Master's thesis

for the Attainment of the Degree

Master of Science

at the TUM Department of Mechanical Engineering

of the Technische Universität München

Evaluating Assistance Systems in Production 2.0: A Case Study of Assistance Systems in the Automotive Industry

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Submitted on: 23.10.2018

Abstract

In a market, which demand highly customized products, workers face a great amount of complex tasks. To support them, the automotive industry has progressively adopted new innovative systems, called assistance systems. This human-system collaboration combines the effective characteristics of a system with humans' unique cognitive skills. Due to the great value and variety of assistance systems, companies encounter big challenges when deciding in which one they should invest.

So far, traditional criteria to evaluate manufacturing systems focus on their performance. These indicators could be grouped into economic factors, efficiency, quality, maturity and flexibility. Nonetheless, they fail to assess assistance systems, suggesting that the classic criteria might not be sufficient to encompass all the characteristics of those system. A promising approach, which could overcome these shortcomings, is considering user acceptance as a decisive criterion.

This thesis presents a comparative between the traditional and the new criteria. For this purpose, pairwise comparisons and interviews with experts in the automotive field are conducted. This research reveals the importance of user acceptance for a system's successful implementation. Additionally, an approach is presented to estimate the perceived acceptance by users. This method is validated through the evaluation of a smart watch, with a specific industrial application.

In conclusion, the results showed that user acceptance should be included in methods that assess assistance systems. Furthermore, the approach to estimate user acceptance allows a more detailed analysis of users' perceptions towards an assistance system.

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List of Abbreviations

IT – Information Technologies

IoT – Internet of Things

3D – Three-dimensional space

CAD – Computer-aided Design

RFID – Radio Frequency Identification

AS – Assistance systems

BMW – Bavarian Motor Works

VW - Volskwagen

FSU – Facility Space Utilization

VDA – Association of Automobiles

OEE – Overall Equipment Effectiveness

EDI – Electronic Data Interchange

AHP - Analytic Hierarchy Process

1 Introduction

This chapter will present the definition and delimitation of the problem by outlining the shortcomings in the most relevant previous findings in this area. In addition, the motivation and structure of the research work will be covered.

1.1 Motivation of the research work

Automotive production is currently facing many challenges. The increase in global competition, increasing customer requirements and the change in societal values are leading to very volatile market demand. This creates a strong necessity for economic flexibility and adaptability in production. Accordingly, operators must perform more and more tasks with an increasing level of complexity. This increase of difficulty in production lines demands supportive measures for employees.

In order to overcome these challenges, new approaches and technologies must be developed. "Industry 4.0" - characterized by increasing digitalization and networking of products, people and value chains - offers the opportunity to make the production system economical, ergonomic and versatile.

One aspect of "Industry 4.0" is innovative assistance systems. This includes all technologies that support employees in carrying out their work and enable them to concentrate on their core competencies. These include, for example, technologies for providing information such as visualization systems, data glasses, tablets or aids for motorized support of motion sequences, such as exoskeleton. In a new industry concept, the role of the human is far from obsolete. The human is conceived as the value creator and the problem solver.

The adoption of these assistance systems by manufacturing companies in production has progressively increased. By this means, a new collaborative environment between human and systems is created, which has improved working conditions. This leads to better ergonomics, enhancement of human capabilities and more efficient access to information. Accordingly, daily tasks that worker must face are eased. Thus, assistance systems gain a great importance for the future and the present of production.

Despite the importance of assistance systems, manufacturers still struggle to make the right choice when deciding in which technology they should invest. Being able to deduce which factors are more relevant when evaluating these systems could help companies to be more effective when adopting new technologies in this field. Hence, costs are reduced and the decision-making process optimized.

1.2 Definition and delimitation of the problem

The great variety of demand of an internet-based society poses new challenges for the industry. Consequently, companies need to produce with high flexibility, and be able to adapt the production line to the customization of each product. Therefore, there is a push to increase automation by the implementation of innovative technologies. By doing so, plants are able to augment their productivity, increasing the quality of the final outcome as well. (Hannemann & Dr. Krüger, 2013)

Constantly evaluating and adopting innovative production technologies is a major challenge for companies because of a dynamic environment. The specification of the task to be fulfilled by a system in production can rapidly change depending on the production needs of each particular point in time. In this sense, technological advances have become of great relevance for the companies in order to remain competitive in a constantly changing market. Therefore, competitive advantage can arise from being able to detect and anticipate innovation with great potential for production. (Dengler et al., 2017a)

There have been several attempts to assess innovation and to discover the most relevant criteria when evaluating innovative technologies in production. So far, the different approaches and models put the focus on the performance of the system. The results in Table 1 show the most relevant models for evaluating technologies and manufacturing systems.

Table 1 shows the most significant criteria when evaluating technologies in production: cost, flexibility, quality, product feasibility and sustainability. The cost concern all the economic factors needed to produce an asset. That means for example, set up costs, planning costs, producing costs and costs related to the manufacturing process. (Bornschlegl et al., 2015) Then the flexibility is the combination of capability and capacity of a system. Capability corresponds to the ability to perform in different states,

whereas capacity is defined as the easiness of performance of a system, when changing states or fulfilling a task. (Chang et al., 2001a) Quality defines how much a procedure fulfills the customer expectations. (Devaraj et al., 2009a) The sustainability, refers to the ability of a system to be sustained being at the same time respectful with the environment. (Kaku, 2017) Finally product feasibility is the current state of the product and its possible future adaptations. (Dengler et al., 2017b)

Table 1: Overview of traditional criteria

Swamidass 1987 [2]	Kleindorfer & Partovi 1990 [34]	Koho 2010 [35]	Reinhart et al. 2009 [19] 2011 [36]	Friedrich 2014 [20]
Cost	Cost	Cost	Profitability	Cost
Flexibility	Flexibility	Volume Flexibility	Competitive Potential	Flexibility
Quality	Quality	Quality	Maturity	Quality
	Dependability	Time	Product Feasibility	Product Feasibility
		Product Flexibility	Resource Efficiency	Ecology
		Reliability of lead/ delivery time		Throughput Investment

Source: (Dengler et al., 2017c)

Apart from these methods, there are other techniques to evaluate innovation. The method developed by Bürgin (2007) revealed the importance of considering the maturity as a relevant criterion for innovative systems. Maturity is defined as the technology readiness level, which allows to compare the different states of development of a technology. (Mankins, 1995a)

Moreover, in the Industry 4.0, the decision making and the problem solving are tasks performed by humans, who are in charge of value creation. The worker of the future will have to deal with increasingly complex and changing duties, which must be done without affecting the quality of work. Furthermore, workers still today face a lot of physically demanding tasks. Accordingly, healthy working conditions must be created to maintain a high productivity. It is therefore important to find a balance between innovative work systems and ergonomic workplaces. Thus, assistance systems play an important role in the future of the industry. (Nelles et al., 2016a)

Assistance systems are designed so that the users have a better working experience. Nonetheless, the adoption of this systems by operators is done on a voluntary basis. Therefore, if they do not realize the benefits that this assistance system could bring to them, they will never adopt it. Then, in this collaborative environment the user acceptance might be as well an important factor.

The effect of the user acceptance toward an assistance system and its impact on the assessment of these innovative technologies are still not clear.

1.3 Objective of the thesis

Traditional evaluating criteria for manufacturing systems might not be sufficient to respond to the characteristics of assistance systems in production. Despite the fact that assistance systems in production have some common attributes with manufacturing systems, these two systems are different, as assistance systems interact directly with the user. This suggest that evaluating assistance systems by using conventional criteria might not be sufficient.

A promising approach to solve this challenge is the consideration of user acceptance, as a relevant criterion for the evaluation of assistance systems. This thesis will investigate the viability of this approach answering the following question:

Should user acceptance be considered as a criterion to evaluate assistance systems in production?

If user acceptance is found to be relevant to the assessment of assistance systems, then attempts will be made to indicate how this criterion should be evaluated. The developed method should encompass the peculiarities of assistance systems. This assessment approach for assistance systems' user acceptance should answer the following question:

How can the user acceptance of an assistance system be assessed?

If these two questions can be answered, the results may lead to an extension of the existing criteria for the evaluation of assistance systems in production. Moreover, these answers open the possibility of applying the user acceptance and the already existing criteria in a method to evaluate assistance systems in production

1.4 Research method

This thesis answers the research questions using the following method.

Firstly, a literature research allows to describe all the innovative technologies in production and focus on the ones that add a collaborative environment, relevant for the research questions. In addition, literature research and findings on an industrial environment enable to introduce and define assistance systems, offering an overview and a categorization of all the assistance systems in the market and the ones already implemented in production.

Secondly, this thesis describes the criteria currently used to evaluate manufacturing systems, indicating the suitability of these indicators when evaluating assistance systems. Simultaneously, it presents and offers reasons to suggest that user acceptance might be a potential criterion to be considered. Both concepts are developed using the existing literature and findings on an industrial environment.

Once the theoretical background is established, a field study among experts is presented. This study consists of conducting interviews and performing pairwise comparisons with experts of the automotive industry. The objective of this research is to respond to the first research question, by indicating the importance of user acceptance when assessing assistance systems.

In addition, an approach to evaluate user acceptance is presented. This will be developed on the basis of models already established to assess this acceptance, adapting them accordingly to the assistance systems. Literature research combined with the opinions of the experts will be the basis to construct this method. The objective of this approach is to answer the second research question, by describing how to evaluate the assistance systems' user acceptance.

Finally, the method to evaluate assistance systems' user acceptance is validated using a smart watch with a specific industrial application. This validation demonstrates the practical applications of this method.

1.5 Structure of the work

This thesis answers the research questions using the following structure.

Firstly, the state-of the art provide a theoretical background for the introduction and further development of the thesis topics. This second chapter offers a comprehensive presentation of innovative systems in production. Then it presents a definition of assistance systems and remarks the importance of these systems in the industry. Moreover, this section provides an overview of all the existing assistance systems, with special attention to the ones with production applications. Finally, in this chapter, the traditional criteria to evaluate manufacturing systems is presented, outlining its appropriateness of these factors for the assessment of assistance systems. Furthermore, user acceptance is introduced as a promising criterion for the evaluation of assistance systems.

In the third chapter, a field study is performed in order to assess the viability of considering user acceptance as a relevant criterion for assistance systems. This study consists on pairwise comparisons and interviews with experts. The development of the pairwise as well as the form of the interviews are explained in this section. In addition, the results of the pairwise comparison are analyzed and the opinions of the participants in the interviews are discussed. Finally, in this chapter is presented an approach to measure the perceived user acceptance.

The fourth chapter will present a validation of the method to evaluate user acceptance with an assistance system. A smart watch with a specific industrial application is selected to validate the described method. It is then presented a practical application in the industry of this method outlining the benefits of this approach.

In chapter five, both the field study and the validation are discussed. The limitations and the validity of the obtained results is outlined.

Finally, in chapter six the thesis is concluded. In addition, suggestions about possible future work are indicated in this section.

2 State-of-the-art

In this chapter an introduction to innovative technologies in production is presented. In addition, assistance systems are introduced and defined, remarking the importance of these systems for the industry. Moreover, an overview with examples is indicated which allow to have a better understanding of the characteristics of assistance systems. Finally, the criteria to evaluate these systems is outlined.

2.1 Innovative technologies in production

The first industrial revolution, which allows to introduce the first mechanical loom in 1784, have changed forever the interaction between humans and machines. Then right after came the second industrial revolution that allowed mass production due to the introduction of electric energy. The next great industrial leap would lead to the implementation of the first automated systems through electronics and information technology (IT). Today the fourth industrial revolution is achieved through cyber-physical systems (Kagermann et al., 2013). It can be then appreciated that through these industrial transformations the degree of complexity had been increased since the first revolution.

The customer behavior of a society that is highly linked to Internet had transformed the manner companies interact with its clients (Koufaris, 2002). Accordingly, automotive manufacturing companies have to address this volatile market necessities maintaining a high efficiency in their processes. The fulfilment of these objectives relays on the quality of the data and the process of this data in real time (Nelles et al., 2016b). Consequently, companies need to evolve into a more digitalized, networked and flexible form of production, known as Industry 4.0, in order for them to remain competitive (Bauernhansl, 2014). This term was first adopted in Germany. In contrast, the United States of America adopted a new concept of intelligent production, referred as Internet of Things (IoT). The IoT indicate an environment, where a system is connected to internet, allowing it to have access to remote data and remotely interact with other physical systems (Kopetz, 2011). Both concepts referred to internet-based systems able to gather and evaluate massive amounts of data in real time. Hence, this new smart factories lead to more efficient processes as well as higher customers benefits (Kasselmann & Willeke, 2016).

