# The Internet of Things as a Co-creation Tool in the Fuzzy Front End

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## ABSTRACT

In the Internet of Things (IoT), everyday objects provide unprecedented levels of information about products and customers that can be used to improve products and the customer experience. This makes customers co-creators in the innovation process. Particularly, in the fuzzy front end of the innovation process, customer input can play a vital role. This paper introduces a conceptual model on the value of sensor data for different front-end activities that require customer knowledge. The model is the result of a critical literature review. It was empirically tested by means of an expert questionnaire with 14 respondents. From the results, four main conclusions were drawn. First, front-end activities aiming to obtain market intelligence such as the preliminary market assessment and market research can be improved with sensor data only if it is successfully integrated with conventional methods and information. Second, the IoT may enable transferring software development principles to the physical world supporting the development of technically more sophisticated products and devices. Third, customer voice research can be greatly enhanced since sensor data enables getting insights into how customers use products in their daily routines, which was previously not possible. This also generates deeper levels of insights into latent customer needs. Fourth, knowledge about how customers use products and devices can facilitate the testing of prototypes and new product features. In order to tap into this potential, companies need to address privacy and security issues and identify business models that support the generation of sensor data.

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# 1. INTRODUCTION

Currently, devices directly used by humans generate the vast majority of Internet traffic. The main form of interaction in the Internet is human-human. In the near future this basic notion may change radically. Through the rapid proliferation of passive RFID tags in the recent years, objects are becoming increasingly connected to the Internet. Soon the dominant form of interaction will likely change from human-human to human-thing and eventually thing-thing (Biggs, Garrity, LaSalle, Polomska, 2016; Smith, 2012, p. 206; Welbourne et al., 2009). It is estimated that by 2020 there will be 50 billion devices connected to the Internet. By the same year, the world's population is expected to be 7.6 billion people (U.S. Bureau of the Census, 1996). This makes about 6.6 connected devices per person compared to 1.8 in 2010 indicating tremendous growth (Evans, 2011). The world that is emerging from this trend is one cluttered with sensors, which constantly gather information about real-world objects and upload it to the Internet. In this world, things generate the majority of Internet traffic, which is why it is often referred to as the Internet of Things (IoT).

If this trend turns into a reality it becomes essential for organizations to be able to utilize the new stream of data to develop new products and services that fit the changing needs of their customers. Organizations that are unable to change their offerings to the world and fail to create new ways to deliver them risk growth prospects and even survival (Bessant, Lamming, Noke & Phillips, 2005). Even the most ingenious invention will be a commercial failure if it fails to meet the customers' needs. Therefore, companies are looking market-oriented methods of innovation to ensure that the needs of the customers are met (Kristensson, Matthing, & Johansson, 2008).

It is long known that a strong market-orientation and knowledge of customer needs are vital to the success of new products since customer needs and expectations evolve over time (Bonner, 2005; Jaworski & Kohli, 1993). This addresses the need for co-creation with customers. In the literature, co-creation received much attention in the context of Web 2.0 and social media (e.g. Howe, 2006; Lorenzo-Romero, Constantinides, Brünink, 2014; Lorenzo, Oblinger, & Dziuban, 2006; Van Dijck & Nieborg, 2009). However, co-creation in the IoT context has received little attention (e.g. Mejtoft, 2009).

In the past, companies had to rely largely on surveys and focus groups to understand their customers' needs. In recent years, social media and online ratings have opened up new ways to learn about customers' opinions (Gandhi & Gervet, 2016). According to Prandelli, Verona and Raccagni (2006), the collaborative marketing strategies that these new virtual customer environments make possible in combination with customer involvement in the innovation process represent one of the most promising areas of development.

With the IoT, products themselves are starting to provide unprecedented levels of information that can be used to improve both the products and the customer experience. The IoT as a tool for customer involvement or co-creation may be tremendously valuable for organizations as it provides information that was previously unavailable: where the products are being used, how they are being used, and which customers are using them at any given time (Gandhi & Gervet, 2016). Co-creation and the Internet of Things have been identified as important tech-enabled trends for future business (Bughin, Chui, & Manyika, 2010).

In the IoT, devices and products continuously gather data. Since consumers use such devices and products, the data inevitably provides insight into their behavior. If companies use this data to develop new products, customers become passive co-creators in the innovation process (Mejtoft, 2011). Therefore, those organizations that understand the role of the IoT as a co-creation tool in the innovation process will likely have a significant competitive advantage in the future over those who do not.

In the fuzzy front end (FFE) of the innovation process, the foundation for the subsequent product development stages is laid out. Involving potential customers at this stage already is of particular importance to reduce the risk of market failure (Barradas & Ferreira, 2010; Sanders, 2005).

The objective of this research is to identify the potential value of data generated from connected devices (sensor data) to enhance co-creation in the FFE of the innovation process. This objective will be achieved by answering the following central research question:

*How can companies use the Internet of things as a co-creation tool in the fuzzy front end?*

In order to answer the central research question adequately, several sub-questions are addressed first:

*1. How do firms innovate nowadays and what is the role of co-creation in the fuzzy front end?*

*2. What is the IoT and what kind of data does it generate?*

*3. Which activities are performed in the fuzzy front end and what input do they require?*

*4. To what extent is data generated from connected devices valuable to enhance the identified fuzzy front end activities?*

*5. What are possible constraints/challenges of using sensor data for the purpose of innovation?*

# 2. METHODOLOGY

In order to answer questions (1), (2) and (3), a critical literature review is conducted. On this basis a model that illustrates possible relationships between sensor data generated in the IoT and activities on the fuzzy front end is established. The concept of co-creation is important to establish a link between innovation and the IoT. Question (4) is approached by means of an empirical investigation in the form of an expert questionnaire. Finally, question (5) is addressed by reviewing the most essential constraints/challenges. As a starting point for the literature review, the supervisor of this thesis provided a folder containing 41 articles relating to the IoT from various journals and magazines. However, the major part of the cited literature is taken from additional sources.

The IoT is a fairly recent phenomenon. It was first mentioned in 1999 (Ashton, 2009) and it is still in its early stages, which is why scientific literature on this topic is scarce. Therefore, also non-peer-reviewed literature is included in this literature review. The majority of non-peer-reviewed literature included in this study has been published in management magazines such as Sloan Management Review, California Management Review, Harvard Business Review, and The McKinsey Quarterly, but also conference papers, for example of the Internet of Things 2010 Conference (IoT-2010), and analyst reports are included.

The concepts of innovation and co-creation have been discussed in the literature for many years. A large part of the literature is found in major journals, including Journal Of Management, Journal Of Product Innovation Management, Industrial Marketing Management, The Service Industries Journal, Journal Of Marketing, and Journal Of Interactive Marketing.

