiliar animal would be more acceptable because people wouldn't be comparing its movements and behaviors with a real live animal. Among different species of unfamiliar animals, a baby harp seal was chosen. A baby harp seal was evaluated to be appropriate as it was found, from a set of interviews, that most people did not know exactly what a harp seal was and did not have experience of interacting with one (Shibata and Tanie, 2000). Also, it was selected as it had a shape that could be comfortably held by people if designed with an appropriate size and weight. In other words, the baby harp seal was chosen partly because of its "ergonomic shape." In addition, baby harp seals have an appearance that is perceived as cute and attractive by most people. By making PARO as a robot that resembles a baby harp seal, Dr. Shibata thought that potential users would be attracted and would "want to have it as a pet," and that people who have PARO wouldn't be shy to show it to others.

In 1998, while working as a visiting research scientist at the MIT Artificial Intelligence Laboratory, Dr. Shibata developed the first prototype of PARO. The initial prototype was "hand-made from scratch," and was developed to see how the idea could be realized. Another prototype was then built with some design changes. Similar to the initial prototype, the second prototype was also built to demonstrate the concept in a physical form. Functionalities were limited in the early generations. The next prototype was more advanced in its mechanical structure. This prototype, which was the third generation of PARO, had seven actuators that dictated the system behaviors. While the third prototype was able to demonstrate many of the technical functions, it still used parts that were readily available, rather than building parts that were optimized for the particular system.

Being durable and practical became the key concern for the fourth and fifth generations. For theses prototypes, physical form and mechanical parts were built so that PARO would be able to withstand practical use environments and situations such as clinical experiments, home usage, and therapy in hospitals or nursing homes. The fifth prototype was tested with people to identify the design changes that would be necessary for developing PARO into a marketable product. It was shown to the general public at technical exhibitions, where Dr. Shibata conducted questionnaires. Also, the fifth prototype was tested at nursing homes and children's hospitals in Japan for three to four months to evaluate its effectiveness, acceptability and functional performance. During the prototype testing, functional problems were identified as people interacted with PARO. When a malfunction was found, the mechanical parts inside PARO were examined to identify problem areas and potential causes.

#### 5.5.3.3. System-level design

Prior to the full-scale development, several key requirements were outlined to guide the design stages. A main requirement was that PARO should be durable and robust. Since PARO was aimed to function as a substitute for a pet, it needed to withstand various external forces and hold up for a long period of time. More specifically, PARO was designed to "survive" for more than 10 years to have a "life length" that is comparable to that of a typical dog. The duration was set to meet the length of time that a user would expect to live with a pet. The reliability requirement was also emphasized to address potential issues in user interactions in terms of confidence. It was found that when people were often afraid that they may break it when they were first introduced to PARO without much prior experiences.

Another requirement was defined around the physical form of PARO. While the shape and appearance of a baby harp seal were selected for user acceptance, other physical measures also needed to be defined so that PARO can effectively interact with people and deliver the intended benefits. Since the human cognition is stimulated by sensory inputs, it was decided that the size, weight, and temperature would need to be defined so that interacting with PARO can generate positive associations as perceived by its users. Based on the requirement, it was decided that PARO would be designed so that it feels and weighs similar to a human baby when held – "it should be very comfortable, and needs to stimulate people who have experiences related to having children or grandchildren." Accordingly, the current version of PARO, which is the eighth generation, has a length of approximately 55cm and a weight of 2.7kg (Shibata, 2012).

The main information flows and interactions were outlined as well. Since an objective was to develop a robot that can behave similar to a live pet, it was decided that PARO would need to be sensitive to external stimulation such as touch, and that it should show reactions to system inputs such as voices. Thus, a requirement was defined to design PARO so that it shows actions and reactions that can be interpreted by people those that come from a pet with "a heart and feelings."

Starting with the sixth generation, PARO was developed as a full-scale product. Based on the findings from the previous stage, the sixth generation was planned to be built with modular design. The main mechanical parts – the actuator systems, sensors, and recharge functions – were built into modules which can be assembled to form the main body of PARO. The modular structure enabled easy assembly. The modular design was also employed to allow easy repair and maintenance – "So if PARO has any malfunction in a module, it can be replaced."

The sixth version was different from the earlier generations in that in was built with mechanical structures that were defined with a complete system-level design. The sixth generation was also used to confirm its durability requirement. Although it was not yet a commercial product, Dr. Shibata began a broader testing with potential users outside of Japan when the sixth generation was developed. For example, in 2002, PARO was exhibited at a science museum in London for 45 days from January to March. During the exhibit, PARO was shown to about 110,000 people who visited the museum. PARO did not experience any functional problems during the frequent interactions, which confirmed its ability to withstand frequent interactions.

#### 5.5.3.4. Detail design

A number of different parts and components were designed and produced to realize the interactive features that were outlined during the earlier stages. Similar to its early prototypes, a total of seven actuators were designed to enable PARO's motions and reactions. The seven intelligent actuator systems were built to tolerate forces exerted by users and to move its parts without noise. Various sensors enable its interactions with users and the environments. PARO can sense light, sound, touch, and motion with two light sensors for stereo vision, three microphones for speech recognition and sound localization, two tactile sensors on its whiskers, another set of tactile sensors throughout its body, temperature sensors, and a posture sensor. PARO also has two computer chips and several microchips that provide hierarchical distributed computing to process inputs detected by the sensors and to dictate its movements and behaviors. The artificial intelligence also allows PARO to recognize a new name given by its owner and to learn which behaviors are more favored, which enables it to build a relationship with its user as a pet and a companion.

In order to design PARO as a lovable baby harp seal that is safe to use, the materials were chosen to make its body soft and warm. PARO's body is covered with artificial fur that is antibacterial and anti-dirt and has a finishing that prevents hair loss. The internal circuit has an electromagnetic shield that prevents it from interfering with other devices, such as a heart pacemaker, that may operate in its proximity when used by older adults. In order to make its movements and sounds realistic, lively, and cute, an observation was conducted around the appearance of baby harp seals and the cries they make.

Ease of use was another important design requirement that was emphasized in the design. Since PARO was targeted at older adults with dementia and children with developmental disabilities, it was essential that it could be operated easily by everyone, including those with limitations in physical and/or cognitive capabilities. This requirement was met by putting no other controller except for a power switch on PARO's body. The battery charger was designed in the shape of a baby pacifier which could be simply plugged into its mouth – "I designed PARO to be used very easily. There is one switch and one charger. That's all."

The early prototypes were built mostly by Dr. Shibata himself, with the help of some students whom he worked with. However, as PARO became fully developed, he felt that he needed to work with specialists who could produce and supply complex mechanical and electrical parts. After he went back to AIST, he started working with companies that specialize in the design and development of the necessary parts, including mechanical design, electronic circuit board design, programming, and more. In order to select the companies to collaborate with and to outsource the development to, he did a technology assessment to search for companies with available technologies and evaluated their individual performances. For the eighth generation of PARO, which is the current version that is commercially available, he worked with more than 80 companies who were responsible for different parts of PARO.

#### 5.5.3.5. Testing and refinement

PARO was tested and evaluated more extensively as it became fully developed and got close to its commercial launch. Starting with the sixth generation, which is the first prototype with a modular structure and robust design, PARO was tested with a large number of potential users in varied settings. The experiments and trials aimed at evaluating and ensuring its durability, reliability, acceptability, perceived usefulness, and clinical efficacy. Overall, evaluations were done in three main directions: internal assessments, acceptance analysis, and clinical trials.

Prior to user trials, each PARO was internally tested for its dependability and examined for any defects. Various methods were used to ensure that each PARO can work in various use environments without functional problems. The tests included a voltage test, a drop test, and a 100,000-time stroking test. Each PARO was made to withstand these external forces. In addition to conducting tests on each PARO as a whole, each individual functions and components went through internal evaluations as well.

The user acceptance and perceptions were evaluated with questionnaires and user meetings. The survey collection started with the fifth prototype and expanded when the sixth and seventh generations were developed. Over time, Dr. Shibata and his research team collected questionnaires from about 2000 people in seven countries, including Japan, United States, Korea, Sweden, Italy, Brunei, and United Kingdom. In the questionnaires, people were asked to indicate their expectations for PARO, describe their perceptions toward the technology, and give feedback based on their interactions. When the questionnaires were distributed to older adults, the Geriatric Depression Scale (GDS), a standard set of self-assessment questions used for identifying depression experienced by older respondents, was included. For older adults and young children with who may find it difficult to read questions and options and answer verbally, face scales were used as a simple way to assist respondents as they expressed their emotional states. The face scales included seven or more faces with different facial expressions, and the respondents were asked to point at the face that they feel most similar with. Also, Profile of Mood States (POMS), a rating scale with a set of adjectives, was included in the questionnaires to assess respondents' mood states.

In general, it was found that people had positive perceptions toward PARO and placed high value on its features. However, with a principal component analysis, which is a statistical technique that transforms a large number of variables with possible correlations into fewer variables orthogonal from one another, two major directions were found on how people perceived PARO. In one component, PARO was found to be associated with qualities of a pet. In the other dimension, PARO was expected to perform as a therapeutic tool. An interesting finding was that these two dimensions reflected cultural differences. In the US and Brunei, PARO was rated high on both dimensions, meaning that people in these countries expected PARO to perform as both a pet and an assistive tool. In Korea and Japan, the ratings were much higher on the "PARO as a pet" dimension compared to the other, which indicates that people in the two countries expected PARO to behave like a pet. On the other hand, in the European countries, ratings were higher on the "PARO as a therapeutic tool" dimension, meaning that the respondents from these countries valued PARO's therapeutic features higher than its ability to behave like a pet. The cultural differences were thought to have come about from the respondents' prior experiences and established mental models related to the interactions between humans and animals. For example, animal therapy was more popular in Europe compared to Asian countries. In many European countries, people were well aware about animal therapy programs and their clinical effects, whereas, in Asian countries, details about animal therapy were less known and related intervention programs were not widely available. Also, it was found that people in European countries thought of their pets and other animals as equals to human beings, while people in Asian countries often thought that animals are lower beings compared to humans. In short, various factors including availability of related programs, people's awareness of the programs, and people's perceptions and valuation of pets were thought to be associated with the cultural differences in expectations toward PARO.

The user inputs also helped Dr. Shibata to identify directions in which the designs and features can be changed to improve acceptability. For example, during the exhibition in London, some people were frustrated when they tried communicating with PARO because it did not respond or react well when it was spoken to in English. On the other hand, people who interacted with PARO in Japan gave higher ratings for PARO as it was able to recognize some Japanese words. Since PARO was planned for commercialization in a global market, it was later improved to recognize simple words in multiple languages. The current version of PARO, which is its eighth generation, has been made to recognize Japanese, German, Dutch, French, Italian, and English, depending on the country it is being sold in.

The scale of clinical trials expanded with the development of the seventh generation. The clinical trials were conducted to evaluate the therapeutic effects of PARO in three dimensions – psychological, physiological, and social. More specifically, many of the tests were aimed at analyzing if interacting with PARO can improve its users' emotional states, reduce medication usage, and promote positive behavioral changes. While the questionnaires were mostly done by Dr. Shibata and his research team, the clinical trials were conducted with regional distributors, other research laboratories, and care facilities such as nursing homes and hospitals. The professionals he worked with include academic researchers, government officials, physicians and therapists. Some of the clinical trials were planned as long-term tests. For example, some nursing homes are still using the seventh generation of PARO, and there is one that has been using it since 2003 for a continued analysis of its effects. Also, many of the clinical trials on the effectiveness of PARO are designed as randomized controlled trials, where participants are randomly assigned to different treatment groups for comparison. For example, in a clinical trial in Australia, an experiment was conducted to compare PARO to reading books. In New Zealand, PARO was tested in an experiment with 40 participants, and was evaluated against animal therapy that involved interactions with dogs. In addition to these countries, PARO has been evaluated with clinical trials and studies in Italy, France, Germany, United Kingdom, Denmark, Sweden, Hong Kong, Singapore, Canada, and United States. Many of these studies are ongoing.

Based on quantitative and qualitative analysis of data from the clinical trials, PARO was found to be effective for improving conditions related to loneliness and isolation in older adults (Robinson et al., 2013). Based on observation of participants in multiple clinical trials, it was found that older adults showed improvements in communication and sociability when they interacted with PARO (Shibata, 2012). Psychological benefits were also observed as interacting with PARO was found to improve older adults' emotional states and mood (Moyle et al., 2013). In the case of people with dementia, PARO was shown to improve the patients' emotional and behavioral conditions. For example, the groups that interacted with PARO experienced less wandering or loitering, showed less aggressive behaviors, and displayed a more calm emotional state compared to those who didn't interact with it. The changes in mood and behaviors were also observed with quantitative assessments, such as electroencephalogram (EEG) and functional near-infrared spectroscopy (fNIRS) recordings (Shibata, 2012).

#### 5.5.3.6. Production and post-sales activities

The eighth generation of PARO was developed in 2004. While the features and appearance remained the same as the seventh generation, the eighth version was different as it was refined for commercialization. With its eighth generation, PARO was first launched in Japan in March 2005. Since PARO was found to be better accepted as a pet in Japan, as indicated by the survey results discussed earlier, it was first sold to individuals rather than care facilities and organizations. PARO was introduced to the general public through a lot of media coverage, and individuals got in contact to purchase PARO. The first 200 PAROs in stock were sold in three days, and 80 more PAROs were sold during the following week. Because of a limited production capacity of 80 units per month, orders were temporarily halted in May 2005. A total of about 400 PAROs were sold by then. They started taking orders again as they secured enough units in stock, and collaborated with department stores in Japan to start selling PARO to individuals as a pet. An accumulated number of 500 PAROs were sold by the end of year 2005. By then, about 80% of the customers were individual users. As of February 2014, over 2000 units have been sold in Japan. A little over 50% of them were sold to individual users, while about 40% has been purchased by hospitals, nursing homes, and other care facilities. The rest have been purchased by other organizations, such as museums. Among the individuals who purchased PARO in Japan, about 60% are 60 years of age or older. Another 33% are in their 40s and 50s, many of whom are taking care of their parents.

Denmark was the first to accept PARO in Europe. Based on a national project, the Danish Technological Institute concluded that PARO would be a very effective tool to assist caregivers and therapists in healthcare facilities. With the result, the institute decided to distribute PARO to care facilities in Denmark and professionalize its adoption and use by training and certifying caregivers, therapists and managers of the care facilities.[40] In Denmark, PARO is used as a therapeutic tool, rather than a pet, and is only sold to institutions with certified professionals. In the beginning, PARO was used in Denmark mainly for dementia care. Its application area has expanded since then, and PARO is now being used for people with developmental disabilities, autism, and other behavioral conditions in Denmark. Also, for care facilities that are owned or managed by local governments, the purchase of PARO is subsidized with government funding based on approval. As of February 2014, there were about 300 PAROs in Denmark, which has a total population of about 5.6 million, and more than 70% of municipalities, or local governments, have adopted PARO.

PARO had cleared many global regulations by year 2008, including the European Restriction of Hazardous Substances Directive (RoHS) regulations and the Conformité Européenne (CE; European Conformity) certification. In 2009, PARO was approved as a bio-feedback medical device by the Food and Drug Administration (FDA) in the United States. PARO was first introduced to the United States in September 2009. Currently, PARO is being used in about 30 countries.

Several factors influenced the decisions related to the sales and distribution of PARO. A key area of concern was the perceived affordability. PARO is currently priced at $6000 per unit in the United States, which is perceived by many people as expensive. In order to overcome this hurdle, Dr. Shibata and his team tries to communicate the potential cost efficiency by comparing the cost of getting a PARO to the costs associated with owning and taking care of a real pet and to the costs of additional medications and clinical care people may need. Also, a lease-to-own pricing model has been introduced in the United States as an alternative to a one-time payment system. In the alternative system, individuals or institutions can use PARO for $200 per month and own one after 36 months. It was found that this pricing system works particularly well with organizations as they found it easier to execute budgets when small costs are distributed over time. Subsidization models and insurance support are being explored as well. For example, the city of Okayama in Japan has started to subsidize individual rentals of PARO with their public welfare insurance. Dr. Shibata believes that “it is a good test,” and that more local governments and organizations will follow to make PARO more affordable – “it’s just the beginning.”