With regard to Industry 4.0 and IoT, the technologies that are encompass in this category are shown and described in Table 2.

Table 2: Technologies related to Industry 4.0

Technology	Description	References
Additive Manufacturing	Is a technology that allows 3D CAD models to be printed, layer by layer, into one solid piece. It can be printed in different materials such as metal, wax, plastics, and ceramics. It also allows to produce mechanical parts that couldn't be fabricated by regular processes	Berman (2012), Harris and Director (2011), Oettmeier and Hofmann (2017), Scott and Harrison (2015)
Big Data & Analytics	Is the information available by the acquisition of different sensors, gathered into a historical and real time dataset. Analytics is the use of tools and statistical method to use information in managerial decisions	Hazen et al. (2014), Lee et al. (2013, 2014), Megahed and Jones-Farmer (2013), Posada et al. (2015), Shrouf et al. (2014), Witkowski (2017)
Cloud Computing	Is the use of data and software available through networks instead of being installed physically on a local computer	Bughin et al. (2010), Marston et al. (2011), Rüßmann et al. (2015)
Cyber-Physical Systems	Is an automated system that orchestrates the communication among several devices and equipment through a computing infrastructure. It includes smart machines, storage systems, and production facilities that can exchange information with autonomy and intelligence, are able to decide and trigger actions, and can control each other independently	Baheti and Gill (2011), Hermann et al. (2016), Lee (2008), MacDougall (2014), Posada et al. (2015)
Cybersecurity	Is the protection of the information available by the devices connected to a computer network, adding to the security of the user connected to the network and their assets	Von Solms and Van Niekerk (2013), Wang et al. (2016), Waslo et al. (2017), Witkowski (2017)
Internet of Things	Is characterized by the interconnection of equipment and devices (things) through the Internet. Equipment provides information (such as their status, environment, production processes and maintenance schedule, among others) to the network by embedded electronics (RFID tags, sensors, etc.), being also able to perform actions based on the information of other devices	Hermann et al. (2016), Hofmann and Rüsch (2017), Shrouf et al. (2014), Rüßmann et al. (2015)
Collaborative Robotics	It can be defined as robots who can interact with human operators and other robots in an intuitive self-learning behaviour	Awais and Henrich (2013), Rüßmann et al. (2015)
Visual Computing	It can be defined as the entire field of acquiring, analysing, and synthesizing visual data by means of computers that provide relevant-to-the-field tools	Paelke (2014), Posada et al. (2015), Shellshear et al. (2015)

Source: (Dalmarco & Barros, 2018)

In addition to the overview offered in the previous table, Rüßmann et al. (2015) categorized the technology forms of Industry 4.0 using Nine Pillars of Technological Advances. Those are: Autonomous robots, Simulations, Horizontal and Vertical system integration, The Industrial Internet of Things, Cybersecurity, The Cloud, Additive Manufacturing, Augmented Reality and Big Data and analytics.

Among all the technologies present on Industry 4.0, the are some that directly support the human on the fulfillment of their tasks. From the ones previously presented, the technologies that possess these capabilities are: collaborative robots, autonomous robots, cyber-physical systems and visual computing – in which the augmented reality could be clustered-. The clearest example could be found with collaborative robots. These systems coexist with workers in production, supporting them in tasks such as handling. That relieves the user from arduous and high physical demanding assignments. (Gambao et al., 2012). Hence technologies interacting with the user are present in the Industry 4.0.

Under this category of supporting technologies, there exist some systems that they principal objective is to give direct support to the user in a great variety of forms. These systems are called assistance systems, which are introduced in the following chapter.

2.2 Relevance and definition of assistance systems in production

It has been believed for many years that the future of the production industry relies in smart factories fully automatized. In this concept, humans are substituted by machines. However, they have unique cognitive skill to react quickly, gain experience and communicate with others not yet developed by machines (Zäh et al., 2003). Thus, companies must promote this human-system interaction in order to benefit from these particular human skills. It is clear then that in the context of Industry 4.0 the human is a decisive factor when measuring the success of production systems (Haase et al., 2015). Therefore, systems able to promote this interaction, such as the assistance systems, are of a great relevance for today and future production.

According to Lewin et al. (2017) an assistance systems, in the context of Industry 4.0, is: "…technical system components with the aim of supporting the user in the fulfilment of his task in an informative, cognitive or physical way. The aim of assistance systems is to provide employees with the information they need as quickly and easily as possible,

anytime and anywhere.". By this definition assistance system can support a human in the following manners: *informative,* which are all the assistance systems that provided information to users by means of simple identification or position recognition. Then, these systems are limited to access already existing information, stored in a sensor or a database; in *cognitive* assistance systems the information is adapted correspondingly to each situation and to the operator. Thus, these systems are more complex and flexible than the informative ones; *physical* assistance systems relieve the human from high physically demanding tasks, promoting a more ergonomic workplace.

In another study (Niethaus, 2017) assistance systems are defined as: "mobile or close-fitting portable terminals (Wearables) in industrial application, which prepare information in real time, provide decision support, or also issue work instructions for the employee.". This definition refers to systems that are transportable. Moreover, those systems are aim for industrial applications.

Rügge et al. (2003) refers to the assistance systems as wearable computing technologies, which are mobile or close-fitting computer systems, that make the information and communication technologies more accessible than ever before, transforming mobile activities into more effective tasks.

Assistance systems could be understood as supporting systems (hardware or software solutions) that help the user to perform their tasks with more efficiency, more flexibility, higher quality, and relieving the operator from high physical demanding tasks. This support offered by assistance systems is materialized by means of providing the necessary information in real time, in the simplest, fastest, and effective way possible, and giving the users the opportunity to make the most out of their unique cognitive skills.

2.3 Overview and categorization of assistance systems in production

Production lines are plenty of systems already implemented which adjust to the definition of assistance systems (AS). One of the most adopted AS is the Smart Wearable or Wearable Technologies. In 1998 the Tampere University of Technology and the University of Lapland and Reima Ltd cluster those wearables in three different groups (McCann & Bryson, 2003): *wearable computers*, which are computing devices that can be carried on the body, present a user interface, and can be used wherever the user goes

at any time; *wearable electronics* are designed to be worn on the body and are programmed to fulfill one set of specific tasks, whereas the wearable computers could adapt to each situation; *intelligent clothing* are textiles equipped with a new functionality, without losing its traditional characteristics such washability or wearability.

In this first categorization of smart wearables, comprising the three groups described before, Table 3 illustrates different examples of these type of assistance systems.

Table 3: Smart Wearable technologies

Smart Wearable	Application	Source
Belt	Smart belt to promote health measures to reduce the obesity	(Hyejeong Nam, 2016)
Bracelets	Smart jewelry bracelet, to automatically sense, detect, and identify physical assault	(Patel & Hasan, 2018)
Exoskeleton	Exoskeleton to assist people to walk suffering from multiple sclerosis	(Afzal et al., 2017)
Headsets	Control of a robot arm using a headset	(Aguiar et al., 2016)
Ring	A wearable ring platform that enables text input into computers of different forms	(Nirjon et al., 2015)
Shoes	Smart shoe with gait detection as a measure to decrease elderly injuries due to fall	(Majumder et al., 2015)
Smart Glasses	Low cost obstacle detection ultrasonic glasses for blind people	(Agarwal et al., 2017)
Smart Gloves	Emotion recognition through sensors placed in a sensing fabric glove	(Valenza et al., 2010)
Smart Watch	Watch that allows to recognize the user by means of temperature body recognition	(Enamamu et al., 2017)

Source: Own representation

Another category that adjust to the definition of assistance systems is smart devices. These are according to Poslad (2011): "devices design to assist and automate more human tasks and activities, to enrich human social interaction and enhance physical world interaction". The equipment that can be worn is excluded from this category, since it is already covered in the smart wearables. Some examples to clarify this concept are presented in Table 4.

Table 4: Smart Devices technologies

Smart Device	Application	Source
Tablets	Tactile feedback device which ease the communication with a robot	(Kumazawa & Koizumi, 2013)
Smartphones	Smartphone that allows to process real-time digital signals	(Kehtarnavaz et al., 2015)
Projectors	Augmented reality system which interact with the user by means of a projector camera-based AR, and a smartphone	(Lim et al., 2015)
Intelligent light	Adjustable illuminance to improve the ergonomic conditions	(Lin et al., 2011)

Source: Own representation

Assistance systems could be categorized in other manners rather than just its characteristics. There are other forms to cluster these systems by means of the sector which they belong, the application of each system, its functionality or the products itself.

In Figure 1 it is represented the great variety of assistance systems, and the different categories in which they could be cluster, such as type of products, functionality, applications, and sector.

With regard to industrial applications, some examples could be found in the automotive industry. Manufacturers of this sector have already adopted assistance systems in their

production lines. BMW, for example, has already implemented exoskeleton, smart gloves or augmented reality devices to support the worker in their production tasks (BMWGroup, 2017). Or Volkswagen (VW) that has already implemented a clip set assistance system or orthoses to relieve stress. (Schlott, 2015) These implementations demonstrate that assistance systems are present in production lines, and companies perceived them as relevant tools for production tasks.

Figure 1: Categorization of wearable technologies
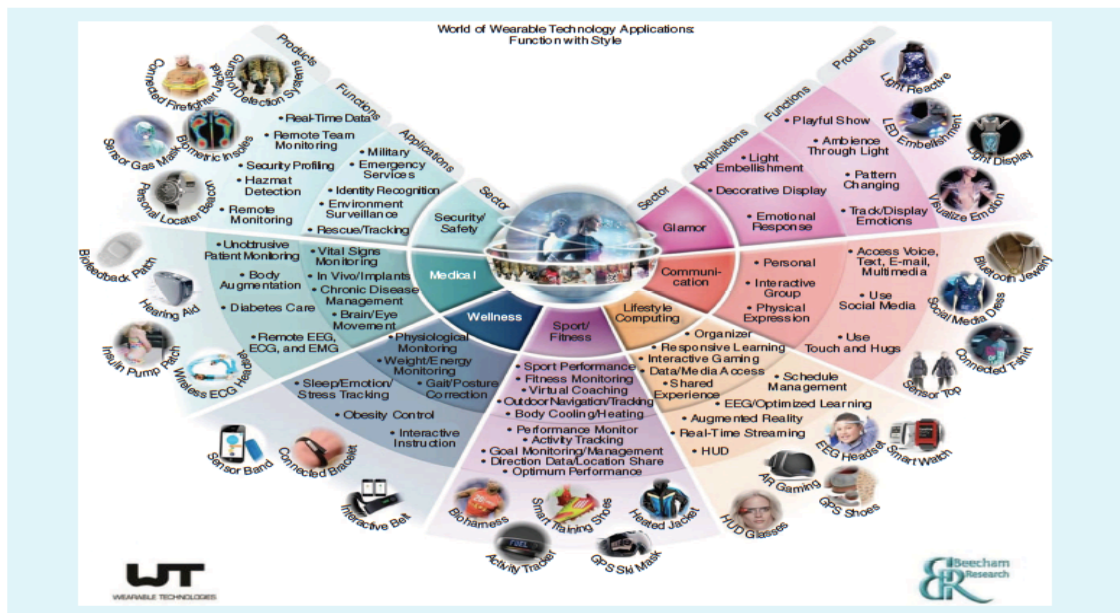
Source : (Wei, 2014, p. 54)

2.4 Traditional criteria to evaluate assistance systems

Assistance systems, as other systems present in the production, have the objective to reduce costs, make the work more efficient, with more flexibility, improving the quality of the final product. (Lewin et al., 2017) However, its particular objective, to support the human on their tasks, may lead to alternative criteria not been covered by conventional production systems.

The manufacturing objectives of an automotive company, with regard of production, can be modelled into measurable criteria related to costs, flexibility, effectivity, production quality and maturity of a technology. These indicators are traditionally used in the decision-making process. The criteria are presented in Table 5.