The creation of the model followed the following process. First, the literature on innovation is reviewed to provide a clear image of the current state of knowledge in this field. Second, the concept of co-creation and its role in innovation is reviewed. Third, the concept of the IoT and the nature of the data it generates are reviewed to see what kind of outputs the IoT generates. Fourth, the activities that are performed in the process of innovation are surveyed. This clarifies the types of inputs necessary to innovation successfully allows for a comparison between the data outputs from the IoT and required inputs to the innovation process. With this information a conceptual model is created.

Based on the conceptual model an expert questionnaire is formulated. For this study, experts are considered people who work for a company or department that deals with IoT solutions, conduct research on the IoT, held a talk about an IoT-related subject at a conference, or own a company that operates in the field. The experts are identified by browsing lists of speakers of technology trade fairs, company websites, and university websites. Then, they are approached via email to participate in the questionnaire. A total of 66 experts are contacted. They are asked to indicate to what extent they consider sensor data valuable for 14 different inputs to the innovation process. Each of the 14 inputs is covered in a separate question in a standardized format (**Appendix 1**). The answers can be indicated via an ordinal rating scale (Not valuable – Less valuable – Neutral – Valuable – Very valuable). This provides an overview over the opinions of the experts, which allows for comparison and gives an indication about the extent to which they agree with the theoretical findings. For each question they were given the option to justify or comment on each of their answers. This mechanism is important as it can explain possible inconsistencies in the answers of different experts.

# 3. LITERATURE REVIEW

## 3.1 The Fuzzy Front End (FFE) of the Innovation Process

The increasing complexity and turbulence in competitive environment create uncertainties forcing companies to innovate on a continuous basis to generate and sustain competitive advantage (Shane, 1995). Innovation is defined as "the creation of any product, service or process, which is new to a business unit" (Tushman & Nadler, 1986, p.75). Fundamentally, there are two types of innovation: product innovation, referring to changes in a firm's product or service; and process innovation, referring to changes in the way a product or service is made (Tushman & Nadler 1986). Since customers generally have little insight into firms' processes, the scope of the presented research is limited to the innovation of products.

Innovations are brought to the market following the innovation process. The innovation process consists of three main stages: Fuzzy Front End (FFE), New Product Development (NPD) and Commercialization (Product Development and Management Association, 2002). Especially the early stages of the innovation process are shaped by uncertainty. Uncertainties can create difficulties with establishing goals of a project, forecasting and decision-making throughout the innovation process (Kim & Wilemon, 2002; Zhang & Doll, 2001). Gupta and Wilemon (1990) pointed out that the uncertainties associated the development of new products are increasing in conjunction with the pressure to create more new products. Companies need to develop superior new products to their competitors and need to be faster with the development. Moenaert, Meyer, Souder and Deschoolmeester (1995) showed that successful project teams working on an innovation project are capable of reducing uncertainty in the FFE.

The FFE is the phase starting from the generation of a new product idea to its approval for development or termination. It is of special importance not only because it reduces uncertainty to a large extent but also because it constitutes up to two-thirds of the total cost of the innovation process and has the largest impact on the design of the innovation. It determines quality, costs and timings. Therefore, it is one of the most important areas to consider for the improvement of the overall process (Herstatt & Verworn, 2001; Gassmann, Sandmeier & Wecht, 2006). According to Cooper and Kleinschmidt (1988), managers who took successful products to market typically spent considerably more money and effort on the FFE than those in less successful companies. Studies haves shown that new product success and failure is often decided in the FFE (e.g. Cooper, 1988, 1998). Mootee (2011a) notes that for industry leaders in particular it is vital to integrate the FFE is into their strategic planning process as they often have a false sense of competitive advantage that prevents them from recognizing a potential opportunity.

Successfully conducting FFE activities implies the acquisition of input from a diverse set of sources. Particularly sources outside the company are of great value to the innovation process. It is thus vital to look beyond the boundaries of a company's R&D department for input to the FFE (Bobrowski, 2000; Chesbrough, 2003; Muller and Välikangas, 2002; Quinn, 2000; Rigby and Zook, 2002). This approach towards innovation is referred to as "open innovation" (Chesbrough, 2003). Open innovation is the counterpart of the conventional concept of closed innovation, where a company generates, develops and commercializes its own ideas. Closed innovation dominated R&D activities of numerous leading industrial corporations for most of the 20th century (Chiu, Chi, Chang, & Chang, 2011). In contrast, open innovation sees R&D as an open system as opposed to closed innovation where R&D is considered a self-reliant unit. Companies adopting an open innovation approach commercialize their own ideas as well as external ideas and use outside as well as in-house pathways to market (Chesbrough, 2003; Von Hippel, 2005).

A company's capability to search and mine internal and external knowledge bases is critical for achieving success in the FFE (Tarafdar and Gordon, 2010). Gassmann et al. (2006) suggest that "in response to the new open innovation paradigm, new ways to integrate customers' knowledge into the innovation front-end must be explored" (p. 46). Involving the customers right from the beginning of an innovation project into the FFE is a way to acquire customer knowledge. However, doing so successfully represents a challenge for companies (Gassmann et al., 2006). Several other authors have referred to the integration of customer input into the FFE using different terms such as "customer involvement" (Lagrosen, 2005), "voice of the customer" (Griffin & Hauser, 1993), "human-centered design" (Steen, Kuijt-Evers & Klok, 2007) or "customer-driven product development" (Kärkkäinen, Piippo & Tuominen, 2000). In this work, the more general term "co-creation" is used.

## 3.2 Co-creation as a key driver in the Fuzzy Front End

In its traditional conception, the process of value creation was considered company- or manufacturer-centric, meaning that value creation occurred solely inside the firm and outside markets. Consumers were viewed as external entities to this process that only contribute by having needs that companies identify and fulfill by developing new products (Prahalad & Ramaswamy, 2004a; Von Hippel, 2005).

The traditional view is also referred to as goods-dominant (G-D) logic. It emphasized operand resources, the physical good, the transaction and good's value that is transferred to the customer during the exchange (Terblanche, 2014).

In recent years, a service-dominant (S-D) logic has emerged that is in essence a consumer-centric view on value creation. Under a S-D logic, producers and consumers cooperatively and reciprocally co-create value by interacting with each other through the integration of resources and application of competences (Vargo & Lusch, 2004; Vargo, Maglio & Akaka, 2008). According to Prahalad and Ramaswamy (2004a) "the interaction between the firm and the consumer is becoming the locus of value creation and value extraction" (p. 6).

The consumer-centric approach to innovation offers great advantages over the traditional approach since companies often lack understanding of the consumers' needs. In co-creation, the users can co-innovate exactly what they want (Von Hippel, 2005).