The importance of technical support a factor that was emphasized as the customer service model was developed. It was thought that “the reputation of PARO depends on the service,” and that “without having good service, customers lose their trust in it.” In order to keep all PAROs well-functioning for a long time, the owners are asked to send their PAROs to a PARO Clinic once a year. At the PARO Clinic, each

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[40] Project - Robotic seals for welfare & comfort, http://www.dti.dk/projects/project-robotic-seals-for-welfare-and-comfort/26231?cms.query=paro

PARO that was sent in goes through a “health check-up,” gets cleaned, and has its battery replaced if necessary. Dr. Shibata and his team have set up PARO Clinics in the countries that PARO is being sold in.

Experience is another factor that was found to be important during people’s initial use of PARO. During its early releases, individuals who purchased PARO were asked to provide feedback by completing a questionnaire. According to questionnaires from about 500 individuals, it was found that those who experienced problems interacting with PARO were the ones who purchased PARO without trying it out first. That is, people who simply ordered PARO based on the information they got from TVs or newspapers were more likely to report problems compared to people who had a chance to see, touch, and hold a PARO at an exhibit, an institution, or at someone else’s place. Based on this finding, Dr. Shibata and his team decided to “not to sell PARO to individuals who have never interacted with PARO.” Now, when they get individual orders, they first ask them if they have any experiences with PARO before the orders are completed. If the customers are found to have no experience of interacting with PARO, they are then directed to museums, events, or organizations where they can be first introduced to one. To improve user experience and satisfaction, Dr. Shibata and his team tries to ensure that its customers have a pretty good idea of what a PARO looks, feels, and acts like before making a purchase.

Lastly, it was considered important to ensure the independence and autonomy of the older adult users. Although PARO was developed to deliver therapeutic effects to older adults with dementia, Dr. Shibata was careful not to emphasize the clinical purposes too strongly. It was thought that overly emphasizing its usefulness for managing dementia would create a negative association as well as a stigma. That is, if the dementia care functionality was emphasized too much, potential users may be apprehensive toward interacting with PARO as it may cause other people to view them as a dementia patient who is in need of help. While it was found to be acceptable and even helpful to emphasize the dementia care functionality when providing PARO to professionals and to organizations, its pet-like features are more emphasized when it is sold to individuals. This effort to avoid stigmatization enabled a word-of-mouth effect in the distribution of PARO, in which existing users show and recommend it to other people they know.

While the eighth generation of PARO is a complete product that has been commercially available for over nine years since its first introduction in 2005, Dr. Shibata believes that there are still many topics to be studied with PARO, and that it could still be improved for enhanced user experiences. An example of the continued effort on testing and evaluation can be found in Australia, where a large-scale randomized controlled trial, which is planned to involve about 30 nursing homes with about 400 older adults, is scheduled for a more detailed and generalizable study of PARO’s clinical effects. Also, design changes are currently being implemented to the ninth generation of PARO to address battery life issues that have been brought up by some of the current users. This upcoming version is expected to enable its users to live with PARO without having to charge it often or having to wonder about how much power PARO has left at some point in their interactions.

#### 5.5.3.7. Summary and implications

In this section, a case description was presented to trace the design activities and strategic decisions involved in the development of PARO, a therapeutic robot in the shape of a baby harp seal. As a novel application of robotics and sensor technologies, PARO was developed to address issues of isolation and loneliness in older adults and to provide therapeutic effects to older adults with dementia and people with developmental or behavioral disabilities.

While its commercialization was in plan from the beginning, PARO was also a long-term research project that involved repeated experiments, user evaluations, and clinical trials. The results from laboratory experiments, feedback from potential users and findings from randomized controlled clinical tests were referenced to assess its acceptability and effectiveness. The results were also incorporated into the design of PARO in various ways to improve its features from the early generations to a complete product. With a global commercialization in plan, PARO was tested and evaluated with users and researchers from a number of different countries to assess cultural implications and to seek ideal positioning and placement.

Several design requirements and functional qualities were considered from throughout the design, development and distribution of PARO. It was important for PARO to demonstrate its psychological, physiological, and social benefits to its end users and institutional buyers clearly. Also, because PARO is something that people do not have relevant knowledge of, enabling potential users to see and touch PARO was considered to be essential for its adoption. Durability, ease of use, and aesthetics were other factors that were emphasized for increased emotional appeal and user confidence. Later during the process, customer service, and cost issues influenced decisions around distribution and post-sales management. Table 56 summarizes the case description with the key activities and decisions.

**Table 56. Summary of the PARO case description**

| Design stage | Key activities and decisions | Implementation of user involvement | Consideration on the adoption factors |
|---|---|---|---|
| Planning | − Defining project goals and application areas<br>− Technology assessment<br>− Defining target markets (primary and secondary) | − n/a | − Value<br>− Emotion<br>− Lifestyle fit<br>− Independence |

| | | | |
|---|---|---|---|
| Concept development | – Defining overall physical appearance<br>– Defining key features<br>– Development of early functional prototypes | – Interviews<br>– Questionnaires<br>– Prototype testing with potential users | – Value<br>– Conceptual fit<br>– Independence<br>– System reliability |
| System-level design | – Defining design requirements<br>– Implementation of design changes for prototype improvement<br>– Structural and functional definition of main parts | – Questionnaires<br>– Prototype testing with potential users | – Emotion<br>– Experience<br>– Conceptual fit<br>– System reliability<br>– Technical support<br>– Confidence |
| Detail design | – Development of preproduction prototypes<br>– Material selection<br>– Outsourcing of part manufacturing | – Prototype testing with potential users | – Emotion<br>– System reliability<br>– Usability<br>– Interoperability |
| Testing and refinement | – Internal quality testing<br>– Analysis of user perceptions and acceptability<br>– Implementation of design changes | – Questionnaires<br>– User meetings<br>– Observations<br>– Prototype testing<br>– Clinical trials and controlled experiments | – Value<br>– System reliability<br>– Emotion<br>– Conceptual fit<br>– Experience |
| Production, distribution and post-sales services | – Full-scale production and launch<br>– Differentiation of delivery channels between cultures<br>– Development of professional certification program<br>– Technical customer service | – Prototype testing<br>– Clinical trials and controlled experiments | – Service trust<br>– Accessibility<br>– Affordability<br>– Technical support<br>– Experience<br>– Conceptual fit<br>– Independence<br>– Social support<br>– Lifestyle fit |

While the initial ideas around PARO were conceived from research on capabilities of existing technologies and shortcomings of existing services, the following stages involved extensive user evaluations with prototype tests, surveys, and clinical trials. Various methods of user involvement were employed from the concept development stage to gather user feedback on functionality and acceptability. Later in the design process, more rigorous experiment methods were used in various settings to demonstrate and evaluate PARO's usefulness. The continuous development and rebuilding of prototypes with user inputs were described to be helpful and effective for identifying problem areas and necessary design changes before detailed design specifications were finalized. However, having demonstrated the therapeutic effects in various settings, it can be discussed that possible variations or similar products may also benefit from user involvement from the project definition stage.

The design and development of PARO were aimed at delivering emotional and clinical value with an interactive technology that is easy, pleasurable, and reliable in use. Thus, factors including value, emotion, usability, and system reliability were considered as essential. In order to ensure that these requirements were met, user inputs were collected to evaluate its acceptability. Other factors were also considered at various points, and the complete set of adoption factors, as defined in chapter 3, were covered at the end. Some factors were considered with a little different at one stage compared to another. For example, during the planning stage, independence was considered as a use context and living situation that PARO was developed to enhance and promote. In contrast, during distribution, independence was more considered in terms of the social visibility and perceptions around the use of PARO. In addition, some factors were rather addressed explicitly, while others were more implied. For example, the reliability factor was clearly defined as a design goal, while service trust and accessibility were less explicitly discussed while they affected the decisions around distribution channels.

The case description on the design, development and distribution of PARO points out several implications for future systems and solutions that aim to address issues around aging-in-place, dementia care, and management of behavioral and emotional conditions.

- Communicate through appropriate channels with targeted messages: An important thing that was found from the questionnaires with potential users was that people with dissimilar conceptual models and experiences may have very different expectations toward PARO. The finding strongly informed the ways in PARO was displayed and distributed. If a system can be perceived in various ways by people of different characteristics, the differences should be addressed in how information is communicated and how products are delivered for increased adoption.
- Consider relationships between issues and needs: During the user studies, various requirements and issues were found to be tightly associated. For example, experience and conceptual fit were found to be closely related in people’s perceptions toward PARO. Also, ensuring system reliability was discussed to have a positive effect on user confidence. It is likely for related systems to see such associations in various ways. For better user experience and increased acceptability, such relationships would need to be addressed with physical design and information communication.

- Clearly show and demonstrate potential benefits: Being a new type of technology, it was important for PARO to communicate its effectiveness to users and buyers who may not have any relevant experience. Other new technologies that may be a leap for its users in terms of experience may also be able to benefit from experiment results and endorsements.

More design implications and insights can be discussed for various types of technologies in general. The key learnings, which can be applied to various products across domains and generations, can be identified as listed below.

- Work with prototypes: A number of prototypes were developed from the concept development stage to demonstrate the features, test the system performance, and evaluate the effectiveness and acceptability. Having a tangible, physical prototype from the early stages enabled the collection of feedback throughout the design process.
- Build iteration into design practice: PARO was built with repeated iterations. Eight generations were developed as a whole, and each part and design component also went through iterative processes. By having an iterative design rather than going through a linear process, design changes and improvements were implemented quickly and effectively.
- Looks matter: While the functional features and practical benefits were defined as the primary objectives, it was essential for PARO to look and feel attractive, appealing, and lovable in order to deliver the intended values. It was found that the fluffy, cute, and lovable appearance of PARO was effective for attracting people, even those who were skeptical about the idea, to interact with it. It can be discussed that an appealing design is helpful for encouraging interactions and increased usage.
- Deeply consider perceptions and experiences: Prior experiences and established mental models of the potential users were considered at various stages from concept development to full-scale distribution. Analysis on the perceptions and expectations based on experiences and conceptual models informed and guided various activities in design and distribution. For increased acceptability, a thorough assessment of perceptions and experiences would be advantageous compared to simple usability tests.
- Talk to the users: Dr. Takanori and his research team utilized various methods to gather inputs directly from potential users throughout the design process. They also extended the effort to post-sales stages by collecting feedback from people who bought PARO. The team found the communications with users effective for identifying problem areas and generating design solutions that the team alone would not have been able to find.

- Focus on service delivery: Conscious efforts were made for providing necessary services to the individual and institutional users. It was thought that the availability and quality of customer service, such as the PARO Clinic, were important for building trust and improving user experience.

### 5.5.4. Integration of case study results

In the previous sections, the key activities and decisions during the process of planning, designing, developing and distributing have been described for three existing cases – e-Home for Seniors project by MIT AgeLab, MISTY by Parental Health, and PARO by AIST. The case descriptions included details of various user involvements during the design stages, including the methods, the main findings, and the implications on the design and delivery practices. Any considerations around the adoption factors, defined earlier in chapter 3, were discussed in the case descriptions as well.

It can be seen from the descriptions of the three cases that many of the key activities took place at the same stages. During the planning stage, all three cases included activities for understanding the target segment(s) and their overall needs to outline and define project objectives and application areas. The concept generation stage commonly included decisions on generating alternative concepts and selecting one for further development. This stage also consisted of defining main system components and design requirements and evaluating them with prototypes to guide through the following design stages. During the system-level design stage, the three cases were found to have conducted activities related to defining specific system requirements and outlining major system operations. This stage was followed by the detail design stage, where the design specifications for the system parts and components were finalized. During the testing phase, the systems were evaluated to identify directions for design changes and refinements. In the three cases, methods of user studies were employed to gather inputs on design suggestions and problem identification. The user inputs were then incorporated into design, based on assessments of their effect on the system performance and user experiences, prior to full-scale distribution. While e-Home did not enter the production and distribution stage as it was planned as a research project, MISTY and PARO were distributed through their respective channels and continuously evaluated. Also, while the two systems were initially released to the primary target populations, the user bases continued to expand into secondary segments that were defined during the planning stage.

Several differences between the three cases were observed as well. For example, while MISTY started with an assessment of needs based on a personal experience that involved observation of a potential user from the beginning, the general needs that informed the project definitions of e-Home and PARO were rather based on literature reviews and technology assessments during the planning stage. During the concept development stage, e-Home and MISTY began with collecting and analyzing user inputs for development of use cases, defining product concepts and describing key components, whereas the PARO case involved users for evaluating various concepts and testing early prototypes. The system-level design stage differed between the three cases in that it included development activities informed by user inputs from the previous stage for e-Home and MISTY, while for PARO, the overall design was a series of evolution based on prototype testing. The detail design and production of systems varied between the cases in terms of the degree to which the actual development and manufacturing processes were done within the project teams. The software and hardware components of the e-Home system were all constructed within the research team, which included members with various skill sets. However, it can be discussed that if e-Home were to be developed for commercialization with enhanced functionality and reliability, more professional development may be necessary. For MISTY, detailed and coding of the software was outsourced to developers, while the project team maintained continued communication with design requirements and feedback. The development and production of the commercial version of PARO included outsourcing of part manufacturing and in-house assembly, while the earlier prototypes were mostly developed within the research team.

During the testing phase, the e-Home system was tested with potential users in a field study, in which the participants interacted directly with the research team. The testing of MISTY involved collecting feedback on its beta version, which was release through its actual distribution channels. Since MISTY was distributed through organizations, the evaluations came through those organizations rather than directly from the end users. While the evaluations for e-Home and MISTY focused more on user perceptions and usability issues, the testing of PARO also involved controlled trials for an assessment of its clinical effectiveness. Also, because PARO was distribute through two separate channels – organizations and individuals – depending on the countries it is being sold in, feedback came through varied sources, including the end users, organizations and institutions, and external research groups.

After MISTY and PARO reached the market, customer service was provided to varied degrees. For MISTY, technical services were provided by the organizations that purchase the system and provide it to the end users, while for PARO, a dedicated service system handles the technical assistance activities. The differences in the delivery of technical services may be due to the differences in system components and overall design. That is, PARO, which is a hardware-centered product, may require more professional support, while issues around use of the MISTY software can be solved at the user level with troubleshooting mechanisms. The similarities and differences between the development practices for the three cases are summarized in Table 57.

**Table 57. Summary of cross-cases analysis: comparison of key activities and decisions**

| Design stage | Common activities and decisions | Differences between cases |
|---|---|---|
| Planning | − Defining target segment(s)<br>− Understanding overall needs<br>− Defining project objectives and application areas | − Source of overall needs identification: potential users vs. review of literature and existing technology |
| Concept development | − Generation of alternative concepts<br>− Final concept selection<br>− Defining main system components and overall design requirements | − Timing and purpose of user involvement: concept generation vs. concept evaluation and prototype testing |
| System-level design | − Defining specific system requirements<br>− Outlining major system operations | − Incorporation of user inputs: translation of inputs collected during concept development stage vs. prototype testing |
| Detail design | − Finalizing design specifications<br>− Part selection | − Responsibilities for actual development: in-house, outsourcing, and a mixed form |
| Testing and refinement | − User evaluation<br>− Identification and implementation of design changes | − Purpose of testing: user perceptions vs. objective efficacy<br>− Feedback channels: end users vs. organizations |
| Production, distribution, and post-sales services | − Full-scale distribution (except for e-Home)<br>− Continued collection of user feedback<br>− Expansion of end user bases | − Technical service channels: existing organizations vs. dedicated service structure |

User involvement was practiced to varied degrees across the three cases. For the development of the e-Home system, user inputs were gathered mostly during the concept development stage and the evaluation stage. During the generation and selection of its concept, inputs from potential users were gathered from focus groups and results from a previous survey study. With additional evidence from a literature review, the concept of the e-Home system was primarily defined based on the user inputs. After developing a complete prototype, potential users were involved in a long-term field study, during which they kept and used the system in their homes for 8 weeks. While e-Home was a research project that did not enter full production, the findings from the field study were analyzed to define implications for future systems.

During the development of MISTY, user inputs were gathered from the start of the project as the main objectives were defined from personal experiences and frustrations. Following the project definition, a large number of interviews and focus groups were conducted to develop user stories, and prototype testing was carried out with users as the product was being developed. After its release, user feedback were collected based on user observations to some degree, while the main channel of post-distribution feedback collection was the organizations who provided the system to the end users.

In the case of PARO, potential users were involved from the concept development stage with interviews, questionnaires and prototype testing. From the early prototypes, users were asked to interact with PARO and provide feedback to be incorporated into the following generations of the product. With the more advanced prototypes, when most of the design was finalized, the scope of user involvement to include clinical trials with randomized controlled experimental designs. As a combination of a commercial product and a research project, PARO is being continuously evaluated based on user inputs.