Table 5: Criteria to evaluate a manufacturing production system

I.   Reduction of Running Costs
II.   Reduction of New Investment
III.   Increase of Quality/ Reduction of Rework
IV.   Increase of Flexibility
V.   Increase of Overall Equipment Effectiveness
VI.   Increase of Energy and Resource Effectiveness
VII.   Improvement of Ergonomics
VIII.   Increase of Space Utilization
IX.   Reduce of Ramp-up Costs
X.   Reduce of Planning Costs
XI.   Increase of Digitization/Networking/Smart Production
XII.   Maturity of a technology

Source : Own representation based on (Wunderl, 2018, p. 69)

As it can be seen in the previous table, the following criteria can be outlined when evaluating manufacturing systems in production: *costs, quality, flexibility, ergonomics digitalization,* and *maturity of a technology*. The *costs* involved all the economic factors that a system might be able to improve in order to cheapen the production of a car. That relates with the criteria I. Reduce of Running Costs, II. Reduce of New Invest, IX. Reduce of Ramp-up Costs and X. Reduce of Planning Costs. Then *quality* is defined as how much a procedure fulfills the customer expectations (Devaraj et al., 2009b). This indicator is reflected by the objective III. Increase of Quality/Reduction of Rework. *Flexibility* refers to the ability of a system to perform in different states, as well as the easiness of performance of a system, when changing states or fulfilling a task (Chang et al., 2001b). This objective is covered by factor IV. Increase of Flexibility. *Efficiency* is understood as an economical factor. To maximize the efficiency the production of a good or service should be done at the lowest possible cost (Comission, 2013). That is measured through factors V. Increase of Overall Equipment Effectiveness, VI. Increase of Energy and Resource Efficiency and VIII. Increase of Space Utilization. *Ergonomics* is described as the promoting compatibility between humans and systems (Jaffar et al., 2011) It is expressed by the indicator VII. Improvement of Ergonomics. The *digitalization*, which represents the integration of multiple technologies into all aspects of daily life that can be

digitized. (Gray & Rumpe, 2015), is reflected in factor XI. Increase Digitalization/Networking/Smart Production. Finally, the *maturity* is represented in the indicator XII. Maturity of a technology.

Despite the fact that these criteria are suitable for manufacturing systems in production, that might not be the case for assistance systems. In order to adapt these criteria, the factors covered in Table 5 are going to be discussed. Then an alternative list is to be presented with adapted indicators regarding assistance systems in production.

The cost assessment of an assistance system in comparison with a manufacturing system does not present substantive differences. The economical evaluation of any system in production has the same objectives. Those are, as seen before, to reduce running costs, to reduce the new invest, to reduce ramp-up costs and to reduce planning costs. Assistance systems, the aim of which is to support the worker on its production tasks, face the same economic challenges.

As an illustration, it is considered that a Smart Watch is to be evaluated. The application of which is to display to user's relevant information about each car in production. This device can lead to a reduction of running costs by shortening assembly tasks. Without this device the worker might have to spend some time looking for this particular information, either in a paper or in a screen. Time in production means an impact on the final price of the car. Hence, this assistance system has an impact on the running costs.

Using the same reasoning, one could find solid arguments in favor of the other economic factors. The other costs, which are investment costs, ramp-up costs, and planning costs, are economical means in order to implement a new system in production. The implementation process of a smart watch is subjected to these costs. The acquisition of this system, in terms of the necessary hardware and software for this technology, constitute the investment costs. In addition, there are some planning costs w, such as the number of devices that might be needed per production line, the substitution of this devices in case of a malfunction of one of these systems or scheduling the maintenance tasks. Finally ramp-up costs, such as delivering the devices to the workers at the right time (Westerlind, 2004a). Therefore, these costs criteria are considered relevant for assistance systems evaluation.

The quality aspect of assistance systems in comparison with manufacturing system do not present substantive differences. The evaluation of this indicator in production is the same for both systems. The factor to describe the quality is the reduction of rework. To illustrate the relevance of this criterion in the evaluation of assistance systems, a pneumatic clip is used, which has been developed by Festo AG and has been adopted by Volkswagen in production lines. (Hannemann & Dr. Krüger, 2013, p. 324) This clip is used in the assembly lines to relieve the strain from operators when assembling a great number of clips. Here the objective is to increase the ergonomics of the working station while reducing the human error factor, due to the great amount of work and the monotony of it. The reduction on the inaccuracy of the operator lead to a considerate reduction of rework. This remarks the importance of this criterion when assessing assistance systems.

The flexibility measurement of an assistance system in comparison with a manufacturing system does not present substantive differences. The objective, to increase the flexibility and therefore make the system able to perform well in different conditions, is present in assistance systems. As an example, it is assumed that a car manufacturing company produce a car model A. This company wants to implement an augmented reality glasses that could provide the exact location of the part of the car to be assembled in each process and for each car. For that purpose, the glasses must contain the information regarding the car model A, and all the parts within this model. The car manufacturing company decide after implementing these glasses, that from now on a new model B is to be assembled. If the assistance system is not flexible enough to adapt to this new model, this system is going to be obsolete. As showed in this last example, the flexibility criterion is important as well for assistance systems

Before moving forward to ergonomics, the digitalization will be discussed. With regard of this factor, it is found to have no adding value when evaluating assistance systems. Every time that an assistance system is adopted the production is digitalized (Hold et al., 2017). That means that this could not be an evaluation criterion, since the results when evaluating each technology are going to be the same. If this indicator is going to be equal for all the systems, might not be appropriate to discern between technologies but only to give an additional information. Hence, this criterion will not be used to evaluate assistance systems in production.

Ergonomics of an assistance system might not be enough to describe the unique interaction of these systems with the humans. Simplifying this cooperation with the indicator ergonomics improvement is not sufficient. Different studies suggest that the ergonomics constitute a part of what they called user acceptance. Wiedmann et al. (2018a) categorize this acceptance in five factors: usefulness, ease of use, performance, society and safety. Ergonomics is encompass in this last indicator. Zahng et al. (2010a) showed that when adopting a new technology of the e-learning type, the relevant factors are: perception on relative advantage, perception on compatibility, perception on complexity, perception on trialability and perception on observability. This is as well part of this user perception of a system. These studies remark that the simplification of this user interaction by means of ergonomics is not sufficient. Therefore, user acceptance will be presented as a new indicator, trying to investigate the impact of this factor on assistance systems.

Finally, the criterion that describe the maturity of a technology could be used in assistance systems evaluation as well. The reasons to believe that criteria might have an impact on these systems are as followed. Firstly, regarding that this assessment is enclosure in the early stages of technology recognition, might suggest that the degree of development of an innovative system could make a difference. The less development of a technology the more resources and time is going to be needed in order to adapt it an implement it (Garcia et al., 2002). Secondly, it allows to compare the maturity between different types of technology. Regarding the variety of assistance system, that would be a suitable approach to evaluate these systems with such a diversity. This evaluation is done by clustering the maturity within nine Technology Readiness Levels (Commission, 2014).

Once reviewed the criteria used for evaluating manufacturing systems in production and the adaption of this indicators for assistance systems has been discussed, the Table 6 is presented. This representation will help to clarify which criteria are selected for the assessment of assistance systems in production.

The criteria are subdivided into four strategic objectives: cost, flexibility, user acceptance and maturity. A further breakdown of the cost objective was decided since cost is a multi-faceted objective and still the most important driver during the decision-making process for a new invest.

Table 6: Criteria to evaluate assistance systems in production

Costs:

I.   Reduction of Rework Costs
II. Reduction of Running Costs
III. Reduction of Required Space
IV. Reduction of Energy and Resource Costs
V.   Increase the Overall Equipment Effectiveness
VI. Reduce Investment Costs
VII.   Reduce Planning Costs
VIII.   Reduce Ramp-up Costs

Flexibility:

IX. Increase of Flexibility

User Acceptance:

X. User Acceptance

Maturity:

XI. Maturity of a technology

Source: Own representation

The criteria represented in the previous table are described, indicating how these indicators are defined and measured.

Reduction of Rework Costs: This criterion is calculated based on minutes of rework for each car, the car per year that a specific factory produces, and the cost of each minute of rework. Rework tasks include the correction of defective, failed, or non-conforming products, during or after inspection. In addition, this factor includes also all follow-up efforts such as disassembly, repair, replacement and reassembly. (Brahmankar, 2013)

Reduction of Running Costs: Also referred to as the cost of production, running costs include expenditures relating to the manufacturing or creation of goods. For a cost to qualify as a production cost, it must be directly tied to the generation of revenue for the company. It generally has two aspects: costs related to the materials required to create an item and costs related to the labor need to create it. Moreover, in production, there are direct and indirect costs. Direct costs for manufacturing an automobile are materials, such as plastic and metal materials and the labor required to produce the finished product. Indirect costs include rent, administrative salaries, and utility expenses. (Monteiro, 2001) Since the reduction of needed materials is irrelevant to assistance system and the indirect costs are not influenced, the running costs refers only to production costs related to manual assembly (direct) work.

Reduction of Required Space: The Floor Space Utilization (FSU) metric is used in industry to measure the sales revenue generated per square meter of factory floor space. This metric expresses the amount of value that a factory is able to obtain, in terms of an effective use of space. It is demonstrated, that the more efficient a factory surface is utilized the more the fixed costs can be reduced. (Bozarth & Vilarinho, 2006). Fixed costs attached to the production of a car, such as factory space, are usually rather high and not desirable. Hence, there is a strong desire to minimize the use of space by the manufacturing processes. To increase the FSU value, the production areas must be optimized, and therefore reduced. This often means rethinking a process layout and eliminating inventory to reduce the necessary space. The introduction of a new assistance system can lead to a reduction of space required in an assembly station and thus increase area efficiency. As an example, one can consider the case of a Virtual Reality assistance system for layout planning of the commissioning area(A.F. & W.Y., 2003). This virtual environment allows to the production planners to try new area dispositions, modeling the new layouts in 3D models. Therefore, these tests could lead to the calculation of space utilization or measurements of the time needed per process. Such experiments suggest the importance of assistance systems in the area related planning tasks.

Reduction of Energy and Resource Costs: Energy consumption in the production is required in every production step for: machine function, press, paint shop, assembly, cooling, logistics, lighting, tools and welding. The energy costs are fixed for each specific plant and represent an aggregated value to the final product. The energy forms present in a production plant are: natural gas, electricity, and geothermal energy. (VDA, 2014)

Therefore, an improvement of these resources utilization results into a product with lower fixed costs. Therefore, assistance system should be design toward a more efficient energy and resource manufacturing.

Increase the Overall Equipment Effectiveness (OEE): The OEE key figures of any asset, machine, line or even the overall production are defined with the following three factors: Availability, Performance Efficiency, and Quality Factor. (Singh et al., 2013) Simple OEE approximates this indicator by simplifying the calculation to the actual output of the equipment divided by the theoretical output within a specific time. This simplification of the OEE calculation represents the first two elements of OEE, Availability and Performance Efficiency (Pomorski, 1997). This criterion identifies the percentage of manufacturing time that a system is truly productive. An OEE score of 100% means that only good parts are produced, as fast as possible, with no stop time. This translates into 100% Quality (only good parts), with 100% Performance (as fast as possible), and 100% Availability (no stop time). The interconnection of OEE with incurred costs is irrefutable, as one minute of downtime in production incurs maintenance costs, spare parts/materials, personnel costs, restart costs, etc. Hence, OEE can be estimated as a cost indicator.

Reduction of Investment Costs: The calculation of the investment costs for a new technology is the summation of one-time costs (e.g. purchase of hardware, training costs) and recurring costs (e.g. technical support, monthly/annual licensing models). The components of one-time costs are shown below in Table 7 and of recurring costs in Table 8. This criterion allows to discern between technologies of the same type. If two assistance systems have the same abilities, and they are able to perform the same tasks, then this criterion could be a decisive indicator in the decision making. In addition, this investment reduction has an impact on the fixed costs of a car (Spence, 1986). Hence must be minimized in order to deliver a more attractive product for the customers.

Table 7: One-Time Costs

One-Time Cost Type	Cost Type Subcomponents
Software	Application Software
	Data Management Center / EDI Software
	Database Software
	Adhoc Reporting

	Other Software (localization software)
Hardware	Web Application Servers
	Database Servers
	Cables
	Printers
	Racking
	Scanning Devices
	Localization Devices
External Services / Consulting	Project Management and Consulting
	Installation
	Integration
	Technical Training
	End-User Training
	Data Cleansing, Conversion, Migration
	Business Reengineering
	Modifications and Customizations
	Manuals and Documentation
	Travel and Expenses
Internal	Software Selection and Benchmarking
	Project Management
	Training
	Support during Roll-out

Source: Own representation based on (Westerlind, 2004b, p. 36)

Table 8: Recurring Costs

Reccurring Cost Type	Cost Type Subcomponents
Maintenance	Software maintenance (10% annually of the software cost)
	Hardware maintenance (15% annually of the hardware cost)
Support	Helpdesk and Technical Support
Internal	Personnel / System Administrator
	Housing / Facility

Source : Own representation based on (Westerlind, 2004c, p. 37)

Reduction of Planning Costs: this criterion includes all personnel and material costs in planning functions that arise in the course of realizing a product project. Material costs comprise materials and services, low-value assets and travel expenses (Gallego, 2001). In connection with the investment costs, a reduction of the planning costs affects the price of the final outcome. Hence, this criterion must be minimized.