Co-creation is broadly defined as "the creation of value by consumers" (Zwass, 2010, p. 11). Consumers are being involved in the production of the services they buy and this creates extra value for them (Sundbo, Sundbo, & Henten, 2015). According to Ramaswamy (2011) "co-creation is the process by which mutual value is expanded together, where value to participating individuals is a function of their experiences, both their engagement experiences on the platform, and productive and meaningful human experiences that result" (p. 195). The terms co-creation and user innovation are used synonymously as both refer to the creation of value by consumers through their participation in the development of new products or services (Bogers, Afuah, & Bastian, 2010; Constantinides, Wittenberg, & Lorenzo-Romero, 2014).

In this research, co-creation is defined as follows:

*Co-creation is any activity that generates valuable input for the innovation process through direct or indirect involvement of customers in that process.*

In the context of social media marketing strategies, Constantinides (2014) distinguished between the *active approach* and the *passive approach*. In the active approach customers are involved in the innovation process by actively engaging in co-creation efforts organized by a company, such as a customer community or crowdsourcing. In contrast, the passive approach refers to the indirect involvement of customers in the innovation process. Here customers do not invest time and effort to be involved. Instead, they conduct their daily routine as usual while they generate data, which serves as a valuable source of intelligence for companies.

Prahalad and Ramaswamy (2004a, 2004b) developed the DART model to illustrate the fundamentals of value co-creation practices. DART is an acronym for dialogue, access, risk-assessment and transparency as the building blocks of effective co-creation. Combining the building blocks enables companies to better engage customers as collaborators.

*Dialogue* refers to the open interactions between the company and the consumer. Both parties need to be willing and capable of sharing knowledge so that a mutual understanding can arise. It provides an opportunity for customers to express their view of value in the value creation process. A productive dialogue requires clear rules of engagement for the interactions.

*Access* challenges the notion that value only be experienced through ownership. By granting consumers access to information and experiences at multiple points along the value creation process, as opposed to the mere ownership of products, companies may discover new ideas for innovations, business opportunities and markets.

*Risk-assessment* implies that as consumers become co-creators, they are more risk-conscious and demand more information about potential risks associated with the goods or services. However, they may also deal with those risks more responsibly.

*Transparency* of information establishes trust between the firm and the consumer. In the past, firms benefited from exploiting the information asymmetry between them and the consumers, but in co-creation the sharing of information is an essential to enable the dialogue.

Companies are now experimenting with and seeking new tools and methods for co-creation, particularly for the FFE of the innovation process as here the foundation for the subsequent phases is laid out (Sanders, 2005). This is because the FFE involves strong interaction with end-users to transfer knowledge between users and the innovation team (Barradas & Ferreira, 2010). Paying close attention to the customers' needs is especially, but not exclusively vital in the information and communications technology (ICT) industry since companies here face an increased risk to produce undesirable outcomes for the customers (Steen et al., 2007). A profound understanding of the customers and their needs is central to successfully develop new products. (Kärkkäinen et al., 2000; Lagrosen, 2001). However, despite all efforts, many new product development projects fail and lead to products that do not meet the expectations of customers (Matzler & Hinterhuber, 1998).

The development of Web 2.0 and social media has brought about many opportunities for firm-customer interaction and great potential for firms to co-create with customers (Lorenzo et al., 2006; Piller, Vossen, & Ihl, n.d.). However, involving customer in online co-creation activities imposes a challenge on companies since it requires them to create a whole experience environment for the customer (Constantinides et al., 2014). Now the Internet of Things is emerging that continuously generates data about users of devices and products. This could facilitate co-creation as it makes customers passive co-creators in the innovation process.

The contribution of users is beneficial for companies aiming to advance with the IoT for a number of reasons. First, specific knowledge and experience from users of specific problem areas can be exploited to develop innovative products. Second, developers with diverse backgrounds are required to cope with the diversity of applications, physical items and products. Third, involving users in the development process enhances technology acceptance. Fourth, user-generated content can trigger and allow for new forms of applications (Michahelles, 2009).

## 3.3 The Internet of Things (IoT)

In 1999, Kevin Ashton introduced the term "Internet of Things" (Ashton, 2009). It is a still evolving phenomenon that has been defined in different ways.

The expression "Internet of Things" consists of a combination of two terms. The term "internet" refers to the network oriented nature of the IoT, while "Things" emphasizes the integration of ordinary objects into a common framework. Since different people and organizations have approached the technology from either an internet-perspective or a things-perspective, there is an unequal understanding of what it is exactly (Atzori, Iera, Morabito, 2010). Different definitions for the "Internet of Things" focus on different facets of this technology. According to the European Commission (European Commission & EPoSS, 2008, p. 6), from a more things-focussed perspective, the IoT can be defined as "Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts". It may also be described as "Interconnected objects having an active role in what might be called the Future Internet", if the focus is on the integration of objects in the Internet. A definition may also include technological aspects. Then the IoT is "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" (European Commission & EPoSS, 2008, p. 6; He et al., 2011). The IoT can also be considered as a global network, which allows the communication between human-to-human, human-to-things and things-to-things (Aggarwal & Das, 2012). According to Biggs et al. (2016), "the IoT is perhaps best understood as a set of related technologies that can be used together to achieve exciting ends, and it can be defined in terms of its contributing technologies, including the use of sensors, RFID chips, nanotechnologies and identification systems (chips, cards, SIMs), among others" (p. 11).

There are some other terms that refer to the same technologies but emphasize different aspects such as ubiquitous/pervasive computing, cyber-physical systems, smart, environments/spaces/cities, the industrial Internet and ambient intelligence (International Telecommunication Union, 2015).

In essence, what all definitions have in common is that they all rooted in the idea that in the emerging Internet, data is no longer solely created and disseminated by people, but also by things.

The vision for the IoT of a worldwide net of physical objects providing connectivity at anytime, anyplace for anything and anyone, has attracted attention in the recent years (International Telecommunication Union, 2005; Kosmatos, Tselikas, & Boucouvalas, 2011).

Connecting everyday physical objects into a worldwide network is made possible through tags, sensors and actuators that are increasingly being built into them. This trend is fueled by steady falls in the cost of microchips, sensors and communications capacity (International Telecommunication Union, 2015).

Harrison (2011) noted, some of the key elements of the IoT are "unique identification of physical objects, automatic data capture and suitable data carriers (e.g. optical barcodes, radio-frequency identification (RFID) tags), distributed information and mass participation, ubiquitous reader devices for detecting and interrogating objects, discovery and sharing of information, and standards for data exchange and contextual annotation" (p. 19).

## 3.4 Sensor Data

To interact in the physical environment, connected objects use sensors to measure the state of the environment and actuators to change or affect it (Fell, 2014).

The primary modes to realize the IoT's potential to add value are sensors. The majority of current IoT devices utilize connected sensors. Some up-to-date smartphones already accommodate a multitude of embedded sensors such as a microphone to capture sounds, cameras to capture images, a fingerprint sensor, GPS, accelerometer, gyroscope, thermometer, pedometer, heart rate monitor, light sensor, touch screen, and barometer. There are also various connectivity technologies such as Wi-Fi, Bluetooth, GSM/ CDMA, LTE and NFC (Biggs et al., 2016).