For all three cases, involving potential users early and throughout the development stages was essential as the ideas were new and unseen for many of the target population, and because the benefits they intend to deliver are those that may not be immediately tangible. With consideration of the potential gaps in knowledge, experience, and perceptions, the selection of the product concepts relied to some degree on the user inputs, and testing was done throughout the design activities with working prototypes. Table 58 shows a summary of the similarities and differences between the three cases in terms of the user interactions and user input collection practices during design and development.

**Table 58. Summary of cross-cases analysis: comparison of user involvement practices**

| Design stage | Common activities | Differences in user involvement practices |
|---|---|---|
| Planning | − n/a | − MISTY: personal experience and observation |
| Concept development | − Interviews and user survey for generating and/or selecting concepts | − PARO: user interactions for testing early prototypes |
| System-level design | − Defining system features based on user inputs from the previous stage | − PARO: continued prototype testing |
| Detail design | − Collection of user inputs for detailed design using various methods | − e-Home: digital user observation<br>− MISTY and PARO: prototype testing |
| Testing and refinement | − User observation for analyzing user perceptions | − e-Home: field study with questionnaires and interviews<br>− MISTY: collection of user inputs through distributors<br>− PARO: questionnaires, prototype testing, and clinical trials |
| Production, distribution, and post-sales services | − Collection of inputs from existing users (except for e-Home) | − MISTY: collection of user inputs through distributors<br>− PARO: user questionnaires and clinical trials |

Several conclusions around the adoption factors can be made from the three case descriptions. First, it can be seen that the relative importance of each factor varies by the stages of design. That is, at different stages of design, different factors may be considered more importantly than others which may be at the top priority during other stages. In general, value, or the potential usefulness, was considered throughout development, but was more emphasized during planning and testing when the project objectives were defined and later evaluated. On the other hand, issues around usability and interoperability were more emphasized during the detail design stage when the user interfaces were actually designed and developed. It was found from the MISTY and PARO cases that accessibility and service trust became important as they were identifying effective distribution channels and delivering their products to the end users.

The second conclusion can be found in the associations and relationships between factors. It was observed from the three cases that some factors may be more closely associated than others. For example, experience and conceptual fit were observed to be tightly coupled in that mental models relevant to the interactions of potential users with the systems were often formed by prior experiences. Also, value and emotion were associated in that a part of considerations around potential benefits included the emotional and social effects. During the later stages of the design processes, accessibility and service trust were found to be related as they together affected decisions around distribution channels.

Another conclusion is that a factor may assume different roles and have different implications depending on the activities or decision it is related to. For example, independence was commonly considered as an overall objective and a usage context in that the products were aimed at promoting independence and assisting those who are aging in place. However, during the later detail design stage, independence was considered more as a physical design issue in that the appearance of a system should not show any signs of dependency or frailty. Similarly, while social support was considered as an emotion-related objective during the early stages, it was rather considered as a possible way of increased distribution during the post-production stages.

Lastly, while some factors are easily defined and measured others were shown to be more difficult to explicitly define but rather discovered through user interactions. For example, in the PARO case, factors including value, usability, emotion, and reliability were explicitly written as product goals, whereas cultural issues around experience and conceptual compatibility were found through user interactions.

Table 59 shows a summary of the adoption factors that were considered throughout the process of design, development, and distribution in the three cases. Overall, the cases were analyzed to have successfully covered various factors that may affect the adoption and use. It can be seen that, across cases, more factors are considered during the actual design stages, while less factors are addressed during planning.

Also, based on the case descriptions, it was found that different factors are considered at various stages depending on the product type – hardware or software – and project orientation – commercial or research.

**Table 59. Summary of cross-cases analysis: comparison of adoption factors considered**

| Design stage | Common factors | Differences in considerations of factors |
|---|---|---|
| Planning | − Value<br>− Emotion<br>− Independence | − e-Home: affordability considered during technology assessment<br>− MISTY: Other factors such as technical and social support considered as project goals<br>− PARO: lifestyle fit considered for organizational use |
| Concept development | − Value<br>− Usability<br>− Emotion<br>− Social support | − MISTY: lifestyle fit considered for behaviors of family users<br>− PARO: reliability set as a goal for hardware durability |
| System-level design | − Value<br>− Usability<br>− Experience<br>− Lifestyle fit<br>− Technical support<br>− Interoperability<br>− Emotion<br>− Reliability | − e-Home: affordability considered for technology selection<br>− PARO: confidence addressed in connection with reliability |
| Detail design | − Value<br>− Usability<br>− Reliability<br>− Technical support<br>− Experience<br>− Emotion<br>− Interoperability | − e-Home: affordability considered for part selection, and confidence and conceptual fit addressed with intuitive interface design |
| Testing and refinement | − Value<br>− Usability<br>− Emotion<br>− Reliability | − e-Home: affordability investigated with user questionnaires<br>− MISTY: accessibility and service trust considered for distributing beta version<br>− PARO: cultural issues around experience and conceptual fit investigated with user studies |
| Production, distribution and post-sales services | − Accessibility<br>− Service trust<br>− Affordability<br>− Independence<br>− Lifestyle fit | − e-Home: n/a<br>− MISTY: usability issues investigated with feedback from end users collected through organizations<br>− PARO: technical support addressed with dedicated service structure |

# 6. Discussion and conclusion

The advancements in medical practice and science that brought increased longevity, along with shifts in the workforce that decreased fertility rates, have resulted in an important trend in demographic change – population aging. As a global phenomenon, the growth of the older population is expected to rapidly take place across the globe, including the developing countries as well as the more developed nations. Globally, the median age is expected to increase from 29 in 2013 to 36 in 2050 and to 41 in 2100. In the US, even with an overall fertility rate higher than that of many European countries and other developed nations, the median age is projected to increase from 37 in 2013 to 41 in 2050 and to 44 in 2100 (US Census Bureau, 2013).

The significant change in the numbers is bringing changes and challenges to many areas of today's society. The aging of the population calls for different ways to address problems and issues in health care, housing, transportation, employment, product development, and more. As a solution to cope with the changes, technology-enabled products and services have been developed for older adults and introduced to the market with great promises. However, while they are described to be potentially beneficial for older adults, the adoption rates still remain very low.

The causes for low adoption have been discussed to come from complexities and uncertainties inherent in the social, technical, and political systems related to the growing user segment. It is not entirely incorrect to describe the older population based on the physical, cognitive, and experiential characteristics that differ from those of younger people. However, the related stereotypes and biased social perceptions have prevented from a more comprehensive understanding around older adults needs, values, and expectations in various contexts of technology adoption and use. While older adults are often viewed as weak, dependent, and unwilling to accept changes, today's older population is in fact among the wealthiest and most demanding consumers who are willing to try and use new technologies that can be useful for maintaining independent, active, and socially connected lifestyles (Rogers and Fisk, 2010; Mynatt and Rogers, 2001; Conci et al., 2009; Coughlin, 2010; Holzinger et al., 2007).

The motivation for this dissertation came from the need for addressing the topic of older adults' technology adoption and use with a holistic understanding of related socio-technical environment. While the growth of the older population brings difficult challenges and problems, it also presents designers, engineers, managers, and policymakers with opportunities for innovation. This dissertation sought to understand and describe the needs and expectations of older adults as potential consumers and users of technology-enabled systems. With an integrated approach that looks at both the users and the designers, as well as both the individual characteristics and the socio-technical aspects, this dissertation aimed at providing a general framework to inform future research, as well as the design, development, and delivery of products and systems for older adults.

## 6.1. Dissertation summary

The first part of this dissertation examined the existing models and previous research on technology adoption and product development. It was found that the related topics have been explored and studied in various academic disciplines. A number of different models and frameworks have been suggested based on conceptual analyses and empirical findings to describe the processes and patterns of technology adoption use at the individual level. On the development side, staged frameworks and methods of user studies have been developed to guide practitioners in designing technology-enabled products that effectively meet the users' needs.

The survey of prior works identified limitations that need to be addressed with further research. A main gap is that the issues around individual users' adoption of technology and innovations have often been studied separately from the discussions on product development which were mostly bounded to include processes only up until production. Also, the existing body of related literature was found to be limited in that they are mostly based on and targeted toward the general population. That is, the review of related works raised the need for a better assessment of older adults' characteristics and needs that affect their decisions around adoption and use of technology, as well as identifying ways in which the understanding of the segment can be incorporated into the design, development, and delivery of technology-enabled systems.

The main body of this dissertation presented a detailed description on studies that were conducted to explore and describe the factors that influence and determine older adults' adoption and use of technology. Specifically, three main research questions were answered in this dissertation, including identification of a comprehensive set of adoption factors, description of the importance and roles of the factors during different decision stages of adoption and use, and description of the factors in the context of design and development processes.

In chapter 3, a set of factors that influence and determine older adults' adoption and use of technology were described with evidence from literature and user interviews. A total of ten factors – value, usability, affordability, accessibility, technical support, social support, emotion, independence, experience, and confidence – were identified from a careful review of previous studies. From a series of exploratory user interviews, five more factors related to reliability and compatibility – system reliability, service trust, interoperability, lifestyle fit, and conceptual fit – were described. Based on the descriptions, it was found that older adults' adoption and use of technology are not purely dictated by technical features or individual characteristics, but rather affected by various psychosocial factors and contexts of use, as well as the related information channels and distribution methods. In other words, the results from the factor identification process confirmed the need for empirical research that integrates a more comprehensive understanding of the older population with a detailed description of related practices in design, development, and delivery.

In an aim to empirically validate the importance of the adoption factors and to better understand their roles throughout various decision points throughout older adults' adoption and use of technology, a large-scale survey was conducted as presented in chapter 4. The survey was carried out to assess the overall importance of the adoption factors, to compare the relative importance between the factors, and to analyze associations and relationships among them. Additionally, the results were compared between respondents of different individual characteristics – age, gender, income level, technology experience, and living arrangements – and between different decision stages – purchase, initial use, and continued use. In addition to the close-ended question on the respondents' perceptions and thoughts, open-ended questions were also asked to gather detailed narratives and deeper insights.

Based on a statistical analysis of the responses to the national survey, it was found that most of the adoption factors were perceived by older adults as important at all stages. While independence and social support were found to be less important according to the responses to the closed-ended questions, an analysis of the open-ended responses revealed that they still play key roles in determining adoption and use of various technologies among older adults. Based on the close-ended answers from the older respondents, it was found that affordability, service trust, usability, value, and system reliability were considered as relatively more important during all three stages of adoption and use, while the open-ended responses revealed social support as one of the most important determinants of adoption. Additional analyses on the comparison between groups of different individual characteristics showed that age, technology experience and various living arrangement variables are associated with differences in the respondents' perceptions and thoughts toward the adoption factors. However, contrary to the general perceptions, the differences between the age groups were very small. Based on the findings, a number of managerial and research implications were identified, including the need to define target segments based on experiential traits and lifestyle characteristics rather than age or gender, the potential benefits of emphasizing different service qualities to users at different stages of use, the need for a description of current practices in development of technologies that are less known to older users, and the importance of an integrated approach with multiple methods of data collection.

Chapter 5 presents case descriptions for three existing technologies that were developed to fulfill the needs of older adults and their caregivers. A research project – e-Home for Seniors by MIT AgeLab – and two commercial systems – MISTY by Parental Health and PARO by AIST – were included in the multiple case study. These aging-in-place technologies were selected based on a set of criteria defined around the target market and the application domains. During the case study procedure, interviews were conducted with people who were deeply involved in the design, development, and distribution of the systems. Related documents and other materials were also surveyed for additional evidence and for corroborating the findings. The evidence were analyzed against a generic framework to develop detailed description of the activities and decisions, mainly those related to involvement of users and consideration of the adoption factors, that took place during the design processes of the three cases.

The key activities that took place throughout the design stages were mostly common across the three cases, with variations that were brought by differences in project characteristics – research or commercial – and product types – hardware or software. User studies and user involvement were incorporated into the design practices throughout the stages to varied degrees, and most of the adoption factors were found to have been considered at some point during the process of design, development, distribution, and post-sales services. In terms of user involvement, it was found from the three cases that the assessment of needs and evaluation of design alternatives can be made more effective with experience-based methods that involve interaction with tangible prototypes and with continued interactions from the early phases throughout the post-sales stages. The adoption factors were analyzed in terms of the stages during which they are most importantly considered, the changes in their specific meanings between design stages, and the ways in which some factors are more closely associated with others. Several key lessons and implications were identified from the case descriptions, including the importance of developing prototypes from early stages, considering multiple needs and their relationships, using various methods to gather inputs from target users and other stakeholders, focusing on realizing intended value and delivering services, and aligning design with existing conceptual models.

## 6.2. Contributions

The findings described in this dissertation are expected to contribute to the research and practices related to older adults' perceptions, behaviors, and decisions around adoption and use of technology-enabled systems. A main contribution of the dissertation is that it presented an integrated set of findings and implications for understanding both players of technology adoption and use – the older users and the producers. Also, with a comprehensive review of literature and empirical studies, this dissertation addressed aspects of technology adoption that had not been deeply investigated in prior works, such as the psychosocial dimension and the delivery channels. These main points can be expected to contribute to both researchers and practitioners working on the topic of older adults' adoption and use of technology, as well as those investigating ways to design and develop technology-enabled products for improving quality of life at old ages. The overall structure of the research included in this dissertation is summarized in Figure 36.

**Figure 36. Overall structure of the dissertation**

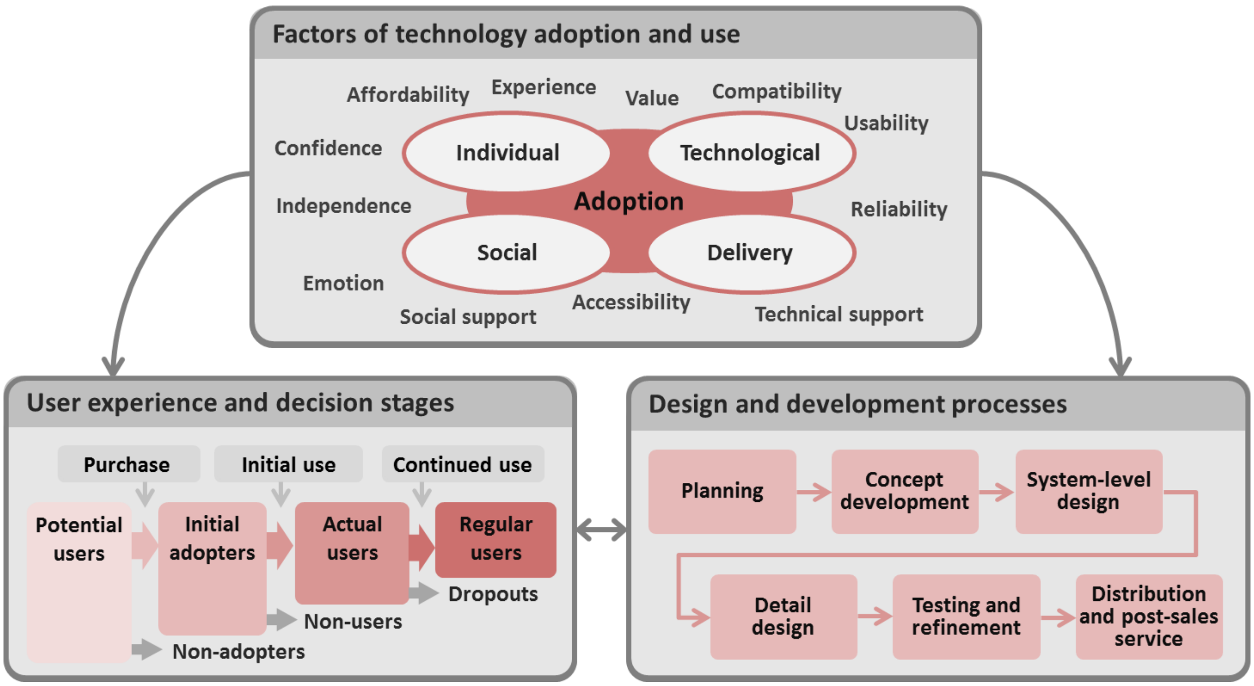
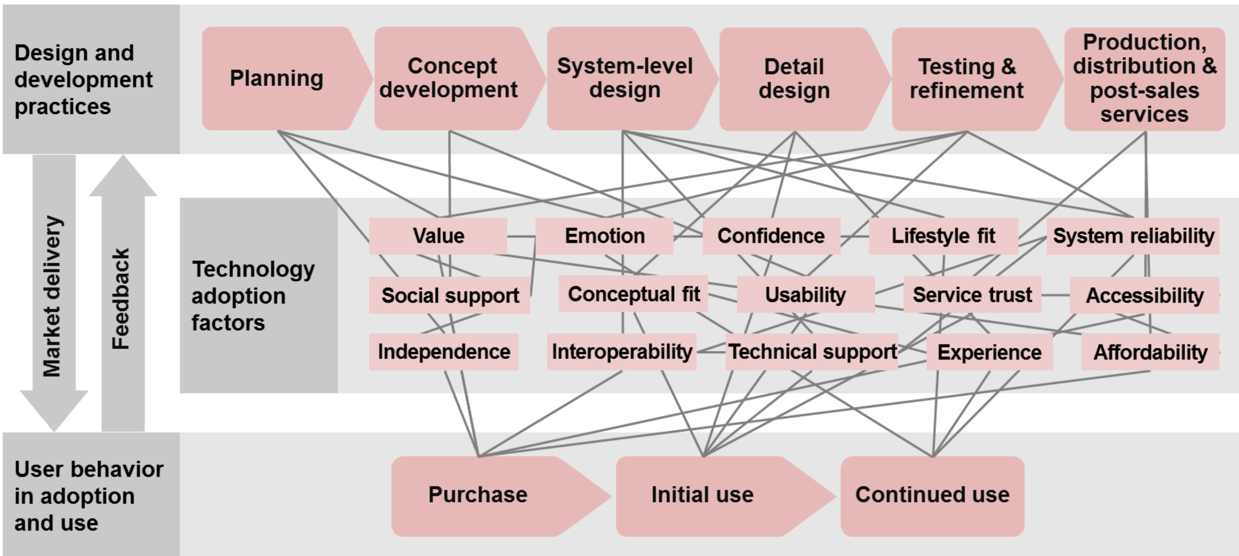



Figure 37 provides a more detailed summary of the topics that were explored and described in this dissertation. In Figure 37, the overall process of product development, the decision stages included in adoption and use of technology, and the interactions between these two processes are illustrated. Also, the adoption factors identified from literature review and user interviews (chapter 3) are mapped on to the processes of product development and technology adoption based on the findings from the user survey (chapter 4) and the multiple case study (chapter 5). The associations between factors, as analyzed from the user survey and the case study, are indicated in Figure 37 as well. In Figure 37, the mapping of the factors are based on an overall summary of related findings, rather than based on statistical significance from a single quantitative analysis.