Reduction of Ramp-up Costs: Involve the economic expenses in the testing process, where production increasingly moves from low rate to the required production rate. The components that affect the ramp-up costs are due to: work allocation, learning new processes, setting-up new systems, efforts to reach a steady cycle-time or efforts to reach capacity. (Ball et al., 2011) In relation with the investment costs and planning costs, ramp-up costs are proven to have an impact as ell on the price of the final product(Hartley, 2017). Hence, this criterion must be minimized

Increase of Flexibility: According to (Schmidt, 2018) this indicator could be calculated through components that have an impact on the overall flexibility of a systems:

•Automation describes the extent to which a process or device is executed or operates under defined conditions without human intervention (e.g. use of robots)

•Digitalization describes the processing of analogue information for processing or storage in a digital technical system. (e.g. from travel atlas to navigation system)

•Standardization describes a standardization of measures, types, components, procedures, structures or other (e.g.: modularly replaceable component of a machine)

•Communication describes the transmission of information between a transmitter and one or more receivers, whereby transmitter and /or receiver can be human or machine (e.g.: visualization of measured values on a monitor, rapid error feedback within the system)

•Mobility describes the ability of a process to enable the mobility of its actions independent of the location that it must operate to (e.g.: machine on wheels)

•Scalability describes the technical, spatial and personal breathability (extensibility and reducibility) (e.g. working time model for adjusting the available capacity, planned extension areas)

•Process maturity describes the fulfillment of defined requirements. These usually consist of acquired knowledge about a technology or technical processes (e.g.: use of new technologies vs. the use of proven technologies)

•Standards / guidelines describe the state of the art based on coordinated results from industry, technology and practice (e.g. risk assessment, implementation of the Machinery Directive)

Those components already mention affect positively or negatively to the flexibility of a system. This allows to assess how flexible a system is in different aspects: Volume Flexibility, which describes the ability of the production system to operate economically in the event of fluctuations or turbulences in production; Product Flexibility, which describes the ability of the production system to manufacture different products or to adapt an existing system and changing products; Work Flexibility describes the ability of the production system to allow staff to be assigned to different process steps and to be able to design their working times in a variable fashion; Routing flexibility describes the ability of the production system to produce certain products via alternative routes through the system. This indicator must be maximized, in order that an assistance system could rapidly adapt to a constantly changing production line.

User Acceptance: defined as the user adoption behavior towards a new technology, and particularly towards the endorsement of assistance systems. There are some already established and proved acceptance models. Davís (1989) concluded that there are some indicators affecting the acceptancy of a system, which can be measured and identified. In this approach, it is used the usefulness and the ease of use as criteria to predict the rejection or acceptance of a technology. Venkatesh et al. (2003) have created a Unified Theory of Acceptance and Use of Technology. This second model adds other criteria such as the social influence or voluntariness of use. These models were created for specific purpose. The first one was for assessing all kind of information systems, whereas the second is used to measure the acceptance in a company environment. Therefore, further adaptations to the assistance systems should be done.

Maturity of a technology: The maturity level of a technology, whether software-centered, hardware-centered or both, is based on the Technology Readiness Level scale (Mankins, 1995b) and has been adapted for general use by the European Commission (Commission, 2014). These levels are presented in Figure 2.

Figure 2: Technology Readiness Levels

TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 9	Actual system "flight proven" through successful mission operations

Source: (Mankins, 1995c)

3   Criteria to evaluate assistance systems in production

The purpose of this chapter is to study whether user acceptance is a feasible approach as far as the evaluation of production assistance systems is concerned. Therefore, a study among experts is presented, by means of a pairwise comparison and interview. Furthermore, an approach to assess assistance systems' user acceptance is indicated.

3.1 Structure of the methodology

In order to conduct the investigation in a structured way, a methodology should be established, which explain how the research has been conducted.

To begin with, the scope of the project has been delimited. In it, the technologies covered in the investigation are presented. In addition, the area of study is concreted, and the aim of this study is introduced in detail. The scope represents the basis of the study, as the

research is built around the statements presented in this section. Consequently, the conclusions of the investigation apply to the context specified in the scope.

Then, once the scope of the project has been defined, the methods for the evaluation and comparison of the established criteria in chapter 2.4 have been developed. For this purpose, comparison method, which is called pairwise comparison, has been used and it is clarified in the following chapters. In addition, questionnaires for the conduction of the interviews have been prepared. These questions had served, firstly, to complement the answers given by participants in the pairwise, and secondly, to allow participants further develop their own ideas about this topic. With this strategy, a great amount of data has been obtained that resulted in consistent conclusions.

Finally, the results have been analyzed and had helped to respond to the first research question. In addition, an approach to evaluate assistance systems had been developed. This approach intended to answer the second research question. As a tool to clarify better the methodology explained before, the Figure 3 is presented:

Figure 3: Structure of the research methodology
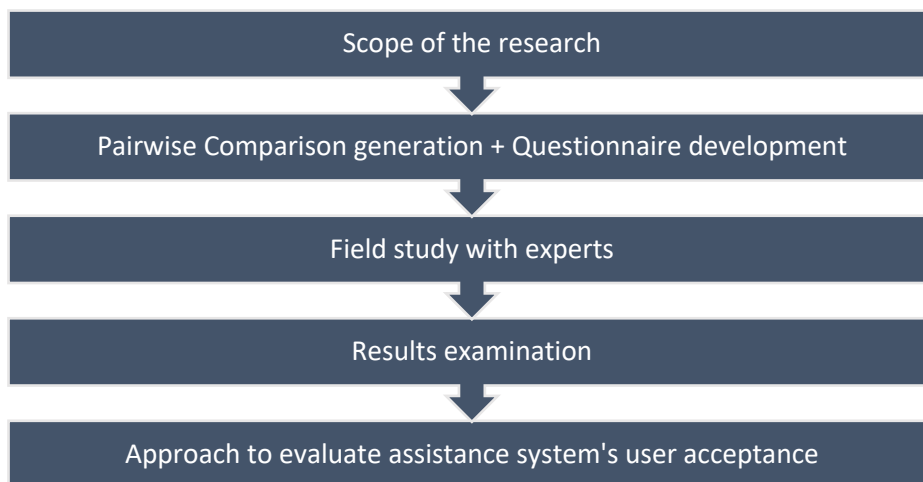
Source: Own representation

3.2 Scope of the research

From all the assistance systems presented in chapter 2.3 this research will focus only on those whose function is to support workers in production within the automotive industry. The majority of assistance systems present in an industrial environment have already been

tested an implemented in production lines. Therefore, these systems provide more contrasted information, which lead to better conclusions and a better understanding of the interaction of assistance systems with users in practical contexts. Hence, the criteria studied in this chapter is related to these specifications.

This research covers as well early stages of technology recognition. Accordingly, not only systems that have already been implemented are to be expected, but rather assistance system in the early phases of development. These undeveloped systems must be aimed to support production tasks in the automotive industry. Hence, this research includes assistance systems in early stages of development, such as prototypes or ideas.

Purpose of the investigation is to assess whether or not user acceptance should be included in the evaluation of assistance system in production. Consequently, to include user acceptance as a novel criterion in traditional methods. The other criteria, which relates to costs, quality, flexibility, and maturity of a technology, have already been tested and have a solid basis for arguing their use in assistance systems evaluation (see chapter 2.3). Hence, they will not be further developed in this study. Main focus relays on user acceptance as a possible evaluating factor.

3.3 Definition of the research method and questionnaire development

To assess the importance of user acceptance to evaluate assistance systems, and additionally to describe a method to assess this acceptance, two approaches are used. Firstly, the Analytic Hierarchy Process, known as well as pairwise comparison method and afterwards, interviews with experts asking an already prepared questionnaire. Both methods are described in this section.

3.3.1 Pairwise Comparison

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach (Saaty, 1980). It is useful to decompose a problem, in this case the evaluation of assistance systems, into smaller objectives or criteria. This approach is structured in two phases: modeling a ranking and the evaluation of those elements in the ranking. The first phase is presented in this chapter, whereas the second one, the assessment of the factors, is described in the next chapter, which belongs to the field study.

AHP is especially helpful when trying to compare criteria difficult to quantify. That is an advantage for the assessment of indicators that evaluate assistance systems, because criteria such as the user acceptance, flexibility or even maturity are complex to quantify. This approach consists on developing a hierarchy of indicators and then compare each indicator with each other. After this comparison, one could obtain the weighting for each decision element, which translate into the relevance of each criteria compared to the others.

The objective of the AHP is the determination of weights to classify the different compared indicators. This consist in the conformation of a pairwise matrix of $a \, x \, a$, where a stands for the criteria that is used in the study. This matrix is constructed in order that criteria in row i ($i = 1,2,3,\dots,n$) is compared with criteria in columns j ($j = 1,2,3,\dots,n$). Consequently, the comparisons between the indicators are reflected in a_{ij} which define the element (i,j) of the matrix (Kabir & Hasin, 2011). Participants fulfilling the matrix could give to the comparison between the criteria i and j either 0, 0.5 or 1. Where $a_{ij} = 0$ indicates that j is more important than i; $a_{ij} = 0{,}5$ means that i and j are equally important, and $a_{ij} = 1$ implies that i is more important than j. To ensure that this matrix is consistent, if an element is given a certain value, such as $a_{ij} = 1$ then the opposite element (a_{ji}) must have a value of 0. In addition, the diagonal element would be set to 0,5, as it illustrates the comparison between the same criteria.

The score of each element in the matrix, b_k is calculated as the sum of all the elements of a line. Hence, $b_k = \sum_{j=0}^{n} a_{ij}$, for $i = (1,2,3,\dots,n)$; $k = (1,2,3,\dots,n)$

The weight is calculated as $W_k = \frac{b_k}{\sum_{k=1}^{n} b_k}$; for $k = (1,2,3,\dots,n)$

To conduct a study using a pairwise model, the selected criteria must fulfil four requirements: completeness, evaluability, relevance, and reproducibility. (Kühnapfel, 2014) *Completeness* expresses that all the selected criteria must identify the problem being considered; *evaluability* indicates that the criteria of the conducted research should be able to be assessed by an evaluator. That implies that all the indicators can be distinguished from each other, and that the evaluators are aware of the technical background of the criteria being evaluated; *relevance* illustrates that the selected criteria must be relevant for the problem to be answered by the pairwise approach; *reproducibility*

means that each criterion must not be influenced by short-term events during the conduction of this research. Otherwise, results may vary if the pairwise comparison is repeated. The criteria exposed in chapter 2.4 fulfill these four different aspects. Therefore, to illustrates the pairwise comparison matrix offered to the experts Figure 4 was created.

Figure 4: Pairwise comparison to assess the criteria for assistance systems in production

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduce Ramp-up Costs	Increase of Flexibility	Reduce Investment Costs	Reduction of Required Space	Reduce Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	Perceived User Acceptance	Score	Weight
Reduction of Rework Cost	0,5											0,5	0,09
Reduction of Running Costs		0,5										0,5	0,09
Increase the Overall Equipment Effectiveness			0,5									0,5	0,09
Reduce Ramp-up Costs				0,5								0,5	0,09
Increase of Flexibility					0,5							0,5	0,09
Reduce Investment Costs						0,5						0,5	0,09
Reduction of Required Space							0,5					0,5	0,09
Reduce Planning Costs								0,5				0,5	0,09
Reduction of Energy and Resource Costs									0,5			0,5	0,09
Maturity of a technology										0,5		0,5	0,09
Perceived User Acceptance											0,5	0,5	0,09
												5,5	1,00

Source: Own representation

3.3.2 Questionnaire development

With the method to compare the criteria already established, next step is to make a questionnaire in keeping with the objectives of this research.

The format of the questionnaire proposed in this section follows a semi-structured interview type (Doody & Noonan, 2013). In it, the interviewer uses predefined questions but has the possibility to ask for some clarifications, making the interview more flexible. This type of interview allows the interviwer to adapt the questions to each participant and to each situation. Moreover, this strategy favor to ask additional questions to explore or clarify new topics.

For the selection of participants for this field study, a purposive sample has been chosen (Fylan, 2005). Accordingly, people from different areas, and with different points of views had been selected, in an effort to maximize the variation of the obtained answers. Optimal strategy would have been to make a large survey with a big population. However, this decision, of selecting a purposive sample, responds to the short time frame of this thesis. Accordingly, participants of this study were selected based on this strategy, which attempt to maximize the variability of the answers given by them.