Sensors convert mechanical, optical, magnetic or thermal signals into voltage and current. Actuators, on the other hand, convert voltage and current into actions performed on the environment. Essentially, sensors measure the physical property and convert it into voltage and current (Fell, 2014).

There are various types of sensors for different purposes. The sensors can take measurements such as temperature, air quality, movement and electricity. Sensors are grouped according to their intrinsic purpose such as environmental sensors, body sensors, home appliance sensors and vehicle telematics sensors and so on. In some cases, they may also have a degree of memory, enabling them to record a certain number of measurements. An instrument, commonly a microcontroller, can process this data. Microcontrollers carry the software that adds intelligence to the sensors and enable connectivity (Fell, 2014; Infocomm Development Authority of Singapore (IDA), 2016).

This is the basis for IoT devices. An IoT device is an appliance that is capable of communication and optionally sensing, actuation, data capture, data storage or data processing. Via sensors, IoT devices collect various kinds of data and provide it to the information and communication networks for further processing. Devices communicate with other devices directly or through a communication network. Communication networks provide data captured by devices to (third-party) applications and other devices. It also transfers instructions from applications to devices (International Telecommunication Union, 2012).

There is a tremendous variety of data that can be generated from connected devices. For example, on the level of the individual, smart phones and wearables produce data on mobile money, fitness, and GPS location. In the community health devices gather data about a person's heart rate, blood pressure, diet. Connected cars capture information such as speed, distance, airbags, crash locations/alerts, and in a smart home remote heating data is generated, for example. Smart cities collect data on things like electricity/water consumption and billing, and traffic flow data (International Telecommunication Union, 2015).

The types of data that a company chooses to capture with its products and analyze depend on its strategy. The company Nest, for example, aims to lead in energy efficiency and energy cost. The company collects comprehensive data on product usage and peak demand. Nest's air conditioning thermostats use this data to tune temperatures before and during times of peak demand to save energy (Nest.com, 2015; Porter & Heppelmann, 2014).

Generally, it can be said that if a company's strategy is aimed at leading in product performance or minimizing service cost, it must normally collect mostly "immediate value" data that can be leveraged in real time. In contrast, if a company aims to achieve a leadership position in the product system, it is sensible to capture a wide rage of data across multiple products and the external environment. For instance, a system of connected products might require data about traffic, weather, and fuel prices for a group of vehicles (Porter & Heppelmann, 2014).

Merging data from multiple sources with analytics can yield deeper insights. Analytics can be of four kinds: *Descriptive* analytics capture a product's condition, environment and operation. *Diagnostic* analytics examine the causes of reduced performance or failure. *Predictive* analytics detect patterns that signal impending events. And lastly, *prescriptive* analytics aim to identify measures to improve outcomes or correct problems (Porter & Heppelmann, 2015).

Before products became smart, companies had to supplement that data with pieces of information collected by means of surveys, research, and further external sources. Through combining and analyzing the data, companies were able to get insight into customers, demand, and costs. However, it was difficult to know details about the functioning of products. With the IoT, the product itself becomes a source and disseminator of data. IoT devices generate an unprecedented variety and volume of information in real time (Porter & Heppelman, 2015). "Data now stands on par with people, technology, and capital as a core asset of the corporation and in many businesses is perhaps becoming the decisive asset" (Porter & Heppelman, 2015, p. 4).

## 3.5 Fuzzy Front End Activities

The Product Development and Management Association (PDMA) (2002) developed the New Concept Development (NCD) model to provide a common language and definition for the key components of the FFE. They identify the following key activities: opportunity identification, opportunity analysis, idea generation and enrichment, idea selection, and concept definition. Leadership, culture, and business strategy of the organization drive these activities. They also note that other influencing factors that are difficult to control such as the outside world and the enabling sciences may affect the innovation process as well (Product Development and Management Association, 2002). In his well-known model the "stage-gate-process", Cooper (1988) distinguishes four stages in the FFE: idea, preliminary assessment, concept, and development. A more recent approach to the FFE consists of seven phases: Collecting customer insights, developing strategic foresights, sense making and opportunity mapping, ideation and concept development, rapid concept prototyping, customer co-creation, brand/market assessment (Mootee, 2011a). Khurana and Rosenthal (1998) propose that the FFE consists of: the formulation and communication of new product strategy, opportunity identification, generation and screening of ideas, product definition and planning and design activities.

It is difficult to propose a universal set of FFE activities as this depends on factors such as the technology's complexity, the importance of the opportunity to a company or how easily changes can be made in the development phase (Kim & Wilemon, 2002). However, as a result of literature survey Reid and Brentani (2004) suggest that regardless of the level of innovation, FFE activities can be classified as early and late. Early FFE activities include opportunity identification and information collection whereas late FFE activities are related to idea generation, concept development, continued information collection and information prescreening. It is striking that several authors tend to classify the FFE activities in exactly two groups. Cooper (1988) points out that the FFE involves two types of activities: technical production activities and market activities. Technical production activities include a preliminary technical assessment and concept generation. Market activities include a preliminary market assessment, concept identification and concept test. However, market activities and technical production activities as identified by Cooper (1988) are not to be equitable with Reid's and Brentani's (2004) early and late FFE activities. Cooper's (1988) activities are to be performed in an alternating manner whereas early and late FEE activities are subsequent. Also the model of Khurana and Rosenthal (1998) starts with two input streams. The first input stream includes the steps from opportunity identification to idea generation and market and technology analysis. The second input stream refers to strategic activities such as product and portfolio strategy formulation.

The activities also vary in their degrees of complexity. For example, the PDMA (2002) identify market research as a method for the opportunity identification activity, whereas Cooper and Edgett (2008) describe market research as a stand-alone activity.

As shown previously, the IoT presents great potential for co-creation. Therefore, it is reasonable to assume that especially those front-end activities that are related to the acquisition of customer inputs can be enhanced with sensor data. Cooper and Edgett (2008) note that the customer or user must be an integral part throughout the entire innovation process. According to them "developing and delivering new products that are differentiated, solve major customer problems, and offer a compelling value proposition to the customer or user is the number one key to NPD success and profitability" (p. 5).

Due to the significance of co-creation in the front-end, the focus of the presented research is on those activities that involve the customer. The nature of sensor data makes customer passive co-creators in the innovation process and more specifically, in the fuzzy front end. Therefore, it is reasonable to assume that customer-input requiring front-end activities will be enhanced by sensor data. However, front-end activities that do not involve customer input were not considered as no plausible relationships between this kind of activities and sensor data are identified based on the literature. The following front-end activities requiring customer information were identified. The basis for these activities is the list of activities that constitute front-end work on a typical major project by Cooper and Edgett (2008). These activities with their inputs are summarized in a table in **Appendix 1**.