**Figure 37. A consolidated framework: the adoption factors and the related processes**




### 6.2.1. Academic and methodological contributions

The discussions around the adoption factors presented in this dissertations builds on to the existing dialogs in various related academic disciplines including, but not limited to, gerontology, human factors, industrial design, and consumer studies and marketing. The topic of technology adoption has been a popular topic in various fields, and a handful of conceptual models and empirical research have been suggested as extensions, expansions and adaptations of the influential early models such as the Technology Acceptance Model (Davis, 1989) and the Diffusion of Innovations framework (Rogers, 1995). Previous studies on the related topics have identified various individual and technical factors contributing to the perceptions, attitudes and behaviors around technology adoption in various settings and application domains. This dissertation is expected to contribute to the body of literature with the identification, description, and validation of psychosocial factors and delivery characteristics in addition to individual characteristics and technical features.

Furthermore, the detailed description on older adults' characteristics in terms of perceptions, attitudes, and behaviors around technology-enabled systems can be expected to inform future research on topics outside of technology adoption as well. For example, research on older adults' interactions with graphical user interfaces, which is mostly conducted in the field of human-computer interaction, can be better designed with a broader understanding of their subjects rather than conducting experiments and analyzing results based on a limited assessment focused on physical and cognitive characteristics. The findings can also inform research outside of the technology domain as well, such as studies on policy implications, caregiving structures, and social communities.

This dissertation also expands existing understanding and perceptions around the older population as it described population aging as an engineering system. With a comprehensive discussion on the changing environment where a rapidly increasing number of older adults - with characteristics, needs, and expectations that are previously unseen - engage in making decisions around technology adoption, this dissertation addresses several important lifecycle properties of engineering systems. A main property discussed throughout the dissertation is adaptability, or a complex system's ability to be reconfigured in response to changes in external environments. A couple of related properties are addressed as well, including evolvability, which concerns fundamental changes that happen in the long run, and agility, the ability of a system to change quickly (de Weck et al., 2011). These factors are related to this dissertation's discussions on how systems need to behave and transform with the social change in interest – the aging of the population. Also, the adoption factors described in this dissertation address several properties that are more concerned with detail design qualities, including usability, reliability, and system resilience.

More specifically, in this dissertation, the growth of the population is described as a complex, large-scale, interconnected, open, sociotechnical (CLIOS) system. In Sussman et al. (2009), a CLIOS system is characterized as an engineering system with wide-ranging social, political, and economic impacts and a current or impending problem. The research presented in this dissertation also discusses various types of complexities among CLIOS systems including structural, behavioral, and evaluative complexity. It addresses structural complexity by describing the various interconnected subsystems that are affected by population aging, such as health care, product design, and public policies. The behavioral and evaluative aspects of complexity is addressed with a discussion around the difficulties and uncertainties related to defining and evaluating successful aging and caregiving from the perspectives of various stakeholders including older adults, their family and communities, related industries, policymakers, and the general public.

In terms of research methodology, this dissertation discussed the importance of gathering evidence and analyzing data with various methods, rather than relying on a single source or type of data. This dissertation presented empirical research based on multiple methods of data collection and analysis. User interviews were conducted in addition to literature review for identification of the adoption factors, which were then further investigated from the perspectives of users and practitioners with a large-scale user survey and a multiple case study, respectively. Specifically, the findings from the user survey addressed a need for using multiple question formats and triangulating the data for a more complete and accurate understanding from subjective responses.

### 6.2.2. Practical and managerial contributions

The set of factors identified and described in this dissertation can be understood as a set of design goals or quality measures that could inform practitioners involved in the design, development, and delivery of technology-enabled systems for the older population. While some factors may be more important that others depending on the application areas and purposes of products being developed, defining the factors as design objectives and setting them as evaluation areas can help ensure that the products and systems are designed with a thorough consideration of the target user segment.

Specifically, the findings from the user survey presented in chapter 4 can guide decisions and strategies for setting design specifications, planning evaluation sessions, distributing products through appropriate channels, and managing user feedback and customer relationships during various stages of development. Based on the results around the relative importance of the factors at the different stages of adoption and use, practitioners can strategically design and distribute products by effectively addressing the most important needs at a certain decision stage. Also, the results on the associations and relationships between the adoption factors can be used throughout the design processes to set primary and secondary goals that can be effectively and efficiently targeted and monitored together, and to realize greater value with the technology-enabled products being developed. In addition, the key lessons and insights that were outlined from the case descriptions can be readily used to guide practitioners through various design activities. The domain-specific implications and the general directions can both contribute to the design, development, and delivery of various technology-enabled products by providing practitioners with a set of important ideas that need to be considered.

The extent of the potential contributions of the discussions carried out in this dissertation can be extended from the product design practitioners to various stakeholders in related social systems. For example, communities and institutions organized for providing care and assistance to older adults can be informed by the findings presented in this dissertation when making decisions on the design of the facilities, planning of programs, and purchase of products. Also, the results can be expected to inform policymakers to understanding the nature of the population change and to address evolving needs and emerging situations with policy initiatives targeted at empowering older adults in use of technology and maximizing the potential benefits that can be delivered.

## 6.3. Directions for future research

The research presented in this dissertation sought to explore and describe issues around the topic of older adults' adoption and use of technology in an integrated framework that includes both user behaviors and design practices. This dissertation can be positioned as a consolidation of existing discussions and an adaptation of established knowledge that can be further investigated by more focused future studies to describe and explain detailed system characteristics and behaviors.

One possible direction for future research is to analyze potential differences in perceptions, attitudes, and behaviors around adoption and use of technology between older adults of different cultural identity. The user interviews and the large-scale survey presented in this dissertation relied on data collected from respondents residing in the continental United States, and the findings may not be generalizable to other regions of the world. It has been suggested that people of different cultural backgrounds show different ways of perceiving objects and information presented to them, as well as the contexts in which they are presented within (Kitayama et al., 2003). Also, perceptions of diseases and use of health services, as well as social norms on caregiving and family relationships, were discussed to be different between people of various cultural backgrounds (Braun and Browne, 1998; Yoon et al., 1999). Since social environments and cultural characteristics can affect individuals' perceptions, attitudes, and behaviors around products, a cross-cultural analysis on the importance and roles of the adoption factors can be useful for gaining a broader understanding in the global world.

Future research would also need to address the possible differences in user perceptions and design practices between technologies of various types and application domains. The findings presented in this dissertation did not distinguish results referring to different types of technologies. For example, during the factor identification process, findings from existing research on various devices and products were pooled together rather than divided by industries. While the user survey respondents were asked to talk about any chosen type of technology to answer the open-ended questions, most people chose mobile technologies and work technologies, which made it difficult to do a cross-domain comparison. Also, the systems investigated in the case study were chosen only from the domain of aging-in-place home technologies. For a more detailed understanding around the importance and roles of the adoption factors in user perceptions and design practices, a comparative analysis between technologies of different types and application domains is necessary. Replication of the survey in various domain contexts or user groups screened based on experience with certain types of technology and expansion of the case study to include a larger variety of existing systems can be carried out for generating more focused results and actionable implications.

Lastly, the case study can be further expanded to include both success cases and failure cases by employing a “two-tail” design (Yin, 2009). With a case study design where cases are deliberately selected to include not only products and systems that have succeeded, but also the ones that have failed in any aspects of design, development, and delivery, the specific conditions, actions and pathways that led to such results can be identified to further inform stakeholders with a more prescriptive framework.

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# Appendices

## Appendix 1. Summary of literature review

| Source | Technology type | Method(s) | Factor(s) discussed |
|---|---|---|---|
| Ahn, 2004 | Assistive technology (aging-in-place systems) | Questionnaire | Technical support, accessibility, usability, experience, affordability, interoperability |
| Arning & Ziefle, 2007 | PDA (personal digital assistant) | Experiment, questionnaire | Value, experience, confidence, usability, technical support |
| Aula, 2005 | Internet (search engines) | Experiment, interview | Value, technical support, usability, experience, confidence |
| Becker, 2004 | Internet (health resources) | Expert evaluation | Usability, technical support |
| Blackler et al., 2005 | Technology in general (user interfaces) | Experiment | Experience, usability, conceptual fit |
| Blackler et al., 2009 | Home technology | Experiment | Experience, usability |
| Brown & Venkatesh, 2005 | Computer systems | Questionnaire | Experience, value, social support, affordability |
| Chung et al., 2010 | Online communities | Questionnaire | Confidence, value, emotion, usability |
| Cody et al., 1999 | Internet | Experiment | Confidence, technical support, social support |
| Conci et al., 2009 | Mobile technology | Questionnaire | Social support, value, emotion |
| Czaja et al., 2006 | Technology in general | Questionnaire | Usability, experience, confidence |
| Demiris et al., 2004 | Assistive technology (aging-in-place systems) | Focus group | Technical support, independence, emotion, usability |
| Eisma et al., 2004 | Information and communications technology | Interview, focus group, participatory workshop | Value, usability, experience, confidence, technical support |
| Ellis & Allaire, 1999 | Computer systems | Questionnaire | Confidence, experience |
| Emery et al., 2003 | Computer systems (multimodal interfaces) | Experiment | Usability, experience |
| Essén & Östlund, 2011 | Community services (with information and communications technology) | Participatory workshop | Independence, emotion, value |
| Gooberman-Hill & Ebrahim, 2007 | Assistive technology | Interview | Independence, social support, value |
| Gregor et al, 2002 | Technology in general (user interfaces) | N/A | Confidence, usability |
| Hart, 2004 | Internet (Web sites for older adults) | Expert evaluation | Usability |

| | | | |
|---|---|---|---|
| Heinz et al., 2013 | Assistive technology (aging-in-place systems) | Focus group | Accessibility, social support, usability, emotion, value, lifestyle fit |
| Hollis-Sawyer & Sterns, 1999 | Computer systems | Experiment | Confidence, technical support |
| Holzinger et al., 2007 | Mobile technology | N/A | Experience, usability, confidence, technical support |
| Kang et al., 2010 | Health technology (remote monitoring) | N/A | Value, affordability, emotion, independence |
| Kaufman et al., 2003 | Health technology (telemedicine) | Experiment, cognitive walkthrough | Usability, experience, conceptual fit |
| Kurniawan & Zaphiris, 2005 | Internet | Focus group, experiment | Usability, technical support |
| Lakey et al., 2009 | Assistive technology | Interview, questionnaire | Experience, accessibility, social support |
| Lam & Lee, 2006 | Internet | Questionnaire, experiment | Value, confidence, technical support, social support |
| Lawry et al., 2009 | Technology in general | Experiment | Usability, experience |
| Liao et al., 2000 | Internet | Experiment | Usability |
| McCloskey, 2006 | e-Commerce | Questionnaire | Value, usability, trust |
| McCreadie & Tinker, 2005 | Assistive technology | Interview | Value, accessibility, experience, usability, affordability, reliability |
| Melenhorst et al., 2001 | Communication technology | Focus group | Value, affordability, accessibility, emotion |
| Melenhorst et al., 2006 | Communication technology | Focus group | Value, affordability, experience, usability |
| Meuter et al., 2003 | Retail technology | Questionnaire | Confidence, experience |
| Mitzner et al., 2010 | Technology in general | Focus group | Usability, technical support, experience, reliability |
| Moschis, 2003 | Businesses for older adults | N/A | Accessibility, independence, affordability |
| Murata & Iwase, 2005 | Computer systems (touch interface) | Experiment | Usability |
| Mynatt & Rogers, 2001 | Assistive technology (aging-in-place systems) | Case study, interview, observation | Usability, independence, emotion |
| Niemelä-Nyrhinen, 2007 | Communication technology | Questionnaire | Experience, confidence |
| Panagos, 2003 | Businesses for older adults | Case study | Accessibility, usability, experience |
| Piper et al., 2010 | Computer systems (touch interface) | Observation, interview, questionnaire | Confidence, usability, value |
| Porter & Donthu, 2006 | Internet | Questionnaire | Value, usability, emotion, affordability |

| | | | |
|---|---|---|---|
| Poynton, 2005 | Computer systems | Literature review | Technical support, confidence, experience |
| Quinn, 2010 | Information and communications technology | Questionnaire | Experience, trust |
| Rodriguez et al., 2009 | Communication technology | Interview, user-based scenario analysis, experiment | Usability, emotion, accessibility, value, lifestyle fit, interoperability |
| Selvidge, 2003 | Internet | Experiment | Usability |
| Steele et al., 2009 | Assistive technology (aging-in-place systems) | Focus group | Value, affordability, independence, confidence, technical support |
| Tanriverdi & Iacono, 1999 | Health technology (telemedicine) | Case study | Affordability, accessibility, value |
| Taylor et al., 2005 | Information technology (health applications) | N/A | Affordability |
| The SCAN Foundation, 2010 | Information and communications technology | Expert panel | Value, usability, technical support, social support |
| Tsai et al., 2012 | Technology in general (product manuals) | Questionnaire, interview | Technical support, confidence, independence, experience |
| Walsh & Callan, 2011 | Information and communications technology (community care setting) | Focus group, interview | Value, social support, emotion, independence, experience |
| Wang et al., 2011 | Health technology | N/A | Usability, accessibility, technical support, social support, value, affordability |
| Wood et al., 2005 | Computer systems (input devices) | Experiment, survey | Usability, experience |
| Woolhead et al., 2004 | N/A | Focus group, interview | Emotion, independence |
| Zajicek, 2003 | Computer systems (speech interface) | N/A | Usability |

## Appendix 2. User interview questions

I would like to speak with you further about your experiences after having the e-Home system for eight weeks. Hearing about your experiences will be helpful for us in understanding how the technology may have affected you and your study partner in the longer term.

The AgeLab research team wanted to add this interview to the study so that we would have an opportunity to hear directly from you about your thoughts and experiences since the study. Your participation in this interview is completely voluntary and you can end this interview at any time. You also do not have to answer any questions that you do not want to; please just tell me and we will move on. Deciding not to participate in the interview, ending the interview early, or skipping any questions does not affect your compensation for the study.