Once the strategy to be followed has been discussed, with regard to the interviews, questions will be generated in line with the research objectives. The questionnaire will be presented along with arguments that support the election of the question.

Question 1:

Do you have the impression that the presented criteria are sufficient for the assessment of assistance systems in production? If not, could you suggest alternative criteria to be considered?

The first question intends to investigate whether or not the presented criteria are coherent with the characteristics of assistance systems. The selected assessment factors are examined to inspect if they are up to date. That must be done before focusing on user acceptance's relevance, major objective of this thesis, to prove the validity of these criteria with experts for the evaluation of assistance systems. This question lead to answers that offers a practical examination of these indicators.

All research, previous to this field study, have been realized on a theoretical basis. It might be possible that not enough research to fully describe the characteristics of these systems exist, since assistance systems are a relatively new concept. Therefore, aim of the first question is to provide a more practical insight for the evaluation of assistance systems in production. Consequently, to investigate with experts if other factors should be considered in the evaluation of these systems, not already covered by previous literature research.

Question 2:

From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?

The purpose of the second question is to find answers to the research question of this thesis: *Should user acceptance be considered as a criterion to evaluate assistance systems in production?* (see chapter 1.3).

Purpose of this question is that participants offer their perspective as far as the importance of user acceptance is concerned, given their experience in production areas. This insight could lead to a better understanding of the relevance of this user-assistance system interaction. The answers given by experts to this question complement the results obtained from the pairwise comparison.

Question 3:

Why do you think most of the evaluating methods, regarding production technologies, don´t consider the societal factor?

Aim of the third question is, as well as the second question, to respond to the research question of this thesis: *Should user acceptance be considered as a criterion to evaluate assistance systems in production?* (see chapter 1.3).

The redirection of the question's focus allows to investigate the reasons for which this criterion has not been included in previous approaches. The answers could help to understand the existing gap between the traditional and the proposed criteria to evaluate assistance systems in production.

Question 4:

Following the topic of social perception of a system, could you think of factors or measures that could increase the acceptance of an assistance systems among workers in production?

This last question seeks to answer the second research objective: *How can the user acceptance of an assistance system be assessed?* (See chapter 1.3)

After demonstrating the importance of user acceptance, the second research objective must be addressed, by offering an approach to evaluate this acceptance. With the experience of participants working with assistance systems, it has been possible to develop a list of factors that potentially affect the perception of the user towards these systems. Influencing elements are further developed in section 3.5 based on literature and the opinion of the experts, which they had expressed in this last question. Therefore, the answers of the experts to this particular question have been a useful contribution to the development of the approach to evaluate assistance systems' user acceptance.

3.4 Field study to assess the importance of the criteria to evaluate assistance systems in production

Before present and evaluate the results of the field study, some clarifications about the structure of this study are noted.

Firstly, all the interaction with participants had followed the same order. First, the pairwise comparison had been fulfilled by the expert and then the interview has been conducted. Reason of this decision was to minimize the influence on the opinion of participants. The interview is structured to ascertain the importance of the user acceptance. Therefore, it focusses only on this criterion. Consequently, if the interview had been conducted before the realization of the pairwise comparison, the results of this comparison might have been misguided.

Secondly, all the interviews are made on a voluntary basis. All the participants have been asked whether they want to respond to some questions or not. If they agreed on doing the interview, they were informed that this could be recorded, in order to transmit the information in the most detailed way possible. However, if they refused to be recorded, notes were made.

Finally, the purpose of the interview has been informed to the participants in advance (how this information is used and to which purpose). Therefore, participants were

informed about the objective of the interview, reserving them the right to decline their participation on it.

Once these clarifications are made, the field study is presented.

3.4.1 Pairwise comparison results

A total of 18 experts have fulfilled the pairwise comparison matrix, comparing the proposed criteria for the evaluation of assistance systems in production. All of them were working in the automobile industry and were located in different factories around the world. The locations are presented in Figure 5.

Figure 5: Locations of the experts which have participated in the pairwise comparison
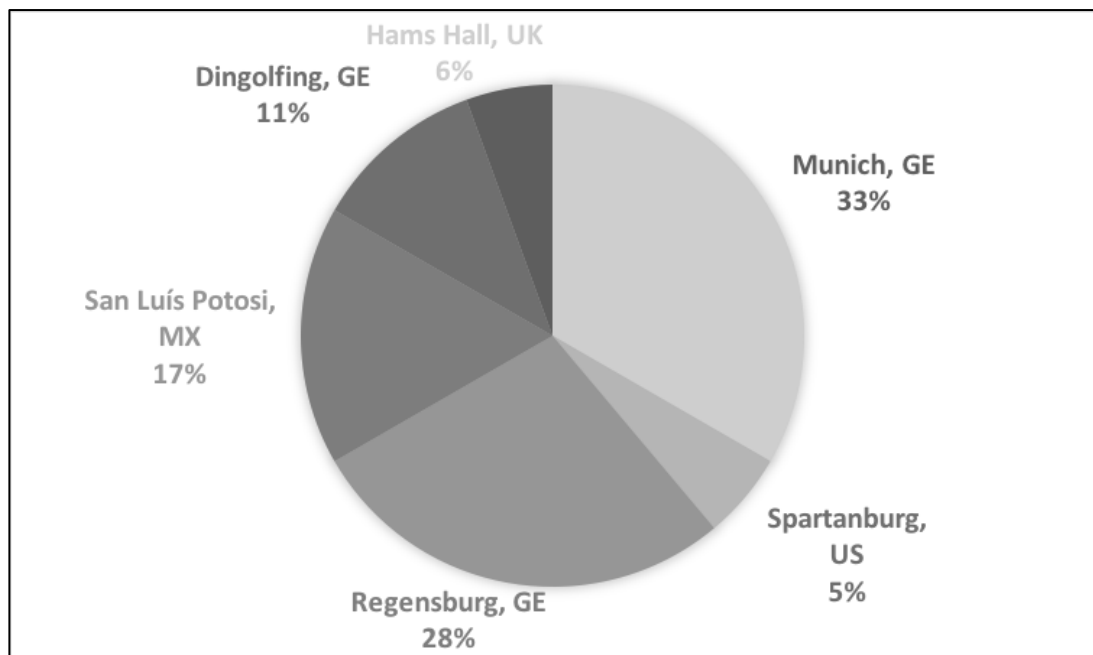
Source: Own representation

The areas to which each expert was responsible for present a great variation as well. It has been tried, as described in the last section, to maximize the variability of the sample as much as possible. The field of each participant is illustrated in Table 9.

Table 9: Area of responsibility of the experts

Area of responsibility	Number of Experts
Project leader Smart Glasses	1
Project leader Exoskeleton	1
Project leader Smart Watch	1
Consultant of Innovation	1
Productions planner	2
Project leader Intelligent Clothes	1
Project leader Smart Gloves	1
Product owner Smart Gloves	3
Smart logistics	1
Production supervisor	2
Innovation management	3
Innovative automation	1

Source: Own representation

In the previous table can be appreciated that most of experts are working directly with assistance systems. Four main technologies can be outlined: smart clothes, smart glasses, exoskeleton and smart gloves. In addition, the opinion of an expert working with innovative automation has been obtained, who was involved in a human-robot collaboration project. This technology could be beneficial for the study of assistance systems, since it has a strong human component. Moreover, the sample of population contains participants working in production areas, such as production planners or production supervisors. Accordingly, a better understanding of the production challenges has been achieved, gathering the opinion of these production experts. Finally, participants that work as an innovation consultant have participated. Consequently, they have offered a better insight about the evaluation of innovative technologies, such as assistance systems.

The values presented in Table 10 were obtained after the fulfillment of the pairwise comparison by the participants of the study. In this table the average score, the average weight, and the standard deviation for each criterion are shown. Both calculations of score and weight are described in chapter 3.3.1. All the pairwise comparison that have served to generate these calculations could be find in the Appendix A. In this section the fulfilled matrix and the responsibility within the company that the participant has are shown.

Table 10: Average values of the pairwise comparison fulfilled by 18 experts

	Average Score	Average Weight	Standard deviation
Reduction of Rework Cost	8,19	0,135	0,0272
Reduction of Running Costs	7,50	0,124	0,0212
Increase the Overall Equipment Effectiveness	6,53	0,108	0,0345
Reduction of Ramp-up Costs	4,69	0,078	0,0320
Increase of Flexibility	6,08	0,101	0,0410
Reduction of Investment Costs	4,39	0,073	0,0337
Reduction of Required Space	3,36	0,056	0,0394
Reduction of Planning Costs	4,64	0,077	0,0334
Reduction of Energy and Resource Costs	3,08	0,051	0,0325
Maturity of a technology	4,47	0,074	0,0456
Perceived User Acceptance	7,56	0,125	0,0490

Source: Own representation

Values in Table 10 can be illustrated by means of a box plot, supporting the analysis of the obtained data. This graphical representation is a resource which facilitate the comparison between groups of data. It uses the median, the minimum and maximum value of the sample to be studied, and the quartiles (Williamson et al., 1989). That helps to generate and impression about of the variability of the participants' answers in this study. Moreover, this plot offers a visual support which is ease further analysis of the obtained data.

The box plot is represented in Figure 6. In it is shown the weight of each criteria. It can be appreciated how the acceptance of the user is valued as important by the research participants. Noteworthy is the importance given to the parameters reduction of rework costs and reduction of running costs. In contrast, the reduction of required space, as well as the reduction of energy and resource costs, are of a few relevance in the evaluation of assistance systems in production, according to the answers of the experts.

Figure 6: Box plot with the weight of each criteria

C1 - Reduction of Rework Costs

C2 – Reduction of Running Costs

C3 – Increase the Overall Equipment Effectiveness

C4 - Reduction of Ramp-up Costs

C5 – Increase of Flexibility

C6 – Reduction of Investment Costs

C7 – Reduction of Required Space

C8 – Reduction of Planning Costs

C9 – Reduction of Energy and Resource Costs

C10 – Maturity of a Technology

C11 – Perceived User Acceptance
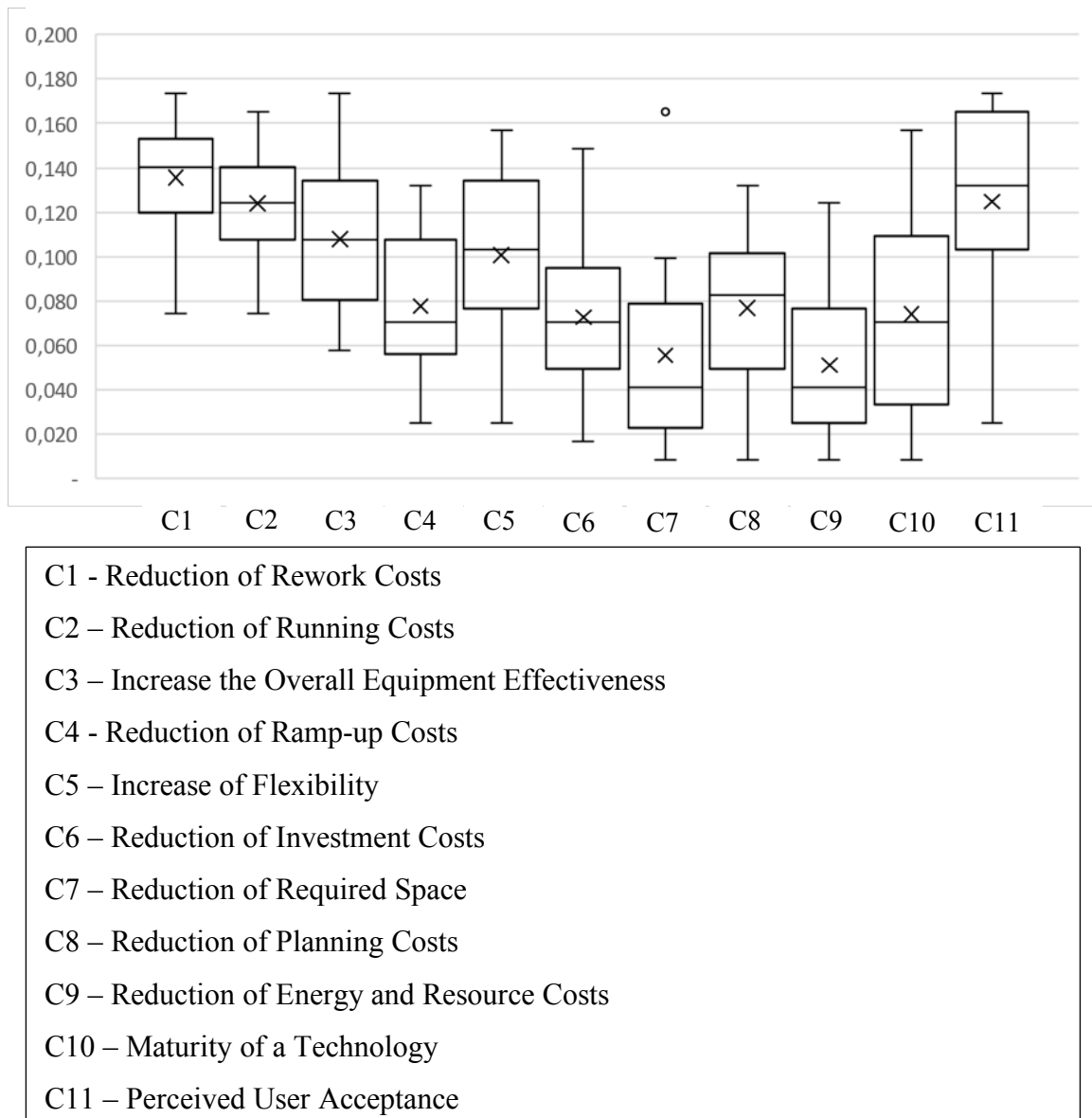
Source: Own representation

This research attempts to assess the relevance of user acceptance as an evaluation criterion for assistance systems. Accordingly, further analysis of the data has focused on the gathered data related to this factor.