### *3.5.1 Preliminary Market Assessment*

The preliminary market assessment is a quick assessment of the market. Its aim is to roughly determine market size and potential, customer interest, initial insights into customer needs, requirements and value (Cooper and Edgett, 2008). According to the Product Development and Management Association (2002) "opportunity identification may occur from a single person recognizing an unmet customer need or previously undetected problem" (p. 15). Therefore, preliminary market assessment is very similar to opportunity identification. For this research, it is defined as a means to discover a new opportunity. Such an opportunity could be a completely new direction for the company or merely an upgrade to an existing product (Product Development and Management Association, 2002).

### *3.5.2 Technical Assessment*

The technical assessment is a pre-development assessment of the technical challenge, identifying the probable technical solution, the development route, technical challenges, risks and potential "showstoppers" (Cooper and Edgett, 2008).

In (Product Development and Management Association, 2002) the identification of new technological solutions and the assessment of its risks (technical success probability) are considered sub-activities of different activity categories. The identification of new technological solutions is described as a sub-activity of idea generation and enrichment whereas the assessment of technical risks is considered to be an aspect of idea selection. However, here the technical assessment includes both activities.

### *3.5.3 Voice of the Customer (VoC) Research*

Voice of the customer (VoC) research refers to the task of identifying customer needs, structuring customer needs, and providing priorities for customer needs (Griffin & Hauser, 1993).

VoC research is often considered an element of market research (Von Hippel, 1986; Cooper & Edgett, 2008), however, given the degree of importance and complexity of VoC research, it is reasonable to consider it as a separate activity from market research to discuss it in detail.

It is long known that an accurate understanding of user needs is essential to the development of commercially successful new products (Von Hippel, 1986). According to Cooper and Edgett (2008), more than two-thirds of high-productivity businesses collaborate closely with their customers to identify their needs and problems, whereas only about 15 percent of low-productivity companies do this. However, it is often a very costly matter for firms to understand users' needs well. This is because conventional market research methods only provide superficial insights into needs and more extensive techniques are time-consuming and difficult (Von Hippel & Katz, 2002).

There are various types of customer needs. Griffin and Hauser (1993) differentiated between basic needs, articulated needs and exciting needs. Mootee (2011b) notes that understanding customer needs includes their unmet needs, latent needs (or unknown needs), and unarticulated needs. In Mootee (2011a) emerging needs are also mentioned. Mootee's (2011a, 2011b) distinction clearly highlights the different aspects of customer needs and allows getting deep insights into their nature.

VoC research is strongly related to ethnographic research. Ethnography is essentially cultural anthropology, and involves observing users in their homes, offices or factories as they go about their daily routine. This helps to truly understand behaviors, cultures and consumers, which are transformed by innovative ideas. Ethnography is about real people in real situations rather than in personas. Such information is especially valuable to identify latent and unmet needs, and problems. In contrast, conventional market research methods are more speculative (Cooper & Edgett, 2008; Mootee, 2011a).

VoC research also involves lead user analysis. Lead users are users whose present needs are likely to become common needs in a marketplace in the near or distant future. They think ahead of the trend and are acquainted with future conditions that other users are not yet aware of. These characteristics make them very valuable for the identification of emerging customer needs. Furthermore, they often make an effort to invent solutions that fill their needs on their own, which and can provide new product concepts and helpful design data (Von Hippel, 1986, 2002).

### *3.5.4 Market Research*

Market research is an in-depth market investigation that helps a firm understand how customers evaluate the benefits and costs of an offering and how they compare these to the benefits and costs of alternative products. Market size and segmentation analysis may be conducted here as well (Product Development and Management Association, 2002; Cooper and Edgett, 2008).

In this research, an assessment of the value to the customer is also considered a sub-activity of market research. This is a quantification of the product's value. It usually involves "looking at the economic impact on customers' operations versus how they solve their problem now (for example, versus competitive solutions and then considering competitive prices and their products' cost in use)" (Cooper & Edgett, 2008, p. 8).

### *3.5.5 Prototype/Feature Testing*

Conventionally, the proposed product is presented to customers in form of, for example, a model, concept or virtual prototype. Then feedback is sought to establish interest, liking and purchase intent. This is valuable research, but no substitute for the VoC research as input. Rather it is complementary to VoC research (Cooper and Edgett, 2008).

## 3.6 Conceptual Model

The theoretical findings are illustrated in a conceptual model (**Figure 1**). Since sensor data generated from connected devices displays great potential to enhance co-creation, it is hypothesized that sensor data has a positive effect on front-end activities that require customer input such as preliminary market assessment, technical assessment, VoC research, market research, and prototype/feature testing as indicated by the plus-signs. This leads to an increase in front-end performance. Due to the significance of the FFE in the innovation process, the increased performance in the FFE is assumed to result in an overall performance increase of a new product development project.

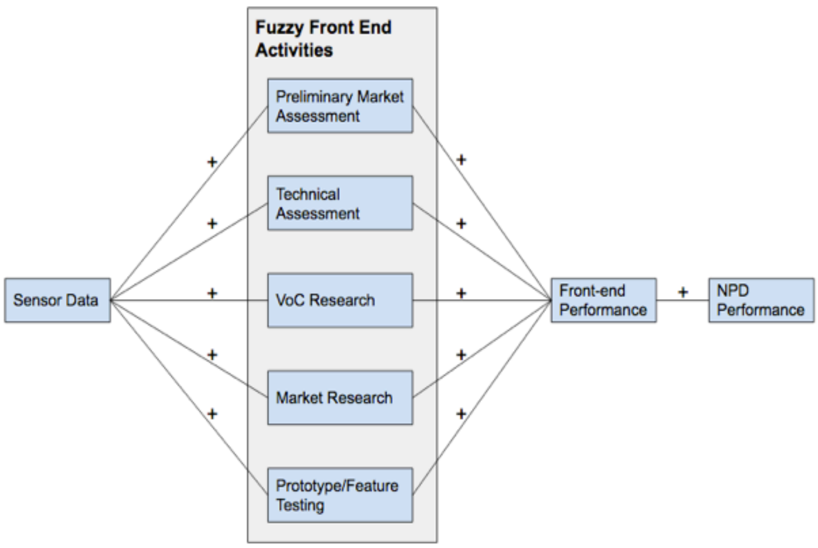


**Figure 1: A conceptual model**

## 4. RESULTS

One of the experts offered to distribute the questionnaire in his network of IoT specialists. In sum, 66 experts were contacted directly and an unknown amount of experts received the questionnaire via him. In the end, 14 experts participated in the study. The respondents are people who work for IoT companies, mostly CEOs and/or founders, but also business developers, sales managers, researchers, public speakers. They are from various countries, companies and organizations. The responses are summarized in **Table 1**. In the following sections, the results for each front-end activity are evaluated. The sub-sections elaborate on the critical inputs that were identified for each activity in a more detailed manner.