If you agree to participate in the interview, we would like to make an audio recording of the interview. After the interviews are complete, they will be sent to a transcription agency for transcribing without any of your personal contact information. Following the end of the study, copies of the audio recordings, without identifying personal information, will be kept at the MIT AgeLab in a secure location for possible future study. If you do not agree to recording, we will take written notes.

We do not anticipate that there are any risks to you from participating in this interview.

Would you like to proceed with the interview?
If YES, ask if recording is OK.
If NO, do not proceed with the interview.

Is it ok if I record our conversation?
If YES, continue with the interview.
If NO, continue with hand written notes.

I am going to begin taping now (if appropriate).

Do you have any questions about the study, the interviews or what we are going to do today?
If YES, answer participants' questions and then go to next question.
If NO, go to next question.

Do you have any other questions for me before we begin?

Before we get started, I just want to thank you again for taking part in the interview. There are no wrong answers to any of my questions; all open and honest input is valuable. I also want to remind you that our conversation is being audio taped (if appropriate), but that your identity and the tape will remain confidential. Finally, I expect that we will talk for about half an hour or so, but please let me know if you would like to take a break at any point.

**1** In general, what were the impacts of having the system in your home for eight weeks?

**1.1** Did your experience with the system have an impact on how you manage your medication?

**1.1.1** Do you think you are managing your medication better after having the system?

**1.1.2** Were there any changes in the techniques you use for managing your medication? If so, please describe.

**1.2** Did your experience with the system have an impact on your relationships or communications with one another?

**1.2.1** Do you think that using the system improved your relationships or the way you communicate?

**1.2.2** Were there any changes in the techniques you use for communicating with one another? If so, what?

**1.2.3** Were there any changes in the contents of your conversations due to using the e-Home system? If so, what?

**1.3** Reflecting on your experience with the system, which part did you feel was more beneficial, the medication reminders or the social communication features?

**2** You were provided with a PC to use after the study, with the software removed. How are you using the PC now?

**2.1** Where and how is it placed?

**2.1.1** Did you change the location in which you had the PC originally installed? If so, why?

**2.1.2** How does the location fit into your home activities?

**2.2** For what purposes do you use the PC?

**2.3** How often do you use the PC?

**3** Based on your experience with the system, what suggestions or comments to you have for possible improvement or extension?

**3.1** If there was a similar product with functionalities same as the system, would you want to buy and use it? Why or why not?

**3.2** What suggestions do you have in terms of the contents of information shared?

**3.2.1** What other information would you want to share with your family using such technology?

**3.2.2** What other information would you want to know about your family using such technology?

**3.3** What suggestions do you have in terms of the technical features and interface design?

**3.4** If the AgeLab had an improved system available, would you be interested in participating in another similar research study using the system? Why or why not?

**4** Did your experience with the system have an impact on the way you think about technology?

**4.1** Are you more or less likely to consider bringing technology into the home in the future to aid with care? If so, why?

**4.2** Are you more or less likely to consider bringing technology into the home in the future for communicating with family and friends? If so, why?

**4.3** How did the system affect your perceptions about technology of various kinds?

**5** After the study, have you bought or started using any technology-enabled products or services? What did you get and why?

**5.1** Did your experience with the system have any effect on your decision to buy those technologies?

**5.1.1** Did you buy or start using stand-alone technologies similar to the one you had used during the study, such as medication management systems or Skype? Why or why not?

**5.1.2** Do you think you might have not gotten it or bought something different if you hadn't experienced the system?

**5.2** For the technologies you got, who made the purchase? Did you buy it yourself? If not, who and why?

**5.3** Are you planning to buy or start using any technologies in the near future? What and why?

**6** After the study, did you continue to tell your friends or other family members about your experiences? If so, what was it about the study that you discussed with them?

## Appendix 3. Survey questionnaire (final version)

### Survey on User Perceptions and Experiences around Purchase and Use of New Technologies

This survey is a part of research conducted by AgeLab, Engineering Systems Division at the Massachusetts Institute of Technology (MIT). In this survey, you will be asked to answer a series of questions about your experiences with technology, your perceptions and thoughts on technology, and your living situation. For the multiple-choice questions, please select the one best response unless otherwise noted. For the open-ended questions, please freely write your answers in your own words.

Your participation in this study is completely voluntary, and you may refuse to answer any questions or end your participation in the survey at any time. Your answers will be saved in a server protected with a password and security software. Any contact information or personal identifying information will be saved separate from your answers. If you have any questions about the study, please contact Chaiwoo Lee at chaiwoo@mit.edu.

*Section 1. Technology knowledge and experience*

Below is a list of a number of different technologies. For the following types of technology, please indicate your knowledge and/or experiences with them.

| | Don't know what it is | Know what it is, but have not used it | Have seen or experienced it sometime | Have it, but haven't used it for some time | Have it, and use it occasionally | Have it, and use it few times a week | Have it, and use it (almost) daily |
|---|---|---|---|---|---|---|---|
| **Mobile device**<br>: technologies that can be carried around easily | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Office / work technology**<br>: devices and software used for work related activities | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Social networking service**<br>: technology services used for networking online | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Entertainment technology**<br>: devices used for gaming, music or watching videos | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Internet-based communications service**<br>: services that use the Internet for talking or texting | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Health management / assistive technology**<br>: technology for managing health and assisting activities | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Data storage / security technology**<br>: technology used for storing and securing data | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Transportation technology**<br>: technologies for assisting people to move around easily | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Home security technology**<br>: technologies for keeping one's home safe and secure | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Home appliances**<br>: technologies used for daily activities in and around the home | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

*Section 2. Detailed description of a chosen technology experience*

Please choose one specific technology that you currently use or have used in the past. Refer to the list of technology examples on the previous page if you need help picking one. What is the technology? Please give a specific name of the device, software or service.

______________________________________________________________________________

For the following questions, please refer to your past or current experiences with the technology you selected above. As you answer the questions, please be as detailed as possible.

As you chose to buy and adopt the technology you chose above, what influenced you in making your decisions? Please describe your experiences around deciding to get the technology.

______________________________________________________________________________

______________________________________________________________________________

After getting the technology (by purchasing the product or joining the service), what influenced you in making your decisions around starting to use the technology and learning about it? Please describe your experiences around your initial use of the technology.

______________________________________________________________________________________________________

______________________________________________________________________________________________________

______________________________________________________________________________________________________

Are you currently using the technology, or did you stop using it at some point? What influenced you in making your decisions around keeping and continuing to use it? Please describe your experiences around continued or discontinued use of the technology.

______________________________________________________________________________________________________

______________________________________________________________________________________________________

______________________________________________________________________________________________________

Have you bought and/or started using any new technologies in the last 12 months?

① Yes
② No
③ Don't know / don't remember

(If yes) What did you buy or start to use? Please list as many as you recall.

_______________________________________________

(If yes) Why did you buy or start using them? Please be as detailed as possible.

________________________________________________________________________________________________

________________________________________________________________________________________________

Have you gotten rid of and/or stopped using any technologies in the last 12 months?

① Yes

② No

③ Don't know / don't remember

(If yes) What did you get rid of or stop to use? Please list as many as you recall.

____________________________________________________

(If yes) Why did you get rid of or stop using them? Please be as detailed as possible.

________________________________________________________________________________________________

________________________________________________________________________________________________

*Section 3. Perceived importance of technology adoption factors*

In this section, we are interested in what is important to you when you purchase and use a new technology. Please indicate how much you agree or disagree with the following statements. Remember to think about your own experiences with various technologies as you answer these questions.

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about the potential benefits that a technology can provide… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about if a technology is easy for me to use… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about the costs associated with getting a technology … | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about where I can get a technology… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about how a technology is relevant to my past experiences with other technologies … | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about how confident I feel with using a technology… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about if using a technology would make me happier… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about how I would look to others if they see me using a technology… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about the quality of technical and professional assistance… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about the things that people around me say about a technology… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about how a technology can operate seamlessly with other technologies I have … | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about how well it would fit into my daily life patterns… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about how comfortable I am with the labels and words used in a technology… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about a technology's ability to work over time without interruptions… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

| | | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree | Don't know /not sure |
|---|---|---|---|---|---|---|---|---|---|
| It is important for me to think about if I can trust the services related to a technology… | … when I choose and buy a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … when I start to use a new technology | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |
| | … after having used a technology for some time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 |

*Section 4. Life events and living conditions*

Below is a list of events and status that may or may not describe you. Please review the list and <u>check ALL that apply to you</u>.

______ I live alone

______ I live with spouse/partner/significant other

______ I live with friend(s)/roommates(s)

______ I live with my child(ren) 12 years of age or younger

______ I live with my child(ren) between the ages of 13 and 18

______ I live with my child(ren) 19 years of age or older

______ I live with my parent(s) 64 years of age or younger

______ I live with my parent(s) 65 years of age or older

_____ I am employed (part-time or full-time)

_____ I am retired

_____ I have regular income (salary, money from family, social security check, etc.)

_____ I am in school (part-time or full-time)

_____ I have a child or family member in school

_____ I have moved during the last 3 years

_____ I am planning to move during the next 3 years

_____ I had a change in family status during the last 3 years (marriage, children's marriage, someone moving in/out, birth, death, etc.)

_____ I am expecting a change in family status during the next 3 years (marriage, children's marriage, someone moving in/out, birth, death, etc.)

*Section 5. Demographics*

What is your age today? _____________

Please indicate your gender.

④ Male
⑤ Female
⑥ Prefer not to answer

Please indicate your current employment status.

① Not working
② Self-employed
③ Employed
④ Full-time student
⑤ Other – please specify _________________________

What is the highest level of education you have completed?

① No formal education

② Elementary school

③ Junior high / middle school

④ High school

⑤ Some college / associate degree

⑥ College

⑦ Graduate school

⑧ Other – please specify ________________________

Including yourself, how many people currently live in your household?

________________

What type of housing do you currently live in?

① A detached one-family house

② Duplex or apartment

③ Dormitory

④ Assisted living facility

⑤ Other – please specify ________________________

What is your annual household income range?

① Less than $15,000

② $15,000 ~ $24,999

③ $25,000 ~ $49,999

④ $50,000 ~ $74,999

⑤ $75,000 ~ $99,999

⑥ $100,000 ~ $149,999

⑦ $150,000 or more

Please indicate your current marital status.

① Single, never married

② Married

③ Living with partner

④ Separated

⑤ Divorced

⑥ Widowed

What is the ZIP code of your current residence?

_________________

## Appendix 4. Survey questionnaire (initial draft)

### Survey on User Perceptions and Experiences around Technology Adoption and Use

This pilot survey is a part of research conducted by AgeLab, Engineering Systems Division at the Massachusetts Institute of Technology (MIT). In this survey, you will be asked to answer a series of questions about your experiences with technology, your perceptions and thoughts on technology, and your living situation. For the multiple-choice questions, please select the one best response unless otherwise noted. For the open-ended questions, please freely write your answers in your own words. The purpose of this pilot survey is to test and evaluate the questionnaire. At the end of the survey, you will be asked to share any thoughts, comments or difficulties you had as you filled out the questionnaire.

Your participation in this study is completely voluntary, and you may refuse to answer any questions or end your participation at any time. Your answers will be saved in a server protected with a password and security software. Any contact information or personal identifying information will be saved separate from your answers. If you have any questions about the study, please contact Chaiwoo Lee at chaiwoo@mit.edu.

Below is a list of a number of different technologies. For the following types, please indicate your knowledge and/or experiences with them.

| | Don't know what it is | Know what it is, but have not used it | Have seen or experienced it sometime | Have it, but haven't used it for some time | Have it, and use it occasionally | Have it, and use it few times a week | Have it, and use it (almost) daily |
|---|---|---|---|---|---|---|---|
| **Mobile device**<br>: technologies that can be carried around easily<br>(examples: mobile phone, smartphone, tablet, e-reader) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Office / work technology**<br>: devices and software used for work related activities<br>(examples: desktop computer, printer, scanner) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Social networking service**<br>: technology services used for networking online<br>(examples: Facebook, Twitter, Foursquare) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Entertainment technology**<br>: devices used for gaming, music or watching videos<br>(examples: game console, MP3 player, smartphone) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Internet-based communications service**<br>: services that use the Internet for talking or texting<br>(examples: Skype, Google Chat) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Health management / assistive technology**<br>: technology for managing health and assisting activities<br>(examples: medication manager, calorie counter, pulse monitor) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Data storage / security technology**<br>: technology used for storing and securing data<br>(examples: Dropbox, external hard drive, USB drive) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Transportation technology**<br>: technologies for assisting people to move around easily<br>(examples: GPS navigation device or app) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Home security technology**<br>: technologies for keeping one's home safe and secure<br>(examples: alarm system, surveillance system) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Home appliances**<br>: technologies used for activities in and around the home<br>(examples: coffee machine, iRobot, smart oven) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Please choose one specific technology that you currently use or have used in the past. Refer to the list of technology examples on the previous page if you need help picking one. What is the technology? Please give a specific name of the device, software or service.

______________________________________________________________________________________________

For the following questions, please refer to your past or current experiences with the technology you selected above. As you answer the questions, please be as detailed as possible.

As you chose to buy and adopt the technology you chose above, what influenced you in making your decisions? Please describe your experiences around deciding to get the technology.

______________________________________________________________________________________________

______________________________________________________________________________________________

After getting the technology (by purchasing the product or joining the service), what influenced you in making your decisions around starting to use the technology and learning about it? Please describe your experiences around your initial use of the technology.

______________________________________________________________________________________________

______________________________________________________________________________________________

Are you currently using the technology, or did you stop using it at some point? What influenced you in making your decisions around keeping and continuing to use it? Please describe your experiences around continued or discontinued use of the technology.

______________________________________________________________________________________________

______________________________________________________________________________________________

In this section, statements are given to describe your decisions around choosing and purchasing a new technology. Please indicate how much you agree or disagree with the following statements.

| | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| The potential benefits that a technology can provide, as perceived by myself, is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology is easy to use, as perceived by myself, is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The costs associated with getting a technology are important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My knowledge about the stores or venues in which I can buy a technology is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The relevance of a technology to my past experiences with other technologies is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology makes me feel confident using it is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology makes me feel better emotionally is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology helps me remain independent instead of making me look stereotypic is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The quality of technical and professional assistance is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The things that the people around me say about a technology are important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology operates seamlessly with other technologies I have is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology fits into my daily life patterns is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology's symbols and languages match the words that I normally use is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A technology's ability to work over time without interruptions is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which I can trust the services related to a technology is important in choosing and purchasing. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

In this section, statements are given to describe your decisions around starting to learn and use a new technology. Please indicate how much you agree or disagree with the following statements.

| | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| The potential benefits that a technology can provide, as perceived by myself, is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology is easy to use, as perceived by myself, is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The costs associated with using a technology are important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My knowledge about the stores or venues in which I can buy a technology is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The relevance of a technology to my past experiences with other technologies is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology makes me feel confident using it is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology makes me feel better emotionally is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology helps me remain independent instead of making me look stereotypic is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The quality of technical and professional assistance is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The things that the people around me say about a technology are important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology operates seamlessly with other technologies I have is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology fits into my daily life patterns is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology’s symbols and languages match the words that I normally use is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A technology’s ability to work over time without interruptions is important in starting to learn and use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which I can trust the services related to a technology is important in purchasing and adoption. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

In this section, statements are given to describe your decisions around continuing to use a technology that you have had for a while. Please indicate how much you agree or disagree with the following statements.

| | Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| The potential benefits that a technology can provide, as perceived by myself, is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology is easy to use, as perceived by myself, is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The costs associated with using a technology are important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My knowledge about the stores or venues in which I can buy a technology is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The relevance of a technology to my past experiences with other technologies is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology makes me feel confident using it is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology makes me feel better emotionally is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology helps me remain independent instead of making me look stereotypic is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The quality of technical and professional assistance is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The things that the people around me say about a technology are important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology operates seamlessly with other technologies I have is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology fits into my daily life patterns is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which a technology's symbols and languages match the words that I normally use is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A technology's ability to work over time without interruptions is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| The degree to which I can trust the services related to a technology is important in continued long-term use. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Below is a list of events and status that may or may not describe you. Please review the list and check ALL that apply to you.

______ Live alone

______ Live with spouse/partner

______ Live with child(ren) 18 years of age or younger

______ Live with child(ren) 19 years of age or older

______ Live with parent(s) 64 years of age or younger

______ Live with parent(s) 65 years of age or older

______ Employed (part-time or full-time)

______ Retired

______ Have regular income (salary, money from family, social security check, etc.)

______ In school (part-time or full-time)

______ Have a child or family member in school

______ Have moved during the last 3 years

______ Planning to move during the next 3 years

______ Had a change in family status during the last 3 years (marriage, children's marriage, someone moving in/out, birth, death, etc.)