For a more detailed analysis, the different weights given to user acceptance by each expert are represented in figure 7. Therefore, each data point corresponds to one expert's input. This representation helps to have a more detail understanding of the opinion of each individual, complementing the box plot.

Figure 7: User acceptance weight of each expert in the pairwise comparison
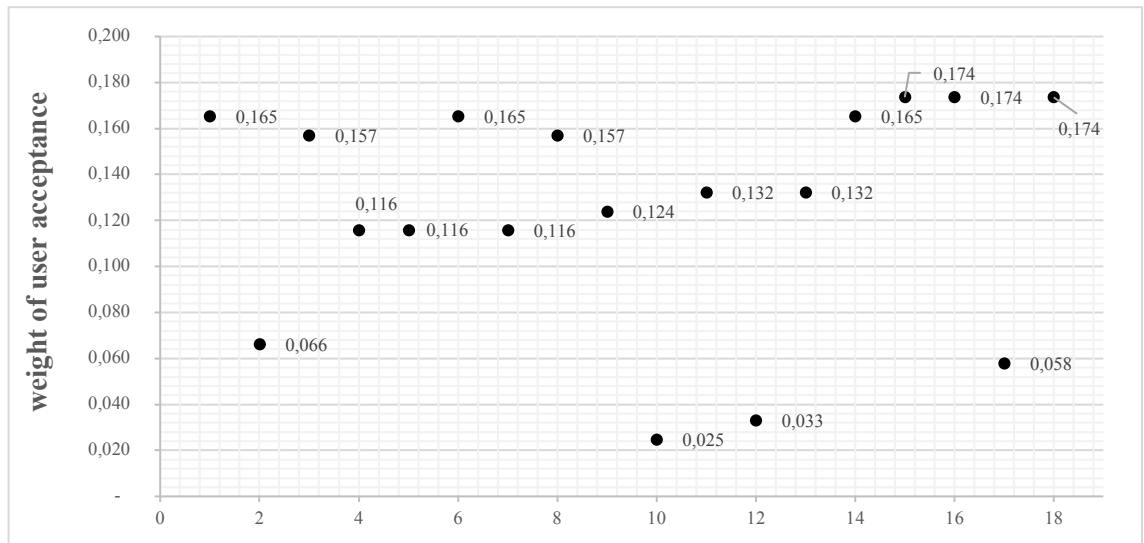
Source: Own representation

In the chart represented in Figure 7 could be appreciated the detailed composition of the sample, in relation with the user acceptance criterion. It could be outlined that the majority of the experts have rated this criterion as important for the evaluation of assistance systems. This trend can also be observed in Figure 6. Despite this pattern, it is worth to emphasize that there are some opinions in disagreement with this idea. Only by looking at the chart is difficult to understand the reasons behind this decision. Therefore, these experts were worth being interviewed. In addition, experts that have rated high the user acceptance were asked for their opinion. These interviews respond to an attempt to comprehend better the collected data and are analyzed in the following section

3.4.2 Interviews analysis

In contrast with the pairwise comparison, the interviews were conducted with 9 experts. Form all the interviews, 3 of them were conducted with experts that have rated the user acceptance rather low in the pairwise comparison.

All the interviewers agreed on the recording of the interview. All the transcriptions, and information regarding to the interviews can be found at the Appendix B. In this section the opinion of the experts is transmitted, extracted from the experts' interviews. In addition, the answer to the asked questions has been analyzed in concordance with the order proposed in chapter 3.3.

The first question was: *Do you have the impression that the presented criteria are sufficient for the assessment of assistance systems in production? If not, could you suggest alternative criteria to be considered?*

The majority of the persons conducting the interview answered that the criteria presented in the pairwise comparison were good enough to evaluate the assistance systems. One of the participants (Lorisch, personal interview, June 2018) stated that the criteria were good balance and allowed to cover all possible situations in the evaluation of assistance systems. In spite of the agreement in the answers, there are few voices that added a point of view worth to consider.

Wolf (personal interview, July 2018) has declared, that she was rather focus on improving the ergonomics of the work places, when developing smart clothes. That means, using her own words: "I should be a bit selfish and think about what the priority for my systems is.". In fact, if one think about smart clothes, due to their specifications, they are mainly focus on improving the working experience of a user. However, this specific objective does not necessarily imply that the other factors are not affected. Several studies (Kosonen & Tan, 2004; Taiwo, 2010) indicate that an improvement in the working conditions lead to a higher productivity by workers. Nonetheless, the impact of this health measures is rather indirect and difficult to assess. Perhaps, and considering Wolf approach, each assistance system should be evaluated differently, according to their priorities.

Wagner (personal interview, June 2018) indicated that the presented criteria in the pairwise comparison were sufficient to encompass the characteristics of assistance systems. In contrast, she thought that the major challenges lied not in the criteria selection, but in deciding which people should assess the importance of these factors. For the systems that she was supervising, the most important criterion was the overall equipment efficiency. However, she remarked that if someone were to speak with other experts, they would realize that the evaluation of assistance systems' criteria is based on the priorities of each expert. In the same way as Wolf, this idea suggest that each individual will fulfill the pairwise comparison based on their priorities. While this is the case, a purposive sample strategy has been chosen precisely to cover as many cases as possible.

That aside, another participant (Pochiro, skype interview, June 2018) declared that the geographic location of the factory might be as well a factor to be considered. He exemplified this idea by outlining the differences in the personal insurance in case of injuries, resulting from the tasks that the employee must perform every day. In American factories, injuries must be paid out of the production budget, whereas in Germany is covered by the contracted insurance. Therefore, these differences may add considerable additional production costs depending on the regulations of the country in which the factory is located.

The second question to be analyzed is the following: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

For this section it will be first evaluated the answers of those experts who rated the user acceptance rather low in the pairwise comparison. Piller (skype interview, July 2018), who rated this criterion with a score of 0,033 - maximum score 0,176 – gave the following reasons. He thought that user acceptance is, in fact, an important factor when evaluating new technologies, such as the assistance systems. However, in the comparison of this criterion with other criteria, such as reduction of rework, user acceptance is a secondary objective. He remarked the fact, that this evaluation is high dependent on the system that one is assessing. Exoskeleton for example, he said, would never be implemented without the acceptance of the user, outlining the importance of this factor. Nonetheless, he expressed that in the development of any production systems other criteria must be prioritize, leaving the user acceptance in a "secondary role", citing Piller words.

Another expert who has rated the user acceptance rather low, with a score of 0,058, was Schalau (skype interview, July 2018). The reasons she gave were similar to the ones from Piller. She stated, that user acceptance is an important factor, nevertheless, less relevant in comparison with the main production objectives. The production systems, in her opinion, should be developed focusing on reducing costs and improving the quality of the product. If at the same time, these systems could have a good impact among users, that would be even better. But, she clearly stated, that this should not be a priority.

Pochiro (skype interview, June 2018) rated the user acceptance with a score of 0,066. He recognized, however, that when he must implement a new exoskeleton in production, user

acceptance is one of the number one goals that he has. Without this acceptance, he stated, the workers will never use the system, finding many reasons to reject it. In order to increase this acceptance, measures must be implemented, which contribute to a better perception of a system. Although he indicated that in the particular case of exoskeleton, user acceptance is a high relevant criterion, he has not given further details that argument the low assessment of this criterion in the pairwise.

As far as the other experts is concerned, they all agreed that the user acceptance is of a great importance when implementing an assistance system in production. Grad (personal interview, June 2018), stated that the user must be convinced that the technology that is offered adds something beneficial for them, appealing to this acceptance of the user. Wagner (personal interview, June 2018) supported the ideas of Pochiro, by indicating that without the acceptance of the user, they would never use assistance systems. Grad (personal interview, June 2018) indicated, that in order to decide whether a system can perform good or not, one must put the focus on performance indicators, such as the overall equipment efficiency. However, for a successful implementation of an assistance system, user acceptance is the most important factor.

Following this topic, Lorisch (personal interview, June 2018) communicated that user acceptance has a huge impact in the development of an assistance system. This criterion is considered through all the innovation process, in order to ensure a high adoption rate of this technology.

The third question to be analyzed is the following: *Why do you think most of the evaluating methods, regarding production technologies, don't consider the societal factor?*

The majority of the interviewed experts agreed on the fact that user acceptance must be a factor to be considered in an evaluation method. They suggested, that reasons of this not consideration of the societal factor were due to the changes that production has experience over the last few years. Assistance systems pose new challenges on their evaluation, due to its differences with traditional manufacturing systems. Wagner (personal interview, June 2018) supported this argument, saying that humans are now more important than ever in production. And she added, that there is a trend toward better conditions for the workers.

Pochiro (skype interview, June 2018) said that user acceptance is not something that you could easily realize on a superficial research. However, this criterion is the core factor to ensure that an assistance system is adopted by workers in production. Moreover, he insisted that companies were working on this topic for many years, gathering data and performing surveys with users, to improve the working experience with assistance systems. That suggest, that user acceptance is already an important factor in the praxis.

Additionally, Grad (personal interview, June 2018), remarked the importance of assistance systems in today's production, due to the increase of complex tasks that the workers must daily face. In addition, he added that with every new product introduced in production, the number of complex tasks that a worker must deal with is even higher. Thus, assistance systems, and consequently the acceptance of those systems by users, will be crucial for the future of production.

Another expert (Lorisch, personal interview, 2018), suggested that the assessment of the user acceptance is not an easy task. It is difficult to develop a method which can conclude whether a system will have a great acceptance or not. He added that even if a method was developed, another challenge would be how to select representative users, who are in charge of assessing user acceptance. Hence, outlining the difficulties of shaping this societal factor in a theoretical method.

The final question to be discussed is: *Following the topic of social perception of a system, could you think of factors or measures that could increase the acceptance of an assistance systems among workers in production?*

The answers given by the participants, were of a great variety. According to Schutz (skype interview, July 2018) and Schalau (skype interview, July 2018), user acceptance depends on the assistance system. For example, if societal perception is desired to be increased in a smart glove, one should increase the ergonomics and safety. Additionally, according to them, one should convince the user that the technology that they are adopting is better than the previous one. In order that they perceived an improvement. The ease of use, as well, might be another factor affecting the acceptance. Finally, they said, that if a worker in production has already tried the assistance system, and had a good experience with it, that might positively affect the perception toward this system of other workers.

Wolf (personal interview, June 2018) supported these previous ideas, remarking that if someone wants to increase the acceptance of smart clothes, they must improve the ergonomics and the ease of use. This is, according to her, connected with the necessities that the user has in production. Be able to recognize them, and satisfy them, should increase user acceptance.

Lorisch (personal interview, June 2018) and Wagner (personal interview, June 2018) agreed, that if someone wants to improve the acceptance, they must involve the user in all developing processes. They suggested measures, such as gather feedback with the operators from the very beginning, or to let the user try the assistance system before implementing it. With a prototype, Lorisch said, is easier for workers to communicate what they feel towards this new technology. In addition, Wagner stated, that if the assistance system is developed without considering the opinion of the final user, then it will have a lower acceptance.