### 4.1 Preliminary Market Assessment

Based on the responses that the experts gave on the questions regarding the critical inputs for the preliminary market assessment, it can be said that sensor data is of value to provide critical inputs of this activity. However, the data cannot substitute all existing sources of information, rather it could have a role as an additional component of the “big picture”.

#### *4.1.1 Market size and potential*

Although more experts consider sensor data valuable than not valuable to determine a potential new market’s size and potential, the results are controversial since every possible answer was chosen by at least two experts. In the comment section, one of the experts who indicated “very valuable” referred to an interview conducted by AutomatedBuildings.com (2016) with the director of business development at Comfy, Erica Eaton. Comfy is an occupant-facing, smart building software that delivers personalized comfort and productivity in the workplace. When she was asked what opportunities she envisions smart buildings enabling in the future, she responded that smart buildings could provide valuable data to buildings owners helping them prioritize investment and real estate decisions. According to another expert sensor data is very valuable but it should only be used in addition to preliminary research such as desktop research. Someone indicated “valuable” but commented that with this answer he assumes that the use data can be extrapolated. However, none of the experts indicating “less valuable” and “not valuable” commented on their answers.

#### *4.1.2 Indication of customer needs, requirements and values*

The vast majority (64.3%) stated that they consider sensor data very valuable for the indication of customer needs, requirements and values. It was commented that such data informs about customer behavior and intent and is a key to customer success, which translates into success of companies. However, according to one respondent it has to be kept in mind that “data is only a component of this picture – it has to be integrated with other aspects of customer needs, requirements and values to be of true value.”

### 4.2 Technical Assessment

The responses concerning probably technical solutions and technical challenges and risks indicate that sensor data could be of great value for the technical assessment. The IoT may enable transferring useful software development principles to the physical world, which provides deeper insights into the functioning of products and helps to make them more sophisticated.

| Front-end Activity | Critical Input for the Front-end Activity | Responses Count: Not valuable | Less valuable | Neutral | Valuable | Very valuable | Graph. Repr. |
|---|---|---|---|---|---|---|---|
| Preliminary Market Assessment | Market size & potential | 2 (14,3%) | 2 (14,3%) | 2 (14,3%) | 4 (28,6%) | 4 (28,6%) | |
| | Indication of customer needs, requirements and value | 0 (0,0%) | 0 (0,0%) | 3 (21,4%) | 2 (14,3%) | 9 (64,3%) | |
| Technical Assessment | Probable technical solutions | 1 (7,1%) | 0 (0,0%) | 3 (21,4%) | 2 (14,3%) | 8 (57,1%) | |
| | Technical challenges and risks | 1 (7,1%) | 1 (7,1%) | 3 (21,4%) | 3 (21,4%) | 6 (42,9%) | |
| Voice-of-the-Customer (VoC) Research | Unmet customer needs | 0 (0,0%) | 3 (21,4%) | 5 (35,7%) | 1 (7,1%) | 5 (35,7%) | |
| | Emerging customer needs | 0 (0,0%) | 1 (7,1%) | 4 (28,6%) | 3 (21,4%) | 6 (42,9%) | |
| | Unarticulated customer needs | 0 (0,0%) | 0 (0,0%) | 5 (35,7%) | 4 (28,6%) | 5 (35,7%) | |
| | Latent customer needs | 1 (7,1%) | 2 (14,3%) | 2 (14,3%) | 2 (14,3%) | 7 (50,0%) | |
| | Customer usage of product | 0 (0,0%) | 1 (7,1%) | 1 (7,1%) | 1 (7,1%) | 11 (78,6%) | |
| | Innovative product designs and solutions (Lead users) | 1 (7,1%) | 3 (21,4%) | 1 (7,1%) | 4 (28,6%) | 5 (35,7%) | |
| | Customer points of pain | 0 (0,0%) | 0 (0,0%) | 1 (7,1%) | 7 (50,0%) | 6 (42,9%) | |
| Market Research | Market size & potential | 2 (14,3%) | 2 (14,3%) | 2 (14,3%) | 4 (28,6%) | 4 (28,6%) | |
| | (New) Market segments | 1 (7,1%) | 1 (7,1%) | 3 (21,4%) | 3 (21,4%) | 6 (42,9%) | |
| | Economic value to the customer | 2 (14,3%) | 0 (0,0%) | 4 (28,6%) | 3 (21,4%) | 5 (35,7%) | |
| Prototype/Feature Testing | Customer interest, liking and purchase intent | 1 (7,1%) | 1 (7,1%) | 1 (7,1%) | 4 (28,6%) | 7 (50,0%) | |

**Table 1: Summary of the responses to the questionnaire (n=14)**

### *4.2.1 Probable technical solutions*

Most experts (57.1%) said that sensor data is very valuable to identify probable technical solutions to customer needs. However, three stated "neutral" and one "not valuable". An expert stating "not valuable" added that the IoT itself could not offer a technical solution and that only a person using the IoT can build such a solution. In contrast, another respondent explained that a so-called "fail fast" approach could be used here. Fail fast is an error-handling approach that is commonly used in software development. The rationale behind it is to stop an application immediately when something goes wrong and report an error message to help detect, diagnose and correct the error. Therefore, the Fail fast approach helps to write more reliable software (Neumanns, 2012). Given the capabilities of sensors, as described earlier, it seems reasonable to apply a Fail fast approach here.

### *4.2.2 Technical challenges and risks*

Most experts consider sensor data valuable (21.3%) or very valuable (42.9%) to identify technical challenges and risks associated with a new product concept. Here it was also suggested to use a Fail fast approach. However, also five people do not see this value. For this question there were no comments given that explain the inconsistencies.

## 4.3 Voice of the customer (VoC) Research

The responses show that there is some dissent about the extent to which sensor data can be useful to identify customer needs, although the responses have a positive tendency. As for the preliminary market assessment, sensor data is only one element of the "big picture". However, this does not apply for latent needs as here the experts mostly agree and explained well that sensor data is very valuable to identify them. Generally speaking, sensor data seems valuable to understand customer problems better. The main advantage for VoC research of sensor data is its capability to inform about how customers use products. This could be a notable improvement for VoC research since this information was unavailable before the IoT. Almost all experts agree that sensor data is very valuable for this matter. The following sub-sections elaborate on these findings in detail.

### *4.3.1 Unmet customer needs*

Here the experts' opinions diverge. Five of them consider sensor data very valuable to get deeper insights into unmet customer needs and five indicated "neutral". The reason for this can be found in the comments. According to the experts, data is only the start of the dialogue between company and customer. It is a part of the overall picture that has to be integrated with other input to deliver meaningful insights. Also, one expert explained that the IoT seems to be improving existing products. Totally new innovations are very few. Therefore, he says, sensor data is valuable but not in order to discover new customer needs rather to better serve existing needs.