______ Expecting a change in family status during the next 3 years (marriage, children's marriage, someone moving in/out, birth, death, etc.)

1. What is your age today? ______________

2. Please indicate your gender.

   ① Male
   ② Female
   ③ Prefer not to answer

3. Please indicate your current employment status.

   ① Not working
   ② Self-employed
   ③ Employed
   ④ Full-time student
   ⑤ Other – please specify _____________________________

4. What is the highest level of education you have completed?

   ① No formal education
   ② Elementary school
   ③ Junior high / middle school
   ④ High school
   ⑤ Some college / associate degree
   ⑥ College
   ⑦ Graduate school
   ⑧ Other – please specify _____________________________

5. Including yourself, how many people currently live in your household? _______________________

6. What type of housing do you currently live in?

   ① A detached one-family house
   ② Duplex or apartment
   ③ Dormitory
   ④ Assisted living facility
   ⑤ Other – please specify _______________________________

7. What is your annual household income range?

   ① Less than $15,000
   ② $15,000 ~ $24,999
   ③ $25,000 ~ $49,999
   ④ $50,000 ~ $74,999
   ⑤ $75,000 ~ $99,999
   ⑥ $100,000 ~ $149,999
   ⑦ $150,000 or more

8. Please indicate your current marital status.

   ① Single, never married
   ② Married
   ③ Living with partner
   ④ Separated
   ⑤ Divorced
   ⑥ Widowed

9. What is the ZIP code of your current residence? ____________

## Appendix 5. Pilot survey e-mail invitation

Greetings,

The MIT AgeLab is currently running a study looking at how people make decisions around adoption and use of new technologies. The study involves completing a questionnaire about your experiences and perceptions around adoption and use of various technologies.

For the study, we are doing a pilot survey to test and evaluate the questionnaire. The questionnaire will take about 15 to 20 minutes to complete. You will be compensated with a $10 Amazon.com gift card for your time. Your responses and identifying information will remain confidential.

We are eager to hear about your views and experiences. Simply click on the link below to participate in the pilot survey. Also, please do not distribute the link to other people, as this email is being sent to a small select number of people. Thank you!

Survey link: http://www.eSurveysPro.com/Survey.aspx?id=b5cb0a0e-a93f-4e2a-af4a-d233b439049d

Best regards,
Chaiwoo Lee

Research assistant
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## Appendix 6. Variable key for survey data

| Section | Variable name | Description | Scale type | Attributes |
|---|---|---|---|---|
| Survey info | ResponseID | ID assigned by Qualtrics | Text | |
| | Time | Time spent on questionnaire (minutes) | Ratio | |
| Technology experience and knowledge | Mobile | Knowledge of / experience with mobile technology | Ordinal | 1: don't know what it is<br>2: know, but haven't used<br>3: seen or experienced sometime<br>4: have, but not used it in a while<br>5: have, use occasionally<br>6: have, use few times a week<br>7: have, use it daily |
| | Office | ... with office / work technology | | |
| | Social | ... with social networking services | | |
| | Entertainment | … with entertainment technology | | |
| | Communications | … with internet based communication services | | |
| | Health | … with health management / assistive technology | | |
| | Data | … with data storage / security technology | | |
| | Transportation | … with transportation technology | | |
| | HomeSecurity | … with home security technology | | |
| | Appliances | … with home appliances | | |
| Technology use experience | InUseHaveUsed | Name of technology chosen | Text | |
| | Purchase | Experiences around purchase | | |
| | Initial | … around initial use | | |
| | Continued | … around continued use | | |
| | Recent Acquisition | If bought any new technology in the last 12 months | Categorical | 1: yes<br>2: no<br>3: don't know or remember |
| | RecentAProduct | What the respondent bought | Text | |
| | RecentAWhy | Why the respondent bought it | | |
| | RecentDisposal | If got rid of any technology in the last 12 months | Categorical | 1: yes<br>2: no<br>3: don't know or remember |
| | RecentDProduct | What the respondent got rid of | Text | |
| | RecentDWhy | Why the respondent got rid of it | | |
| Technology adoption factors | Value_P | Important to consider value (potential benefits) during purchase | Ordinal /interval | 1: strongly disagree<br>2: disagree<br>3: somewhat disagree<br>4: neither<br>5: somewhat agree<br>6: agree<br>7: strongly agree<br>8: don't know / not sure |
| | Value_I | … during initial use | | |
| | Value_C | … during continued use | | |
| | Usability_P | Important to consider usability (ease of use) during purchase | | |
| | Usability_I | … during initial use | | |
| | Usability_C | … during continued use | | |
| | Affordability_P | Important to consider affordability (costs) during purchase | | |
| | Affordability_I | … during initial use | | |
| | Affordability_C | … during continued use | | |

| | | | | |
|---|---|---|---|---|
| Technology adoption factors | Accessibility_P | Important to consider accessibility during purchase | Ordinal /interval | 1: strongly disagree<br>2: disagree<br>3: somewhat disagree<br>4: neither<br>5: somewhat agree<br>6: agree<br>7: strongly agree<br>8: don't know / not sure |
| | Accessibility_I | … during initial use | | |
| | Accessibility_C | … during continued use | | |
| | Experience_P | Important to consider past experiences during purchase | | |
| | Experience_I | … during initial use | | |
| | Experience_C | … during continued use | | |
| | Confidence_P | Important to consider how confident you feel during purchase | | |
| | Confidence_I | … during initial use | | |
| | Confidence_C | … during continued use | | |
| | Emotion_P | Important to consider emotional benefits during purchase | | |
| | Emotion_I | … during initial use | | |
| | Emotion_C | … during continued use | | |
| | Independence_P | Important to consider independence during purchase | | |
| | Independence_I | … during initial use | | |
| | Independence_C | … during continued use | | |
| | TechnicalS_P | Important to consider technical support during purchase | | |
| | TechnicalS_I | … during initial use | | |
| | TechnicalS_C | … during continued use | | |
| | SocialS_P | Important to consider social support (reception) during purchase | | |
| | SocialS_I | … during initial use | | |
| | SocialS_C | … during continued use | | |
| | Interop_P | Important to consider interoperability during purchase | | |
| | Interop_I | … during initial use | | |
| | Interop_C | … during continued use | | |
| | LifePattern_P | Important to consider fit with daily life during purchase | | |
| | LifePattern_I | … during initial use | | |
| | LifePattern_C | … during continued use | | |
| | Conceptual_P | Important to consider mental model compatibility during purchase | | |
| | Conceptual_I | … during initial use | | |
| | Conceptual_C | … during continued use | | |
| | SystemRel_P | Important to consider reliability during purchase | | |
| | SystemRel_I | … during initial use | | |
| | SystemRel_C | … during continued use | | |
| | ServiceTrust_P | Important to consider trust of services during purchase | | |
| | ServiceTrust_I | … during initial use | | |
| | ServiceTrust_C | … during continued use | | |
| Life situation | LiveAlone | If living alone | Categorical / binary | 0: no<br>1: yes |
| | LiveSpouse | If living with spouse / partner | | |

| | | | | |
|---|---|---|---|---|
| Life situation | LiveFriend | If living with friend / roommate | Categorical / binary | 0: no<br>1: yes |
| | Children12 | If living with child(ren) ~12 | | |
| | Children1318 | If living with child(ren) 13~18 | | |
| | Children19 | If living with child(ren) 19~ | | |
| | Parents64 | If living with parent(s) ~64 | | |
| | Parents65 | If living with parent(s) 65~ | | |
| | Employed | If employed | | |
| | Retired | If retired | | |
| | Income | If have regular income | | |
| | School | If in school | | |
| | FamilySchool | If family member is in school | | |
| | Moved | If have moved during last 3 years | | |
| | WillMove | If will move during next 3 years | | |
| | FamilyChange | If had change in family status during last 3 years | | |
| | WillFamilyChange | If will have change in family status during next 3 years | | |
| Demographics | Employment | Current employment status | Categorical | 1: not working<br>2: self-employed<br>3: employed<br>4: full-time student<br>5: retired<br>6: other |
| | AnnualIncome | Annual household income range | Categorical | 1: ~$14999<br>2: $15000~$24999<br>3: $25000~$49999<br>4: $50000~$74999<br>5: $75000~$99999<br>6: $100000~$149999<br>7: $150000~ |
| | Education | Highest education completed | Categorical | 1: middle school or less<br>2: high school<br>3: some college/associate degree<br>4: college<br>5: graduate school<br>6: other |
| | Marital | Current marital status | Categorical | 1: single, never married<br>2: married<br>3: living with partner<br>4: separated<br>5: divorced<br>6: widowed |

| | | | | |
|---|---|---|---|---|
| Demographics | HouseholdPeople | Number of people in household including the respondent | Ratio | |
| | Housing | Current housing type | Categorical | 1: detached house<br>2: duplex or apartment<br>3: dorm<br>4: assisted facility<br>5: other |
| | Age | Age of respondent | Ratio | |
| | AgeGroup | Age bracket that the respondent is in | Categorical | 1: 20~39<br>2: 40~59<br>3: 60~ |
| | Gender | Gender of respondent | Categorical / binary | 1: male<br>2: female |
| | Region | Geographic region that the respondent if living in | Categorical | 1: New England<br>2: Mid Atlantic<br>3: East North Central<br>4: West North Central<br>5: South Atlantic<br>6: East South Central<br>7: West South Central<br>8: Mountain<br>9: Pacific |

## Appendix 7. Perceived importance of adoption factors: correlations with technology experience and knowledge

| Decision stage | Adoption factor | Mobile devices | Office technology | Social networking | Entertain-ment technology | Internet communi-cations | Health manage-ment | Data storage | Transpor-tation | Home security | Home appliances |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Purchase | Value | .292** | .206** | .239** | .252** | .254** | .101* | .276** | .156** | .160** | .232** |
| | Usability | .134** | .118** | .141** | .056 | .131** | .088* | .058 | .111** | .092* | .176** |
| | Affordability | .154** | .041 | .116** | .110** | .037 | -.044 | .030 | .059 | -.025 | .184** |
| | Accessibility | .165** | .143** | .146** | .177** | .150** | .045 | .177** | .051 | .079 | .158** |
| | Experience | .164** | .131** | .162** | .181** | .177** | .151** | .196** | .096* | .081* | .141** |
| | Confidence | .165** | .106** | .170** | .138** | .160** | .142** | .163** | .066 | .137** | .172** |
| | Emotion | .230** | .207** | .170** | .237** | .189** | .198** | .210** | .189** | .137** | .220** |
| | Independence | .125** | .188** | .186** | .193** | .203** | .228** | .196** | .197** | .259** | .082* |
| | Technical support | .126** | .094* | .085* | .081* | .074 | .120** | .110** | .053 | .086* | .132** |
| | Social support | .129** | .191** | .160** | .216** | .204** | .161** | .213** | .154** | .140** | .119** |
| | Interoperability | .204** | .174** | .158** | .221** | .248** | .120** | .238** | .085* | .108** | .160** |
| | Lifestyle fit | .243** | .146** | .168** | .236** | .174** | .130** | .191** | .097* | .095* | .182** |
| | Conceptual fit | .038 | .027 | .105** | .091* | .063 | .111** | .083* | .054 | .047 | .071 |
| | System reliability | .171** | .119** | .141** | .172** | .136** | .001 | .109** | .081* | .016 | .192** |
| | Service trust | .151** | .077 | .085* | .085* | .118** | -.007 | .107** | .008 | .017 | .162** |
| Initial use | Value | .290** | .229** | .245** | .269** | .298** | .167** | .330** | .207** | .201** | .256** |
| | Usability | .189** | .122** | .134** | .093* | .182** | .088* | .093* | .112** | .138** | .186** |
| | Affordability | .121** | -.015 | .097* | .034 | .017 | .008 | .026 | .050 | .033 | .136** |
| | Accessibility | .146** | .136** | .093* | .068 | .151** | .139** | .154** | .075 | .153** | .101* |
| | Experience | .174** | .119** | .174** | .171** | .196** | .196** | .228** | .129** | .109** | .122** |
| | Confidence | .134** | .090* | .173** | .126** | .155** | .145** | .154** | .076 | .097* | .138** |
| | Emotion | .236** | .204** | .170** | .200** | .203** | .186** | .207** | .196** | .174** | .238** |
| | Independence | .142** | .171** | .194** | .204** | .216** | .230** | .196** | .217** | .251** | .100* |
| | Technical support | .188** | .099* | .120** | .142** | .130** | .138** | .125** | .141** | .106** | .162** |
| | Social support | .128** | .185** | .187** | .186** | .219** | .235** | .219** | .162** | .172** | .107** |
| | Interoperability | .216** | .197** | .171** | .229** | .260** | .161** | .246** | .121** | .176** | .172** |
| | Lifestyle fit | .217** | .157** | .194** | .198** | .176** | .120** | .165** | .097* | .128** | .182** |
| | Conceptual fit | .057 | .052 | .115** | .059 | .066 | .112** | .092* | .073 | .088* | .068 |
| | System reliability | .174** | .118** | .129** | .135** | .146** | .074 | .102* | .084* | .056 | .187** |
| | Service trust | .177** | .137** | .147** | .121** | .167** | .082* | .117** | .097* | .107** | .173** |

| Decision stage | Adoption factor | Mobile devices | Office technology | Social networking | Entertain-ment technology | Internet communi-cations | Health manage-ment | Data storage | Transpor-tation | Home security | Home appliances |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Continued use | Value | .273** | .208** | .233** | .214** | .273** | .173** | .267** | .140** | .219** | .212** |
| | Usability | .157** | .086* | .124** | .081* | .173** | .106** | .092* | .082* | .105* | .155** |
| | Affordability | .118** | .002 | .102* | .019 | .039 | .069 | .047 | .101* | .065 | .121** |
| | Accessibility | .115** | .113** | .098* | .057 | .189** | .186** | .159** | .096* | .175** | .062 |
| | Experience | .130** | .110** | .134** | .150** | .150** | .178** | .156** | .130** | .140** | .095* |
| | Confidence | .160** | .098* | .138** | .124** | .159** | .143** | .139** | .053 | .135** | .114** |
| | Emotion | .223** | .166** | .207** | .200** | .199** | .195** | .190** | .154** | .151** | .184** |
| | Independence | .117** | .158** | .177** | .180** | .188** | .216** | .180** | .204** | .241** | .090* |
| | Technical support | .138** | .099* | .109** | .101* | .127** | .135** | .136** | .081* | .140** | .116** |
| | Social support | .092* | .142** | .144** | .130** | .170** | .242** | .159** | .175** | .206** | .056 |
| | Interoperability | .193** | .142** | .157** | .192** | .199** | .123** | .204** | .101* | .119** | .106** |
| | Lifestyle fit | .202** | .087* | .166** | .125** | .174** | .104* | .155** | .066 | .167** | .110** |
| | Conceptual fit | .086* | .057 | .122** | .105** | .106** | .144** | .084* | .083* | .124** | .065 |
| | System reliability | .157** | .133** | .108** | .167** | .128** | .067 | .136** | .120** | .089* | .171** |
| | Service trust | .159** | .088* | .103* | .077 | .137** | .081* | .132** | .094* | .107** | .140** |