Finally, information and education could be an effective measure to increase the acceptance of the user. This idea was introduced by Pochiro (skype interview, June 2018), and he stated that the associates must understand the long-term benefits of using assistance systems in their daily tasks. Therefore, it could be created an area to let the workers try the systems. There, they could experiment with these new technologies, and comprehend better the advantages of using them. For Pochiro, the workers first realize how helpful an assistance system is, when they have felt the difference from using it and not using it at all. At that point, the majority of the associates recognized the benefits of using assistance systems in a daily basis.

From all the interviews it could be subtracted the following statements:

First, the indicators chosen to evaluate assistance systems in production are sufficient to evaluate these systems. However, experts have suggested that a further classification must be made depending on the country and the assistance system.

Secondly, user acceptance is an important factor when evaluating assistance systems in production. This idea is supported by the pairwise comparison results, in which the participants have rated the user acceptance as the third most important factor. Moreover, the experts, who had rated rather low the acceptance in the pairwise, expressed that this

criterion is in fact important for assistance systems. Nonetheless, if this factor is compared with other indicators, it must not be prioritized. Despite of the contrary opinions, experts agreed that without an acceptance from the user, assistance systems would never be implemented.

Thirdly, in connection with the shortcomings of the traditional methods, which does not consider the acceptance as an indicator, the experts attributed that fact to several factors. One of the reasons, according to the participants, might be the difficulty of assessment of user acceptance. Another reason could be the newness of these systems in production, which have left the traditional methods unable to respond to the new characteristics of assistance systems. Lastly, they suggested that this might not be an indicator easy to find on a preliminary research, although companies consider this criterion as an essential factor for the implementation of assistance systems.

Finally, the participants have indicated numerous measures to increase user acceptance. They stated that an improvement in parameters such as ergonomics, safety, ease of use, robustness or relative advantage, could lead to a higher acceptance when adopting assistance systems. In addition, they indicated that the user must be involved in all the development phases. Therefore, this involvement facilitates the adaptation of the assistance systems to the necessities of operators in production. Finally, a better education and more information results in a better comprehension of the benefits that these systems have. Hence, these measures might improve the perception of users toward assistance systems.

3.5 Approach to evaluate assistance systems' user acceptance

As seen in the last chapter, user acceptance has been described as an important factor when determining the potential of an assistance system. Despite the fact that this acceptance might be difficult to assess, objective is to determine a method to evaluate this criterion, reducing as much as possible the subjectivity involving this parameter. So far, there are several studies that presented an approach to measure user acceptance. This research combined with the opinions of the experts has been the basis to construct this method.

In the research performed by Wiedmann et al. (2018b), the perceived acceptance of a user is divided in 5 different factors: ease of use, usefulness, society, safety and performance. This study was conducted in the automotive industry with relevant information systems. Consequently, it will be taken as a reference for the further development of the approach for assistance systems' user acceptance. The indicators used to encompass the acceptance is explained in more detailed in this section.

To support the factors indicated in the research by Wiedmann et al., other studies (Bachfischer et al., 2004a ; Zahng et al., 2010b) proposed the following factors, which affect user acceptance: ease of use, usefulness, trust, expressiveness, risk, mobility, costs, observability. Both studies indented to study the factors influencing the acceptance of mobile payment systems. Therefore, these researches have been used as a support, but their context differs a bit from the automotive industry, which is the focus of this thesis.

In addition to these studies, experts in the interviews had indicated that parameters such as ergonomics, safety, ease of use, robustness or relative advantage, could result into a better assistance system's acceptance.

In this sense, combining both the opinions of the experts with the literature, there are five dimensions that might potentially affect the acceptancy of the user. Those are: usefulness, ease of use, performance, society, safety and ergonomics. A better definition of this factors is presented in the Table 11. Furthermore, elements influencing each factor are indicated.

In order to assess factors affecting user acceptance, a questionnaire was developed. Users are requested to give a grade from -3, which refers to a strong disagreement, to 3, which reflects a strong agreement. Additionally, they have the possibility to evaluate a question with a 0, showing neutrality. Three questions have been developed for each one of the five factors that affect user acceptance. Each question corresponds to each one of the influence factors that affect each element of the user acceptance.

Table 11: Factors affecting assistance systems' user acceptance

User acceptance
I. Usefulness This dimension refers the services and contents that an assistance is able to provide, and how closely they meet the user requirements. *Influence factors: job relevance, reliability, currency* **II. Ease of Use** Commonly known as usability, is the degree to which a person belief that using a particular system would be free of effort. *Influence factors: learnability, aesthetic appearance, terminology* **III. Performance** This element describes the degree to which an assistance system is better than the previous one, and how this system contributes to the improvement of the human capabilities. *Influence factors: relative advantage, human enhancement, efficiency* **IV. Society** This dimension refers to how a system is perceived by the user in terms of image, norms and visibility. *Influence factors: social visibility, social communication, voluntariness* **V. Safety and ergonomics** The extent to which a system is able to prevent injury or avert damage to the user, contributing to health preventive measures. *Influence factors: safety and health guidelines, trust, ergonomic*

Source: Own representation; definitions adapted from (Bachfischer et al., 2004b ; Battini et al., 2011; Buchanan & Salako, 2009) and interviews with experts (Appendix B)

The question, describing the parameters are the following:

I. Usefulness

Question 1 (job relevance)*: The system enables the correct accomplishment of user's tasks.*

Question 2 (reliability): *The information that I, as user, receive is accurate, dependable and consistent and contributes to the user requirements.*

Question 3 (currency): *The information that I receive is sufficiently up-to-date for the task it is used for.*

II. Ease of use

Question 1 (learnability)*: I can productively use the system right away and quickly learn its new functions.*

Question 2 (aesthetic appearance): *The aesthetics and appearance of the system is consistent and appropriate to the task to be performed.*

Question 3 (terminology): *The system provides comprehensive content and information.*

III. Performance

Question 1 (relative advantage)*: The assistance system that I am using is better in terms of performance (speed, quality, etc.) than the previous system.*

Question 2 (human enhancement): *The system positively alters the human characteristics or capabilities for the task to be performed.*

Question 3 (efficiency): *Using the assistance system, I completed the task within a shorter amount of time.*

IV. Society

Question 1 (social visibility)*: When I am using the assistance system my social image among coworkers is positively affected.*

Question 2 (social communication): *Using this system improves my communication and social interaction.*

Question 3 (voluntariness): *The decision of using the system is based on an individual and voluntary basis.*

IV. Safety and ergonomics

Question 1 (safety and health guidelines)*: The system complies to all company safety-related and health-related guidelines.*

Question 2 (trust): *I have no trust issues when using this system, the data I send are secure, and the provider trustworthy.*

Question 3 (ergonomics): *The ergonomics of my workplace are improved when using the assistance system. In terms of stress reduction, or a better comfort.*

Based on the answers to these questions, each parameter of assistance system's user acceptance could obtain a score range between [-9 to 9]. If the sum of a category is positive [1,9], then the user acceptance of that parameter is rated as *good*. If the sum of the indicator is 0, then the user acceptance of that parameter is assessed as *neutral*. In the case of a category score of [-1, -3] then this parameter is evaluated as *bad*. Finally, in the case of a group with a score of [-4, -9] then this group is rated as *very bad*. These evaluations are clarified in Table 12.

This approach eases the analysis of an assistance system's user acceptance, allowing to a person evaluating this system to identify the different perceptions that the user have toward these systems. Consequently, if an indicator or a group is rated low, further improvements on the actual system could be made focusing on that specific aspect of user acceptance. This could be of a great value, because could resolve the acceptance

problematics in a more efficient manner. Hence, increasing the successful adoption ratio of assistance systems in production.

Table 12: User acceptance indicator's group score and its evaluation

User acceptance indicator's group score	Evaluation
[1, 9]	*good*
0	*neutral*
[-3, -1]	*bad*
[-9, -4]	*very bad*

Source: Own representation

4 Validation of the approach to evaluate user acceptance

The purpose of this chapter is to validate the method presented in chapter 3.5. This validation is going to be performed with an assistance system with a specific application in the automotive industry.

4.1 Description of the validation environment

The assistance system, which is going to be used for the validation of the method, is a smart watch used in production lines of an automotive manufacturing company.

In production lines, workers must assemble up to 10 different parts per car. In a day, a production line is able to produce up to 1000 cars per day, 330 car pro production shift. That implies a total of 3300 parts that a worker must assemble per day. Accordingly, the employees must repeat the same task all over the day, making their tasks monotone.

Moreover, there are occasions, within the production shift, that a worker must assemble the parts in a special manner, due to the customization of each product. For example, the Japanese cars have the steering wheel on the right, differing form the European cars, that have it on the left. That could seem really obvious, but when a worker is dealing with a high volume of cars, the risks of committing a mistake substantially increase.

In the current situation, the worker is not actively advised of rarely occurring variants. The worker must proactively gather the information from a monitor, in which the tasks to be performed are listed. Therefore, they need to spend an extra amount of time reviewing the tasks, paying a special attention to the exotic cars - cars with a concrete configuration in comparison with the cars produced in production lines-.

A solution to face those challenges is the implementation of a smart watch. This assistance system could potentially reduce the mistakes made by workers, when assembling exotic cars. Its functionality is based on generating an alert, by means of a vibration, which alert the user that the next car in the production line is exotic. This vibration alarm reminds the worker that a different number of parts will have to be installed during the next work step.

With this smart watch in production, it could be achieved the following objectives:
− process optimization, by means of offering smart solutions to the operators trying to avoid risk that derivate from monotonous tasks.
− cost reduction, by terms of reducing extra reworking tasks, improving the quality of the final car.
− offer a non-invasive solution to the actual problems in production because of the characteristics of the assistance system, which have the shape of a watch.

In this context, this solution is a simple and nice manner to deal with the problematics that the automotive production has. The smart watch with this specific industrial application is used to validate the method that assess the acceptance of assistance systems.

4.2 Presentation and interpretation of the results

The results that are shown in this section, express the opinion of a project leader of smart watch in production of an automotive industry, after gathering feedback from associates that have already tried the smart watch. Therefore, this person is chosen as a representative user for the assessment of user acceptance among workers.

The results of the evaluation of the smart watch are presented in Table 13.

Table 13: Assessment of the smart watch's user acceptance

	Question 1		Question 2		Question 3	
Usefulness	The system enables the correct accomplishment of user's tasks	+3	The information that I as user receive is accurate, dependable and consistent and contributes to the user requirements	+3	The information that I receive is sufficiently up-to-date for the task it is used for	+3
Ease of Use	I can productively use the system right away and quickly learn its new functions	+3	The aesthetics and appearance of the system is consistent and appropriate to the task to be performed	+2	The system provides comprehensive content and information	+2
Performance	The assistance system that I am using is better in terms of performance (speed, quality, etc.) than the previous system	+3	The system positively alters the human characteristics or capabilities for the task to be performed	0	Using the assistance system, I completed the task within a shorter amount of time	+3
Society	When I am using the assistance system my social image among coworkers is positively affected	+3	Using this system improves my communication and social interaction	0	The decision of using the system is based on an individual and voluntary basis	+3
Safety and ergonomics	The system complies to all company safety-related and health-related guidelines	+3	I have no trust issues when using this system, the data I send are secure, and the provider trustworthy	+3	The ergonomics of my workplace are improved when using the assistance system. In terms of stress reduction, or a better comfort.	-1

Source: Own representation

As it is shown in Table 13, usefulness has been rated with a total score of 9 points. This means that the smart watch has a good perceived usefulness. The operators that use this assistance system encounter any difficulty for the correct accomplishment of their tasks.

Moreover, the information they received is real-time data. Therefore, it is constantly actualized, providing accurate and relevant information for each car.

As far as the ease of use is concerned, it has been assessed with a total score of 7 points. This implies that the smart watch has a good perceived ease of use. One of the reasons for this decision is that the smart watch has functionalities that are easy to learn. With an explanation of ten minutes, according to the project leader, the user is able to understand how to operate the assistance system. Another reason is that the aesthetic appearance of the smart watch is similar to a traditional watch. This allows to the users to feel familiar with the system that they will use. In addition to the traditional functionalities of a watch, this assistance system adds visual content and support to the user, such as a vibration when an exotic car is detected. Accordingly, this technology is appropriate to the tasks that the user must performed in production lines.

The performance of the smart watch was evaluated with a total score of 6 points. The user now is able to perform the same tasks in a more efficient manner. With this solution, they do not have to look for the information in a screen or a piece of paper. All the data is now shown in the smart watch. Therefore, this assistance system possesses a relative advantage in relation to the previous system. Moreover, workers could now complete their tasks more rapidly, since the relevant information is displayed in the smart watch. Consequently, they can react faster to the exotic variants, executing the pertinent subroutines. In contrast, this system does not possess the ability to alter the human capabilities. Therefore, the human enhancement was rated with a score of 0 points.