### *4.3.2 Emerging customer needs*

The results are similar to those for unmet customers needs, however, slightly more positive. The majority of experts think that sensor data can be valuable to get deeper insights into emerging customer needs. As for unmet customer needs, the raw data is not enough to get these insights. To forecast future customer needs, the data has to be coupled with analytics. Moreover, it was noted that before emerging needs can be discovered, there has to be an understanding of current customer needs, requirements and values.

### *4.3.3 Unarticulated customer needs*

Most people said that sensor data is at least valuable to get deeper insights into unarticulated customer needs. Also a considerable amount of them gave a neutral response. In the comments it was noted again that a Fail fast principle could be applied here. No explanation of the neutral responses could be found.

### *4.3.4 Latent customer needs*

All possible answers were given, however, the most striking number here is that half of the respondents indicated that they consider sensor data to be "very valuable" to get deeper insights into latent customer needs. According to one expert, emerging technologies are based on the principle of identifying latent needs. A different expert mentioned retail beacons as an example where this is already happening. Beacons are small, wireless devices that are low-cost and battery operated. Essentially, the device transmits a weak Bluetooth signal to other Bluetooth enabled devices in the general area such as a smart phone. The beacons reach out to customers as they walk by with a Bluetooth enabled smartphone and the right application. Beacons can create a more personalized customer retail experience and help draw them back into the stores and keep them inside longer (Kline, 2016). The beacon technology can be used to track the location of retail customers as they enter the store, browse and complete their shopping. With this information, heat maps can be constructed to track anomalies i.e. products or services that customers are willing to track down, even if they have to do a bit of searching. Once this data is on hand, retailers are able to better understand the customer experience in their own store. Then the store's layout can be redesigned to make it feel more accessible to customers (Callahan, 2015). In addition, it is referred again to the use of a Fail fast principle.

### *4.3.5 Customer usage of the product*

Here the consensus is the greatest. Eleven people indicate that sensor data could be "very valuable" to observe how customers use or abuse products in their daily routine. Despite the consensus, the value of sensor data for this purpose may be limited in practice. One expert noted that the use of customer data may be subject to laws and regulations in some countries or may be disliked by customers due to their privacy concerns. However, there is a lot of potential here as another expert said: "Optimizing the daily routine could have a major positive effect on human efficiency." Again it is referred to the use of a Fail fast approach to tap into this potential. It is also stated that the data generated from cars are a very good example of how customers can be observed as they go about their daily routine. Some modern vehicles and collect a great amount of data such as GPS position, trip distance and time, speed and seat belt usage to name a few. Opportunities for using the data include: live traffic prediction, comparing fuel consumption, identifying dangerous intersections, benchmarking, machine learning, and insurance discounts (Simon, 2016).

### *4.3.6 Innovative product designs and solutions*

This question was about how valuable sensor data is considered to discover innovative product designs and solutions created by customers. It is directly related to lead user analysis (Von

Hippel, 1986). The experts gave very diverse responses. The majority of the respondents consider sensor data "valuable" or "very valuable". However, a total of five experts do not recognize this value. It is noted that if customers create solutions, there is no guarantee that companies will have access to that data. Moreover, experts commented: "with what?" and "how?". These responses indicate that this question has been interpreted differently by some of the experts. Therefore, based on this data no conclusions about a possible relationship between sensor data and innovative products designs and solutions developed by lead users can be drawn.

#### *4.3.7 Customer points of pain*

Here the experts were ask how valuable they would consider sensor data to understand customer "points of pain". The result is very one-sided with almost all experts indicating "valuable" or "very valuable". Only one of them indicated "neutral". It was commented that sensor data is especially useful as an input to other activities such as building a business case. One expert stated that it is useful when it is matched with problem statements e.g. "there is something wrong with my car's brakes".

### 4.4 Market Research

The responses on the questions for this activity, suggest that sensor data could generate insights into the aspects of market research discussed in the following sub-sections. Moreover, it is important to integrate sensor data with other market research practices as it can only provide partial information.

#### *4.4.1 Market size and potential*

Determining a potential market's size and potential is as much a part of the preliminary market assessment as it is of market research. The same results that are discussed in section 4.1.1 equally apply here.

#### *4.4.2 (New) market segments*

The option "very valuable" received six responses, which is more than twice the amount as for the other options. The options "not valuable" and "less valuable" were chosen once each. So there is a tendency towards considering sensor data valuable to discover new market segments. It has been stated that discovering new market segments is possible "through unexpected usage" of devices and products. This is also in line with Porter and Heppelmann (2015) who stated that with the IoT, marketers can identify usage patterns which helps to better segment their target groups. Another expert highlighted the importance of conducting preliminary research such as desktop research in addition to the sensor data.

#### *4.4.3 Economic value to the customer*

The overall tendency of the responses suggests a potential value of using sensor data to understand a potential new product's economic value to the customer. However, two experts indicated that sensor data is not valuable in this respect. One expert even stated that he does not see any connection. These results indicate that there could be a weak relationship between sensor data and the assessment of economic value to the customer.

### 4.5 Prototype/Feature testing

For this activity there is a strong agreement among the experts that sensor data can contribute greatly. Half of the experts consider sensor data "very valuable" to facilitate the testing of prototypes and new features and another four of them stated "valuable". Therefore, eleven respondents think that sensor data is at least valuable for this purpose as opposed to three indicating otherwise. According to one expert this may be realized by using a Fail fast approach here as well.

## 5. CHALLENGES OF USING SENSOR DATA FOR INNOVATION

In the responses to the questionnaire, it has been pointed out that customer privacy concerns need to be taken into consideration when using sensor data for innovation. According to Tan and Wang (2010), one of the main challenges with the IoT relates to security and privacy. This section elaborates on sub-question (5) discussing possible challenges of using sensor data for innovation purposes.

### 5.1 Security

The IoT could enable hackers to control physical, real-world devices. This can have severe consequences. If an IoT system is not properly secured, hackers can access private data and cause physical harm through, for example, controlling medical devices like pacemakers and insulin pumps or the engines and brakes of connected vehicles. Besides hacking, social threats can occur when knowledge is leaked in unexpected ways. For example, the information that a smart-house is in an energy-saving mode could be an indicator that nobody is home and attract a burglar (Want, Schilit & Jenson, 2015). At the same time, many IoT companies have little Internet security expertise (International Telecommunication Union, 2015). According to Santucci (2009), in order to meet security requirements the following four components are necessary: (1) Confidentiality: no unauthorized access to data (2) Integrity: no unauthorized/unrecognized manipulation of data (3) Availability: processing of the system functions at the defined time, within the defined period of time (4) Accountability: on every function (and its results) of a system, it must be possible to determine which instance (and/or person) handled its processing.