*: significant at α=0.05, **: significant at α=0.01

## Appendix 8. Perceived importance of adoption factors: mean comparison based on living situation variables

| Decision stage | Adoption factors | Live alone | | Live with spouse | | Live with friend | | Live with children ~12 | | Live with children 13~18 | | Live with children 19~ | | Live with parents ~64 | | Live with parents 65~ | | Employ-ed | | Retired | | Have regular income | | In school | | Family in school | | Moved | | Plan to move | | Had family change | | Will have family change | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Purchase | Value | 6.26 | 6.17 | 6.29 | 6.19 | 6.21 | 6.59 | **6.20** | **6.45** | 6.24 | 6.22 | 6.24 | 6.15 | 6.22 | 6.46 | 6.24 | 6.13 | **6.13** | **6.44** | 6.26 | 6.15 | **6.10** | **6.34** | 6.22 | 6.43 | 6.21 | 6.36 | 6.21 | 6.34 | **6.15** | **6.60** | **6.19** | **6.45** | 6.22 | 6.34 |
| | Usability | 6.30 | 6.28 | 6.27 | 6.31 | 6.29 | 6.28 | 6.30 | 6.23 | 6.29 | 6.31 | 6.29 | 6.30 | 6.29 | 6.30 | **6.31** | **5.87** | 6.26 | 6.36 | 6.26 | 6.39 | **6.19** | **6.38** | 6.29 | 6.36 | 6.27 | 6.40 | 6.28 | 6.34 | 6.28 | 6.35 | 6.29 | 6.29 | 6.31 | 6.20 |
| | Affordability | 6.40 | 6.36 | 6.41 | 6.37 | 6.37 | 6.63 | 6.39 | 6.36 | 6.40 | 6.32 | 6.41 | 6.21 | 6.38 | 6.43 | 6.40 | 6.09 | 6.36 | 6.43 | 6.37 | 6.43 | 6.32 | 6.45 | 6.40 | 6.26 | 6.36 | 6.51 | 6.38 | 6.43 | **6.34** | **6.58** | 6.36 | 6.54 | 6.39 | 6.38 |
| | Accessibility | 5.58 | 5.55 | 5.58 | 5.57 | 5.57 | 5.53 | **5.54** | **5.75** | 5.54 | 5.80 | 5.56 | 5.68 | 5.57 | 5.65 | 5.58 | 5.39 | 5.53 | 5.65 | 5.59 | 5.50 | 5.55 | 5.59 | 5.57 | 5.64 | **5.53** | **5.79** | 5.58 | 5.53 | 5.54 | 5.69 | 5.56 | 5.63 | 5.59 | 5.45 |
| | Experience | 5.70 | 5.71 | 5.77 | 5.65 | 5.72 | 5.47 | **5.66** | **5.96** | 5.70 | 5.75 | 5.71 | 5.64 | **5.68** | **6.17** | **5.73** | **5.04** | 5.67 | 5.77 | 5.71 | 5.70 | 5.70 | 5.71 | 5.70 | 5.73 | **5.63** | **6.09** | 5.71 | 5.68 | 5.66 | 5.89 | 5.68 | 5.81 | 5.73 | 5.53 |
| | Confidence | 5.96 | 5.91 | 5.97 | 5.93 | 5.93 | 6.28 | 5.91 | 6.15 | 5.93 | 6.08 | 5.96 | 5.77 | 5.94 | 6.08 | 5.97 | 5.35 | 5.92 | 6.00 | 5.93 | 6.01 | **5.83** | **6.04** | 5.93 | 6.11 | **5.90** | **6.19** | 5.97 | 5.87 | 5.92 | 6.05 | 5.95 | 5.94 | 5.94 | 6.03 |
| | Emotion | 5.59 | 5.55 | 5.64 | 5.52 | 5.57 | 5.81 | **5.50** | **6.01** | 5.56 | 5.77 | 5.57 | 5.63 | 5.55 | 5.97 | **5.60** | **4.96** | 5.53 | 5.67 | **5.72** | **5.17** | 5.62 | 5.54 | **5.54** | **6.00** | **5.47** | **6.11** | 5.54 | 5.73 | **5.49** | **5.92** | **5.53** | **5.83** | 5.56 | 5.72 |
| | Independence | 3.64 | 3.05 | 3.34 | 3.62 | 3.50 | 3.34 | **3.30** | **4.60** | **3.39** | **4.28** | 3.48 | 3.62 | 3.46 | 3.89 | 3.51 | 3.00 | 3.40 | 3.65 | **3.77** | **2.67** | **3.73** | **3.29** | 3.45 | 3.93 | **3.32** | **4.35** | 3.53 | 3.34 | 3.57 | 3.18 | 3.52 | 3.33 | 3.53 | 3.23 |
| | Technical support | **5.86** | **6.08** | 5.97 | 5.87 | 5.90 | 6.09 | 5.91 | 5.93 | 5.92 | 5.85 | 5.92 | 5.85 | 5.92 | 5.86 | 5.93 | 5.57 | 5.92 | 5.90 | 5.92 | 5.90 | 5.84 | 5.97 | **5.89** | **6.15** | 5.90 | 5.99 | 5.89 | 6.01 | 5.89 | 6.03 | 5.90 | 5.99 | 5.91 | 5.95 |
| | Social support | 4.59 | 4.38 | 4.59 | 4.50 | **4.51** | **5.13** | **4.46** | **5.00** | 4.52 | 4.69 | 4.51 | 4.89 | 4.50 | 5.22 | 4.54 | 4.43 | **4.41** | **4.78** | **4.74** | **3.94** | 4.65 | 4.45 | 4.50 | 5.02 | **4.45** | **5.01** | 4.55 | 4.49 | 4.47 | 4.82 | 4.50 | 4.73 | 4.56 | 4.37 |
| | Interoperability | 5.79 | 5.61 | 5.70 | 5.78 | **5.72** | **6.13** | **5.69** | **6.01** | 5.74 | 5.77 | 5.75 | 5.69 | 5.73 | 5.89 | 5.76 | 5.30 | 5.69 | 5.84 | 5.80 | 5.58 | 5.69 | 5.79 | 5.73 | 5.89 | **5.68** | **6.02** | 5.69 | 5.94 | **5.66** | **6.07** | **5.70** | **5.97** | 5.74 | 5.74 |
| | Lifestyle fit | 6.04 | 6.11 | 6.10 | 6.03 | 6.05 | 6.16 | 6.05 | 6.13 | 6.05 | 6.16 | 6.09 | 5.75 | 6.04 | 6.32 | 6.07 | 5.70 | 6.00 | 6.17 | 6.10 | 5.95 | **5.96** | **6.15** | **6.03** | **6.47** | **6.02** | **6.28** | 6.04 | 6.16 | **5.99** | **6.35** | 6.02 | 6.24 | 6.03 | 6.27 |
| | Conceptual fit | 5.38 | 5.44 | 5.47 | 5.33 | 5.39 | 5.50 | **5.33** | **5.79** | 5.38 | 5.49 | 5.39 | 5.43 | 5.38 | 5.62 | 5.41 | 5.00 | 5.40 | 5.38 | 5.40 | 5.40 | 5.32 | 5.46 | 5.39 | 5.47 | 5.35 | 5.61 | 5.44 | 5.20 | 5.40 | 5.36 | 5.36 | 5.56 | 5.41 | 5.30 |
| | System reliability | 6.13 | 6.10 | 6.12 | 6.13 | 6.12 | 6.25 | 6.10 | 6.28 | 6.12 | 6.17 | 6.11 | 6.21 | 6.12 | 6.11 | 6.13 | 5.87 | **6.02** | **6.31** | 6.14 | 6.08 | **6.00** | **6.23** | 6.10 | 6.35 | 6.08 | 6.33 | 6.08 | 6.28 | **6.06** | **6.37** | 6.09 | 6.31 | **6.09** | **6.38** |
| | Service trust | 6.31 | 6.27 | 6.24 | 6.36 | 6.30 | 6.34 | 6.30 | 6.27 | 6.31 | 6.20 | 6.30 | 6.26 | 6.29 | 6.41 | 6.32 | 5.83 | 6.27 | 6.35 | 6.26 | 6.42 | 6.16 | 6.42 | 6.28 | 6.47 | 6.28 | 6.37 | **6.25** | **6.48** | **6.26** | **6.47** | **6.26** | **6.51** | 6.28 | 6.40 |
| Initial use | Value | 6.14 | 6.11 | 6.20 | 6.08 | 6.12 | 6.41 | **6.09** | **6.38** | 6.14 | 6.06 | 6.15 | 5.96 | 6.13 | 6.27 | 6.13 | 6.22 | **6.04** | **6.31** | 6.18 | 6.01 | **6.00** | **6.24** | 6.12 | 6.36 | 6.10 | 6.30 | **6.07** | **6.40** | **6.06** | **6.45** | 6.10 | 6.33 | 6.12 | 6.21 |
| | Usability | 6.18 | 6.02 | 6.12 | 6.16 | 6.13 | 6.22 | 6.13 | 6.17 | 6.14 | 6.16 | 6.13 | 6.19 | 6.13 | 6.35 | 6.15 | 5.83 | 6.09 | 6.24 | 6.12 | 6.19 | **6.03** | **6.23** | 6.14 | 6.11 | 6.11 | 6.31 | 6.11 | 6.24 | 6.11 | 6.26 | 6.15 | 6.11 | 6.15 | 6.08 |
| | Affordability | 6.04 | 5.86 | 5.98 | 6.00 | 5.97 | 6.28 | 5.97 | 6.11 | 5.99 | 5.98 | 6.02 | 5.68 | 5.98 | 6.11 | 5.99 | 6.04 | 6.01 | 5.95 | 5.96 | 6.07 | 5.97 | 6.00 | 6.00 | 5.89 | 5.97 | 6.11 | 5.99 | 6.00 | 5.99 | 6.00 | 5.98 | 6.05 | 6.03 | 5.72 |
| | Accessibility | 5.11 | 5.04 | 5.06 | 5.12 | 5.09 | 5.09 | 5.05 | 5.31 | 5.06 | 5.29 | 5.09 | 5.02 | 5.11 | 4.78 | 5.10 | 4.83 | 5.09 | 5.08 | 5.07 | 5.13 | 5.09 | 5.08 | 5.09 | 5.02 | 5.05 | 5.25 | 5.11 | 5.02 | 5.08 | 5.12 | 5.10 | 5.01 | 5.11 | 4.94 |
| | Experience | 5.52 | 5.39 | 5.48 | 5.49 | 5.49 | 5.38 | **5.43** | **5.78** | 5.47 | 5.63 | 5.49 | 5.45 | **5.46** | **5.92** | **5.51** | **4.87** | 5.46 | 5.53 | 5.50 | 5.43 | 5.50 | 5.47 | 5.47 | 5.64 | **5.42** | **5.82** | 5.48 | 5.48 | 5.44 | 5.69 | 5.48 | 5.49 | 5.51 | 5.32 |
| | Confidence | 5.85 | 5.73 | 5.77 | 5.86 | 5.80 | 6.06 | **5.79** | **5.99** | 5.79 | 6.02 | 5.84 | 5.62 | 5.81 | 5.89 | **5.84** | **5.26** | 5.78 | 5.89 | 5.80 | 5.86 | 5.75 | 5.87 | **5.79** | **6.17** | **5.76** | **6.10** | 5.83 | 5.75 | 5.82 | 5.82 | 5.83 | 5.77 | 5.79 | 5.99 |
| | Emotion | 5.52 | 5.25 | 5.46 | 5.44 | 5.44 | 5.59 | **5.37** | **5.94** | 5.42 | 5.72 | 5.45 | 5.52 | 5.43 | 5.81 | 5.47 | 5.00 | 5.39 | 5.57 | **5.59** | **5.03** | 5.47 | 5.44 | 5.43 | 5.77 | **5.35** | **5.98** | 5.42 | 5.57 | 5.40 | 5.65 | **5.40** | **5.70** | 5.43 | 5.62 |
| | Independence | **3.63** | **3.03** | 3.31 | 3.62 | 3.49 | 3.22 | **3.30** | **4.49** | **3.38** | **4.25** | 3.47 | 3.53 | 3.44 | 4.00 | 3.49 | 3.04 | 3.41 | 3.59 | **3.74** | **2.68** | **3.67** | **3.30** | 3.45 | 3.77 | **3.29** | **4.37** | 3.50 | 3.35 | 3.53 | 3.24 | 3.48 | 3.41 | 3.50 | 3.31 |
| | Technical support | 5.85 | 5.89 | 5.87 | 5.85 | 5.84 | 6.16 | 5.85 | 5.92 | 5.86 | 5.84 | 5.87 | 5.73 | 5.86 | 5.83 | 5.87 | 5.65 | 5.87 | 5.84 | 5.87 | 5.82 | **5.74** | **5.96** | 5.84 | 6.06 | 5.83 | 5.99 | **5.81** | **6.06** | 5.84 | 5.93 | 5.83 | 5.99 | 5.85 | 5.92 |
| | Social support | 4.39 | 4.06 | 4.33 | 4.29 | 4.28 | 4.84 | **4.22** | **4.82** | 4.27 | 4.58 | 4.28 | 4.63 | 4.27 | 4.84 | 4.31 | 4.13 | 4.22 | 4.48 | **4.51** | **3.69** | 4.45 | 4.18 | 4.27 | 4.72 | **4.18** | **4.91** | 4.34 | 4.17 | 4.25 | 4.52 | 4.26 | 4.55 | 4.32 | 4.22 |
| | Interoperability | 5.67 | 5.46 | 5.53 | 5.69 | **5.59** | **6.10** | 5.57 | 5.87 | 5.61 | 5.64 | 5.63 | 5.40 | 5.61 | 5.68 | **5.64** | **5.00** | 5.56 | 5.71 | 5.66 | 5.49 | 5.56 | 5.66 | 5.61 | 5.70 | **5.56** | **5.88** | 5.57 | 5.80 | 5.57 | 5.79 | 5.57 | 5.83 | 5.62 | 5.57 |
| | Lifestyle fit | 5.88 | 5.85 | 5.89 | 5.86 | 5.86 | 6.19 | **5.83** | **6.12** | 5.85 | 6.06 | 5.90 | 5.63 | 5.86 | 6.11 | 5.89 | 5.48 | **5.80** | **6.01** | 5.90 | 5.82 | **5.75** | **5.98** | **5.84** | **6.32** | **5.81** | **6.19** | 5.85 | 5.99 | **5.78** | **6.26** | 5.83 | 6.09 | **5.84** | **6.14** |
| | Conceptual fit | 5.37 | 5.34 | 5.39 | 5.34 | 5.35 | 5.50 | **5.29** | **5.75** | 5.34 | 5.54 | 5.35 | 5.42 | 5.35 | 5.43 | 5.37 | 5.09 | 5.32 | 5.42 | 5.38 | 5.29 | 5.33 | 5.38 | 5.36 | 5.38 | **5.31** | **5.61** | 5.40 | 5.20 | 5.36 | 5.35 | 5.31 | 5.58 | 5.36 | 5.36 |
| | System reliability | 5.97 | 5.89 | 5.88 | 6.01 | 5.94 | 6.03 | 5.91 | 6.17 | 5.93 | 6.09 | 5.95 | 5.94 | 5.95 | 5.86 | 5.96 | 5.74 | **5.84** | **6.15** | 5.97 | 5.87 | **5.85** | **6.03** | 5.93 | 6.15 | **5.90** | **6.19** | **5.89** | **6.19** | 5.95 | 5.94 | **5.90** | **6.20** | 5.92 | 6.16 |
| | Service trust | 6.22 | 6.04 | **6.07** | **6.26** | 6.17 | 6.22 | 6.15 | 6.29 | 6.18 | 6.12 | 6.19 | 6.06 | 6.18 | 6.16 | 6.19 | 5.87 | 6.13 | 6.26 | 6.14 | 6.27 | 6.01 | 6.31 | 6.17 | 6.28 | 6.14 | 6.33 | **6.13** | **6.36** | 6.16 | 6.24 | **6.13** | **6.41** | 6.16 | 6.30 |