### 5.2 Privacy

Porter and Heppelmann (2014) also addressed this issue. According to them, companies will need to find ways to provide data to third parties without alienating customers. For instance, rather than selling individual customer data, companies could sell blinded or aggregate data on things like purchasing patterns, driving habits or energy usage. However, addressing the customers' privacy concerns is not enough. Since government regulations are becoming stricter, companies must develop data policies that reflect these regulations and transparently define the type of data collected and how it will be used by the company and also third parties (Porter & Heppelmann, (2015). In contrast to that, Santucci (2009) noted that the very concept of privacy will change as the Internet of Things develops. What is considered private information today such as data about a person's health, relationships, and habits may not necessarily have the same privacy status in the near future.

## 5.3 Business Models

Ultimately, such data can only be generated if companies can find suitable ways to monetize the adoption of IoT solutions. Therefore, another challenge is the identification of suitable business models with the IoT (Bucherer & Uckelmann, 2011). An example of such a model is the Product-as-a-service model. Firm can pursue revenue models where they retain full ownership over their products and solely charge customers for their consumption by tying in a recurring payment model. They can offer their products without selling them, but as a service. This implies that companies have to ensure reliable product performance constantly. The consumers' experience is elevated in this model since they only pay for the actual value they receive and nothing more or less. Companies benefit from higher margin revenue and the ability to monetize a product throughout its entire lifecycle (Ashton, 2015; Gandhi & Gervet, 2016; Porter & Heppelmann, 2014). This model may be compatible with Pay-For-Results, Freemium, Pay-As-You-Go and subsciption-based pricing strategies (Bonnet, Buvat, & Subrahmanyam, 2014). Models that involve recurring payments rather than a single sale are especially appealing for co-creation as they foster customer loyalty though personalization (Hui, 2014, July), which creates long-term relationships with the customer long after the product has been purchased (Bonnet, Buvat, & Subrahmanyam, 2014). The opportunity to add digital services to their pre-digital products also enables firms to implement hybrid models between the product-as-a-service model and traditional product sales. Unlike the product-as-a-service model, here ownership over the product is transferred to the customer. However, the firm maintains responsibility and bears the risk of product to the extent that has been agreed upon. Hybrid models may be realized by coupling the physical product with warranty, service or performance-based contracts (Daugherty, Banerjee, Negm, & Alter, 2014; Porter & Heppelmann, 2014).

# 6. CONCLUSION

The literature review has shown that successfully conducting the fuzzy front end is critical for the innovation process. Front-end performance is positively influenced by a company's ability to integrate external sources of innovation, particularly the customer. Co-creation is an approach whereby a company and its customers jointly create such value through customer involvement in the innovation process. Sensor data generated from connected devices displays great potential to enhance co-creation and thus front-end performance. These findings suggest that particularly those front-end activities that involve customer input can be enhanced by sensor data. With this, the research questions (1), (2), and (3) are addressed.

The literature review partially answers the central research question: Companies can use the IoT as a co-creation tool in the fuzzy front end through the adoption of sensor data in front-end activities. With research question (4), this broad conclusion is examined in a more differentiated and specific manner. The expert questionnaire assesses the value of sensor data for the individual front-end activities.

The results suggest that, in general, sensor data could be a great enhancement for the fuzzy front end. Four main conclusions can be drawn from the results of the questionnaire. First, front-end activities aiming to obtain market intelligence such as the preliminary market assessment and market research are improved with sensor data only if it is successfully integrated with conventional methods and information. Second, the IoT may enable transferring software development principles to the physical world. This supports the development of technically more sophisticated products and devices. Third, sensor data can provide deeper levels of insight about customers such as information about latent customer needs. The main advantage with regards to customer voice research is the ability to get insights into how customers use products in their daily routines, which was previously not possible. Fourth, insights into how customers use products and devices can be of great value for the testing of prototypes and new product features.

In order to tap into the IoT's potential for the fuzzy front end, challenges need to be overcome. Privacy and security issues need to be addressed in an appropriate, contemporary manner to not scare customers off and avoid legal disputes. Moreover, companies need to identify suitable business models that support the generation of sensor data.

# 7. LIMITATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

One of the challenges faced in this research is the availability of scientific literature. Since the Internet of Things is a rather recent phenomenon, it is just beginning to become an interesting research topic. Therefore, many of the used articles are non-scientific and have little empirical validity such as management magazines and analyst reports.

Due to the rather small sample size (n=14), it cannot be said that the experts' opinions as found by this research, are representative of the opinions of all IoT experts. Moreover, since qualitative data was collected, the results merely suggest an indication of possible relationships between the variable and not a statistical correlation.

For further research it is recommended to test the conceptual model by means of an empirical study generating quantitative data. For example, by observing how companies use sensor data in the FFE in practice and analyzing the effect of this on innovation performance. Moreover, although it turns out that in general, sensor data could be a great enhancement for voice-of-the-customer (VoC) research, there is considerable disagreement on the questions regarding the identification of customer needs. Therefore, more research needs to be done looking deeper into the value of sensor data to identify the various customer needs (unmet needs, unarticulated needs, emerging needs, latent needs). Finally, it has emerged that sensor data needs to be integrated with conventional methods to acquire market intelligence in the preliminary market assessment and market research. How conventional methods and sensor data could be integrated to jointly create valuable information can be a topic for future research.

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# 10. APPENDIX

## 10.1 Questionnaire

| Front-end Activity | Critical Input for the Front-end Activity | Survey Question |
|---|---|---|
| | | How valueable would you consider sensor data to... |
| Preliminary Market Assessment | Market size & potential | (1) determine a potential new market's size and potential? |
| | Indication of customer needs, requirements and value | (2) get a basic understanding of the customers' needs, requirements and values? |
| Technical Assessment | Probable technical solutions | (3) identify probable technical solutions to customer needs? |
| | Technical challenges and risks | (4) identify technical challenges and risks associated with a new product concept? |
| VoC research | Unmet customer needs | (5) get deep insights into unmet customer needs? |
| | Emerging customer needs | (6) get deeper insights into emerging/future customer needs? |
| | Unarticulated customer needs | (7) get deeper insights into those customer needs that they are aware of but not able to articulate? |
| | Latent customer needs | (8) get deeper insights into those customer needs that they themselves are not even aware of? |
| | Customer usage of product | (9) observe how customers use or abuse products in their daily routine? |
| | Innovative product designs and solutions (Lead users) | (10) discover innovative product designs and solutions created by customers? |
| | Customer points of pain | (11) understand customer "points of pain"? |
| Market Research | Market size & potential | *covered in (1) |
| | (New) Market segments | (12) discover new market segments? |
| | Economic value to the customer | (13) understand a potential new products economic value to the customer? |
| Prototype/Feautre Testing | Customer interest, liking and purchase intent | (14) facilitate the testing of prototypes and potential new product features? |