| Decision stage | Adoption factors | Live alone | | Live with spouse | | Live with friend | | Live with children ~12 | | Live with children 13~18 | | Live with children 19~ | | Live with parents ~64 | | Live with parents 65~ | | Employ-ed | | Retired | | Have regular income | | In school | | Family in school | | Moved | | Plan to move | | Had family change | | Will have family change | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Continued use | Value | 5.85 | 5.74 | 5.86 | 5.78 | 5.81 | 5.94 | **5.77** | **6.11** | 5.80 | 5.97 | 5.83 | 5.74 | 5.81 | 5.92 | 5.82 | 5.87 | 5.75 | 5.95 | 5.82 | 5.82 | **5.68** | **5.93** | **5.79** | **6.19** | **5.75** | **6.15** | 5.77 | 6.00 | **5.76** | **6.04** | 5.80 | 5.92 | 5.82 | 5.84 |
| | Usability | 5.87 | 5.71 | 5.78 | 5.86 | 5.81 | 6.09 | 5.79 | 6.01 | 5.81 | 5.98 | 5.82 | 5.87 | 5.85 | 5.51 | 5.83 | 5.74 | 5.79 | 5.89 | 5.79 | 5.93 | 5.74 | 5.89 | 5.83 | 5.81 | 5.79 | 5.99 | 5.82 | 5.84 | 5.82 | 5.86 | 5.84 | 5.74 | 5.82 | 5.90 |
| | Affordability | 5.77 | 5.52 | 5.67 | 5.74 | 5.70 | 5.81 | 5.67 | 5.89 | 5.69 | 5.86 | 5.72 | 5.56 | 5.71 | 5.70 | 5.70 | 5.78 | 5.70 | 5.71 | 5.67 | 5.80 | 5.63 | 5.77 | 5.69 | 5.89 | 5.66 | 5.95 | 5.73 | 5.59 | 5.71 | 5.69 | 5.72 | 5.62 | 5.72 | 5.63 |
| | Accessibility | 4.80 | 4.65 | 4.67 | 4.83 | 4.77 | 4.50 | **4.70** | **5.07** | 4.72 | 5.06 | 4.77 | 4.60 | 4.77 | 4.54 | 4.76 | 4.57 | 4.76 | 4.74 | 4.75 | 4.78 | 4.81 | 4.72 | 4.75 | 4.81 | 4.72 | 4.95 | 4.79 | 4.61 | 4.78 | 4.68 | 4.78 | 4.63 | 4.79 | 4.56 |
| | Experience | 5.23 | 4.97 | 5.10 | 5.22 | 5.17 | 5.06 | 5.09 | 5.58 | 5.13 | 5.46 | 5.17 | 5.13 | 5.15 | 5.38 | **5.19** | **4.52** | 5.15 | 5.19 | 5.18 | 5.12 | 5.13 | 5.19 | 5.17 | 5.15 | **5.10** | **5.47** | 5.20 | 5.02 | 5.15 | 5.22 | 5.15 | 5.25 | 5.17 | 5.13 |
| | Confidence | 5.71 | 5.49 | 5.58 | 5.72 | 5.64 | 5.81 | 5.63 | 5.76 | 5.62 | 5.95 | 5.68 | 5.38 | 5.64 | 5.92 | 5.67 | 5.30 | 5.61 | 5.74 | 5.65 | 5.65 | 5.56 | 5.73 | 5.63 | 5.96 | **5.60** | **5.90** | 5.66 | 5.64 | 5.63 | 5.75 | 5.64 | 5.71 | **5.60** | **6.04** |
| | Emotion | **5.33** | **5.04** | 5.21 | 5.30 | 5.26 | 5.25 | **5.17** | **5.78** | **5.21** | **5.62** | 5.27 | 5.15 | **5.22** | **5.73** | 5.27 | 4.83 | 5.19 | 5.37 | **5.37** | **4.92** | 5.31 | 5.21 | **5.23** | **5.63** | **5.15** | **5.76** | 5.23 | 5.37 | **5.19** | **5.51** | 5.24 | 5.36 | 5.23 | 5.45 |
| | Independence | **3.53** | **3.00** | 3.23 | 3.53 | 3.40 | 3.13 | **3.23** | **4.34** | **3.32** | **4.00** | 3.39 | 3.38 | 3.37 | 3.65 | 3.41 | 2.96 | 3.35 | 3.47 | **3.63** | **2.67** | **3.61** | **3.20** | 3.38 | 3.53 | **3.23** | **4.17** | 3.42 | 3.26 | 3.45 | 3.13 | 3.40 | 3.34 | 3.40 | 3.32 |
| | Technical support | 5.58 | 5.49 | 5.51 | 5.60 | 5.55 | 5.63 | 5.54 | 5.68 | 5.55 | 5.62 | 5.58 | 5.29 | 5.55 | 5.63 | 5.57 | 5.32 | 5.57 | 5.52 | 5.58 | 5.50 | 5.53 | 5.58 | 5.53 | 5.85 | 5.54 | 5.65 | 5.51 | 5.74 | 5.53 | 5.66 | 5.56 | 5.52 | 5.56 | 5.52 |
| | Social support | **4.05** | **3.59** | 3.93 | 3.93 | 3.91 | 4.31 | **3.84** | **4.49** | 3.91 | 4.11 | 3.91 | 4.19 | 3.90 | 4.49 | 3.94 | 3.87 | 3.88 | 4.03 | **4.11** | **3.40** | **4.12** | **3.78** | 3.90 | 4.34 | **3.81** | **4.54** | 4.00 | 3.64 | 3.92 | 3.97 | 3.95 | 3.83 | 3.95 | 3.84 |
| | Interoperability | **5.52** | **5.14** | **5.30** | **5.53** | 5.40 | 5.81 | 5.38 | 5.67 | 5.41 | 5.53 | 5.45 | 5.08 | 5.42 | 5.38 | 5.43 | 5.26 | 5.35 | 5.57 | 5.46 | 5.29 | 5.37 | 5.46 | 5.41 | 5.57 | 5.37 | 5.66 | **5.36** | **5.67** | 5.38 | 5.60 | 5.40 | 5.51 | 5.40 | 5.58 |
| | Lifestyle fit | **5.64** | **5.34** | 5.49 | 5.62 | 5.55 | 5.72 | **5.49** | **5.94** | 5.54 | 5.75 | 5.59 | 5.25 | 5.54 | 5.78 | 5.57 | 5.30 | 5.51 | 5.66 | 5.56 | 5.56 | 5.46 | 5.64 | 5.54 | 5.83 | **5.50** | **5.87** | 5.56 | 5.57 | 5.51 | 5.76 | 5.57 | 5.50 | 5.54 | 5.68 |
| | Conceptual fit | **5.23** | **4.94** | 5.09 | 5.21 | 5.14 | 5.31 | **5.06** | **5.70** | 5.12 | 5.43 | 5.16 | 5.08 | 5.14 | 5.32 | 5.16 | 4.96 | 5.17 | 5.11 | 5.17 | 5.09 | 5.12 | 5.18 | 5.14 | 5.28 | **5.09** | **5.44** | 5.17 | 5.07 | 5.16 | 5.12 | 5.15 | 5.18 | 5.16 | 5.13 |
| | System reliability | 5.87 | 5.71 | 5.74 | 5.90 | 5.82 | 6.00 | **5.77** | **6.17** | 5.80 | 6.05 | 5.85 | 5.58 | 5.83 | 5.73 | 5.83 | 5.83 | **5.72** | **6.03** | 5.86 | 5.73 | 5.72 | 5.92 | 5.81 | 5.98 | **5.78** | **6.07** | **5.77** | **6.04** | 5.82 | 5.83 | 5.81 | 5.88 | 5.80 | 6.00 |
| | Service trust | 6.02 | 5.84 | 5.87 | 6.05 | 5.97 | 5.88 | 5.93 | 6.20 | 5.96 | 6.00 | 5.99 | 5.70 | 5.97 | 6.00 | 5.97 | 5.83 | 5.93 | 6.03 | 5.92 | 6.12 | 5.89 | 6.04 | 5.97 | 5.94 | 5.95 | 6.07 | 5.94 | 6.08 | 5.97 | 5.97 | 5.95 | 6.04 | 5.94 | 6.14 |

Numbers in bold indicate differences significant at α=0.05.

## Appendix 9. Perceived importance of adoption factors: correlation analysis on responses from the older group (ages 60+)

| Purchase | Value | Usability | Affordability | Accessibility | Experience | Confidence | Emotion | Independence | Technical support | Social support | Interoperability | Lifestyle fit | Conceptual fit | System reliability | Service trust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value | 1.000 | 0.490** | 0.370** | 0.407** | 0.328** | 0.328** | 0.254** | -0.016 | 0.381** | 0.263** | 0.275** | 0.374** | 0.118 | 0.281** | 0.325** |
| Usability | | 1.000 | 0.510** | 0.361** | 0.290** | 0.414** | 0.219** | 0.034 | 0.312** | 0.128 | 0.147* | 0.262** | 0.167* | 0.220** | 0.364** |
| Affordability | | | 1.000 | 0.370** | 0.383** | 0.389** | 0.228** | -0.118 | 0.273** | 0.035 | 0.159* | 0.275** | 0.261** | 0.302** | 0.343** |
| Accessibility | | | | 1.000 | 0.507** | 0.400** | 0.370** | 0.065 | 0.373** | 0.321** | 0.311** | 0.442** | 0.177* | 0.345** | 0.366** |
| Experience | | | | | 1.000 | 0.488** | 0.482** | 0.130 | 0.397** | 0.251** | 0.389** | 0.420** | 0.330** | 0.282** | 0.350** |
| Confidence | | | | | | 1.000 | 0.450** | 0.066 | 0.462** | 0.118 | 0.392** | 0.431** | 0.369** | 0.307** | 0.409** |
| Emotion | | | | | | | 1.000 | 0.328** | 0.458** | 0.268** | 0.483** | 0.515** | 0.359** | 0.182** | 0.246** |
| Independence | | | | | | | | 1.000 | 0.067 | 0.305** | 0.225** | 0.126 | 0.184** | -0.077 | -0.045 |
| Technical support | | | | | | | | | 1.000 | 0.191** | 0.454** | 0.483** | 0.357** | 0.333** | 0.461** |
| Social support | | | | | | | | | | 1.000 | 0.243** | 0.253** | 0.233** | 0.111 | 0.088 |
| Interoperability | | | | | | | | | | | 1.000 | 0.433** | 0.394** | 0.378** | 0.338** |
| Lifestyle fit | | | | | | | | | | | | 1.000 | 0.339** | 0.368** | 0.479** |
| Conceptual fit | | | | | | | | | | | | | 1.000 | 0.258** | 0.366** |
| System reliability | | | | | | | | | | | | | | 1.000 | 0.413** |
| Service trust | | | | | | | | | | | | | | | 1.000 |

| Purchase | Value | Usability | Affordability | Accessibility | Experience | Confidence | Emotion | Independence | Technical support | Social support | Interoperability | Lifestyle fit | Conceptual fit | System reliability | Service trust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value | 1.000 | 0.484** | 0.343** | 0.384** | 0.360** | 0.339** | 0.277** | 0.014 | 0.272** | 0.152* | 0.336** | 0.353** | 0.132 | 0.231** | 0.350** |
| Usability | | 1.000 | 0.428** | 0.387** | 0.304** | 0.422** | 0.178* | -0.030 | 0.300** | 0.166* | 0.193** | 0.239** | 0.160* | 0.231** | 0.346** |
| Affordability | | | 1.000 | 0.317** | 0.368** | 0.264** | 0.169* | -0.052 | 0.251** | 0.077 | 0.192** | 0.270** | 0.253** | 0.153* | 0.353** |
| Accessibility | | | | 1.000 | 0.440** | 0.270** | 0.304** | 0.284** | 0.357** | 0.274** | 0.251** | 0.412** | 0.269** | 0.158* | 0.382** |
| Experience | | | | | 1.000 | 0.526** | 0.486** | 0.213** | 0.337** | 0.316** | 0.420** | 0.498** | 0.291** | 0.264** | 0.413** |
| Confidence | | | | | | 1.000 | 0.396** | 0.097 | 0.337** | 0.168* | 0.254** | 0.438** | 0.341** | 0.332** | 0.399** |
| Emotion | | | | | | | 1.000 | 0.404** | 0.282** | 0.247** | 0.430** | 0.517** | 0.403** | 0.162* | 0.228** |
| Independence | | | | | | | | 1.000 | 0.040 | 0.369** | 0.265** | 0.232** | 0.225** | 0.008 | 0.017 |
| Technical support | | | | | | | | | 1.000 | 0.189** | 0.437** | 0.435** | 0.399** | 0.348** | 0.405** |
| Social support | | | | | | | | | | 1.000 | 0.288** | 0.202** | 0.219** | 0.088 | 0.095 |
| Interoperability | | | | | | | | | | | 1.000 | 0.424** | 0.331** | 0.348** | 0.365** |
| Lifestyle fit | | | | | | | | | | | | 1.000 | 0.367** | 0.333** | 0.481** |
| Conceptual fit | | | | | | | | | | | | | 1.000 | 0.276** | 0.304** |
| System reliability | | | | | | | | | | | | | | 1.000 | 0.398** |
| Service trust | | | | | | | | | | | | | | | 1.000 |

| Purchase | Value | Usability | Affordabi-lity | Accessibi-lity | Experience | Confid-ence | Emotion | Indepen-dence | Technical support | Social support | Interoper-ability | Lifestyle fit | Concep-tual fit | System reliability | Service trust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value | 1.000 | 0.541** | 0.449** | 0.417** | 0.400** | 0.460** | 0.397** | 0.163* | 0.335** | 0.213** | 0.367** | 0.468** | 0.220** | 0.386** | 0.401** |
| Usability | | 1.000 | 0.549** | 0.481** | 0.442** | 0.514** | 0.393** | 0.170* | 0.279** | 0.236** | 0.320** | 0.467** | 0.295** | 0.261** | 0.442** |
| Affordability | | | 1.000 | 0.448** | 0.422** | 0.431** | 0.257** | 0.070 | 0.305** | 0.200** | 0.239** | 0.341** | 0.336** | 0.282** | 0.389** |
| Accessibility | | | | 1.000 | 0.597** | 0.448** | 0.561** | 0.310** | 0.389** | 0.382** | 0.314** | 0.480** | 0.330** | 0.264** | 0.395** |
| Experience | | | | | 1.000 | 0.585** | 0.505** | 0.292** | 0.423** | 0.379** | 0.369** | 0.528** | 0.412** | 0.351** | 0.363** |
| Confidence | | | | | | 1.000 | 0.430** | 0.139* | 0.413** | 0.269** | 0.381** | 0.509** | 0.469** | 0.443** | 0.421** |
| Emotion | | | | | | | 1.000 | 0.409** | 0.386** | 0.295** | 0.516** | 0.511** | 0.447** | 0.340** | 0.324** |
| Independence | | | | | | | | 1.000 | 0.098 | 0.457** | 0.323** | 0.156* | 0.280** | 0.085 | 0.002 |
| Technical support | | | | | | | | | 1.000 | 0.260** | 0.401** | 0.424** | 0.397** | 0.387** | 0.403** |
| Social support | | | | | | | | | | 1.000 | 0.285** | 0.210** | 0.215** | 0.144* | 0.177* |
| Interoperability | | | | | | | | | | | 1.000 | 0.445** | 0.394** | 0.437** | 0.367** |
| Lifestyle fit | | | | | | | | | | | | 1.000 | 0.461** | 0.441** | 0.571** |
| Conceptual fit | | | | | | | | | | | | | 1.000 | 0.407** | 0.432** |
| System reliability | | | | | | | | | | | | | | 1.000 | 0.473** |
| Service trust | | | | | | | | | | | | | | | 1.000 |

## Appendix 10. Case study interview recruitment e-mail

Hi (Participant name),

I'm a PhD student at MIT Engineering Systems Division. I'm working at the MIT AgeLab with Dr. Joe Coughlin on various projects around older adult's adoption and use of technology.

Over the next few months, I'm planning to develop case studies on technologies targeted at older adults. I'm interested in finding out how products and systems are designed and distributed, and how considerations on user needs and characteristics potentially affect development decisions, management practices, and distribution strategies. I think it would be ideal for me to study the development of (Product name) as one of my cases.

I hope my study is of interest to you as well. It would be great to hear what you think, and to start a conversation.

Thanks!

Chaiwoo Lee

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**Research assistant, AgeLab (http://agelab.mit.edu)**

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**Web: http://web.mit.edu/chaiwoo/www**

**Massachusetts Institute of Technology**

## Appendix 11. Case study interview participation consent form

**CONSENT TO PARTICIPATE IN INTERVIEW**

Study title:
Design, Development and Distribution of Technology for the Aging Population: A Study on Industry Practices

You have been asked to participate in a research study conducted by Chaiwoo Lee from Engineering Systems Division at the Massachusetts Institute of Technology (M.I.T.). The purpose of the study is to explore how technology for older adults are designed, developed and distributed in practice, and to develop a general framework of design practices. The results of this study will be included in Chaiwoo Lee's doctoral dissertation. You were selected as a possible participant in this study because you were involved in and have knowledge of the design, marketing or management of a development case. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

• This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. We expect that the interview will take about one to two hours.

• You will not be compensated for this interview.

• Unless you give us permission to use your name, title, and / or quote you in any publications that may result from this research, the information you tell us will be confidential.

• We would like to record this interview so that we can use it for reference while proceeding with this study. We will not record this interview without your permission. If you do grant permission for this conversation to be recorded, you have the right to revoke recording permission and/or end the interview at any time.

This project will be completed by March 31st, 2014. All interview recordings will be stored in a secure work space until 1 year after that date. The tapes will then be destroyed.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

(*Please check all that apply*)

[] I give permission for this interview to be recorded.

[] I give permission for the following information to be included in publications resulting from this study:

[] my name [] my title [] direct quotes from this interview

Name of Subject ____________________________________

Signature of Subject ____________________________________ Date ____________

Signature of Investigator ____________________________________ Date ____________

Please contact Chaiwoo Lee at chaiwoo@mit.edu with any questions or concerns.

If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143b, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253-6787.