The society indicator of user acceptance was assessed with a punctuation of 6 points. The project leader has communicated, that if users wear the smart watch, they perceived that their social image among workers will be increased. Moreover, this automotive manufacturing company offers the possibility to use the assistance system in a voluntary basis. That allows the worker to have a free choice to stick with the traditional methods. This measure has a good impact in the acceptance towards a new technology, as users feel is not an imposition. As far as the communication is concerned, this smart watch not offers the possibility of calling or messaging other workers. Hence, the social communication is the same as the previous method, obtaining this indicator a score of 0 points.

Finally, safety and ergonomics was rated with a total score of 5 points. The smart watch fulfills all the company safety-related and health-related guidelines. The project leader identified this factor as the one of the most important. If a system does not comply with those regulations, it will never be implemented, as the security and safety of workers are the first priority. Furthermore, users have no trust issues with the information they received or manipulate, since they know it is a product developed and supervised by the company. Additionally, they do not have to share personal information, which make them feel more comfortable when using this smart watch. Finally, user do not have the perception that the ergonomics are improved but worsen. This is due to the fact, they indicated, that during the hot season they sweat more wearing that watch. Despite the fact that this problematic is not a critical issue, in terms that does not affect the tasks that the workers must performed, that might affect to the adoption rate of this assistance system.

With this overview of the smart watch's user acceptance, corrective measures could be implemented to improve the actual system. In terms of performance, the smart watch technologies of the market do not offer the possibility to improve human capabilities. Hence, this point is difficult to improve.

Social communication could be however improved, if a phone or a message characteristic are included in the current watch. Those abilities are already implemented in smart watches without an industrial application. However, this might lead to distractions for workers. Furthermore, with regard to the smart watch evaluated, it is not clear whether or not the phone could help the workers to perform their tasks better.

Finally, in terms of ergonomics, rated with -1, measures must be implemented if the adoption rate is to be increased. An example to reduce the sweat, that this smart watch generate, is to wear a wrist brace simultaneously with the watch. This is not the most efficient solution, but it could offer alternatives in an intend to increase the acceptance of this assistance system.

The fact that acceptance of a system could be structure in several indicators, ease the analysis of this criterion. This might lead to better understanding of the adoption rates of a technology, and the perception that users have towards an assistance system. With this detailed analysis, future corrections could be made, leading to a new version of the evaluated system, which might potentially have a better acceptance.

5 Discussions

In this thesis has been presented first, a field study with participants from the automotive industry to investigate the importance of user acceptance, and second, a method to evaluate assistance system's user acceptance. This section analyzes the results trying to outline the limitations of the research, adding some contrast to the findings made in this research document. Moreover, future work and corrections are indicated.

To begin with, the pairwise comparison was conducted with a total of 18 participants. Efforts were made to select a purposive sample, trying to cover as many participants from different areas as possible. However, in the study conducted, it has not been possible to encompass all the opinions from assistance system's experts. The ones that are shown in this thesis were from representatives' subjects from the following systems: smart watch, smart gloves, smart clothes and exoskeleton. That illustrate only a small percentage of the totality of the existing assistance systems. Nonetheless, in the automotive industry they are the most common and wide-spread systems. Consequently, that offer a good overview of the assistance system that are implemented in the industry, that prove the validity of the results obtained.

In terms of the variance of assistance systems' user acceptance, it should be indicated that is rather high compared to other studied criteria. In the box plot results, shown in chapter 3.4, it must be observed that the majority of the sample rate the acceptance with a high score. However, there are 4 discrepant opinions that rated the importance of the user acceptance as low. This explain the high variance of the obtained results. Notwithstanding, these same experts, in the conducted interview, had expressed that the user acceptance is of a great importance when evaluating assistance systems in production. In addition, they remarked that these systems would never be implemented without user's approval. However, they have rated this criterion that low, because they believe there are other production objectives more important than this one. Hence, the pairwise comparison results supported by the interviews validate the importance of the user acceptance. In addition, more experts should be asked, in order to have a more representative sample, minimizing the variance of the answers.

The pairwise comparison method and the interviews are good enough approaches to answer the research questions of this thesis. However, it must be indicated that the

participants are limited to express their opinions by means of three different possibilities, in the pairwise analysis. Accordingly, they could only evaluate the comparison of the different criteria in terms of more important than, equal to or less important than. If a more detailed assessment is needed, they should have the opportunity to rate as well how more or less important one criterion is compared to another. For example, criterion A is 3 times more important than criterion B. Nonetheless, the interviews have been conducted to let the experts express their opinions. Therefore, both methods complement each other and are sufficient for the purpose of this study.

As far as the approach to assess user acceptance is concerned, it has been constructed through the interviews with experts and literature research. The participants of the interviews are only 9 subjects, which represented a small sample of the population. That is due to the time limitations of this thesis and the difficulties to make an appointment with participants of the automotive industry. More feedback should be gathered to have a better understanding of the challenges that the user acceptance poses. Consequently, that could lead to more indicators not covered in the initial approach.

Moreover, the approach to evaluate assistance systems' user acceptance showed in chapter 3.5 was further evaluated in chapter 4 with only one assistance system. Purpose of that validation was to demonstrate the benefits that the method has. It has been proven an efficient tool to analyze the acceptance of a system and to indicate in which aspects the system could be improved. This has been only validated with a smart watch with a specific industrial application in the automotive industry. With more validations, it could be outlined the limitations of the actual method to evaluate the acceptance of other assistance systems. Accordingly, this could be solved with the adoption of more indicators, not yet indicated in the tool, to encompass all the characteristics of all these systems.

Another challenge is the selection of the representative candidates to evaluate each assistance system. Ideally, all the opinions of the users must be considered. However, to ensure that every feedback is collected would be a high time-consuming and laborious task. Further studies must be made, to conclude which participants could be considered representative subjects for the fulfillment of the tool.

6 Conclusions

This thesis was conducted to respond to the questions: *Should user acceptance be considered as a criterion to evaluate assistance systems in production*? and *How can the user acceptance of an assistance system be assessed?* The results obtained in this study showed an effective manner to answer those questions, with further possible practical applications.

In conclusion, automotive manufacturing companies should integrate, to the traditional criteria, user acceptance, as a decisive criterion when deciding the potential of an assistance system in production. The findings on the thesis suggest a hitherto unconsidered indicator, which encompass the peculiarities of the human-system interaction. Furthermore, the non-consideration of this factor could result into a low adoption ratio of an assistance system by users. Hence, methods that evaluate assistance system should include user acceptance.

Moreover, the approach developed to estimate user acceptance allows a more detailed analysis of user's perception towards an assistance system. This method could be used by companies to better comprehend the necessities of users, and further develop or improve assistance systems in order to effectively fulfill their requirements. The validation of the method with a smart watch illustrated how to qualitatively measure the perception of the user, which suggest that this approach could be a resourceful tool to better understand the interaction of the assistance systems with humans.

Although user acceptance improves the evaluation of assistance systems, this factor is not exhausted studied in this thesis. It should be investigated the relevance of other factors such as age, and how those factors might affect the perception of the user toward an assistance system. Additionally, more validations off the approach with other assistance systems should be made, which could lead to the adoption of new indicators used for proposed evaluation of assistance systems' user acceptance

To sum up, the findings of this thesis propose a novel approach for the evaluation of assistance systems. Consequently, they provide alternative methods to improve the decision-making process for the automotive manufacturing companies, which can potentially reduce costs and save time, valuable resources for every company.

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Appendix

A Pairwise comparison results

In this section all the results from the pairwise comparison are shown.

Figure 8: Pairwise comparison results form a smart glasses project leader

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	1	1	1	1	1	1	1	1	0,5	10	16,53%
Reduction of Running Costs	0	0,5	1	1	1	1	1	1	1	1	0	8,5	14,05%
Increase the Overall Equipment Effectiveness	0	0	0,5	0	0	0	0	1	1	1	0	3,5	5,79%
Reduction of Ramp-up Costs	0	0	1	0,5	0	0	0	1	0,5	1	0	4	6,61%
Increase of Flexibility	0	0	1	1	0,5	0	1	0	0,5	1	0	5	8,26%
Reduction of Investment Costs	0	0	1	1	1	0,5	0,5	1	0,5	1	0	6,5	10,74%
Reduction of Required Space	0	0	1	1	0	0,5	0,5	1	0,5	1	0	5,5	9,09%
Reduction of Planning Costs	0	0	0	0	1	0	0	0,5	0,5	1	0	3	4,96%
Reduction of Energy and Resource Costs	0	0	0	0,5	0,5	0,5	0,5	0,5	0,5	1	0	4	6,61%
Maturity of a technology	0	0	0	0	0	0	0	0	0	0,5	0	0,5	0,83%
User Acceptance	0,5	1	1	1	1	1	1	1	1	1	0,5	10	16,53%
												60,5	100%

Source: Own representation

Figure 9: Pairwise comparison results form an exoskeleton project leader

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	1	1	1	1	0,5	0,5	1	1	0,5	9	14,88%
Reduction of Running Costs	0	0,5	0,5	0,5	0,5	0,5	1	1	1	1	1	7,5	12,40%
Increase the Overall Equipment Effectiveness	0	0,5	0,5	1	1	1	1	1	1	1	1	9	14,88%
Reduction of Ramp-up Costs	0	0,5	0	0,5	1	1	1	1	1	1	1	8	13,22%
Increase of Flexibility	0	0,5	0	0	0,5	1	1	0	1	1	1	6	9,92%
Reduction of Investment Costs	0	0,5	0	0	0	0,5	1	0,5	1	1	1	5,5	9,09%
Reduction of Required Space	0,5	0	0	0	0	0	0,5	0	0	0	0	1	1,65%
Reduction of Planning Costs	0,5	0	0	0	1	0,5	1	0,5	1	1	1	6,5	10,74%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	1	0	0,5	1	0	2,5	4,13%
Maturity of a technology	0	0	0	0	0	0	1	0	0	0,5	0	1,5	2,48%
User Acceptance	0,5	0	0	0	0	0	1	0	1	1	0,5	4	6,61%
												60,5	100%

Source: Own representation

Figure 10: Pairwise comparison results form a smart watch project leader

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0,5	0	1	1	1	1	1	1	1	0	8	13,22%
Reduction of Running Costs	0,5	0,5	0	1	1	1	1	1	1	1	0	8	13,22%
Increase the Overall Equipment Effectiveness	1	1	0,5	1	1	1	1	1	1	1	1	10,5	17,36%
Reduction of Ramp-up Costs	0	0	0	0,5	0	0,5	1	0	1	1	0	4	6,61%
Increase of Flexibility	0	0	0	1	0,5	1	1	1	1	1	0	6,5	10,74%
Reduction of Investment Costs	0	0	0	0,5	0	0,5	0	0	1	0	0	2	3,31%
Reduction of Required Space	0	0	0	0	0	1	0,5	0	1	1	0	3,5	5,79%
Reduction of Planning Costs	0	0	0	1	0	1	1	0,5	1	1	0	5,5	9,09%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	0	0	0,5	0	0	0,5	0,83%
Maturity of a technology	0	0	0	0	0	1	0	0	1	0,5	0	2,5	4,13%
User Acceptance	1	1	0	1	1	1	1	1	1	1	0,5	9,5	15,70%
												60,5	100%

Source: Own representation

Figure 11: Pairwise comparison results form an innovation manager

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	0	1	0,5	1	1	0,5	1	1	0,5	8	13,22%
Reduction of Running Costs	0	0,5	0	1	0,5	1	1	0,5	1	1	0,5	7	11,57%
Increase the Overall Equipment Effectiveness	1	1	0,5	1	0,5	1	1	0,5	1	1	1	9,5	15,70%
Reduction of Ramp-up Costs	0	0	0	0,5	0	1	1	0	1	1	0,5	5	8,26%
Increase of Flexibility	0,5	0,5	0,5	1	0,5	1	1	0,5	1	1	0,5	8	13,22%
Reduction of Investment Costs	0	0	0	0	0	0,5	1	0	1	0,5	0	3	4,96%
Reduction of Required Space	0	0	0	0	0	0	0,5	0	1	0,5	0	2	3,31%
Reduction of Planning Costs	0,5	0,5	0,5	1	0,5	1	1	0,5	1	1	0,5	8	13,22%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	0	0	0,5	0,5	0	1	1,65%
Maturity of a technology	0	0	0	0	0	0,5	0,5	0	0,5	0,5	0	2	3,31%
User Acceptance	0,5	0,5	0	0,5	0,5	1	1	0,5	1	1	0,5	7	11,57%
												60,5	100%

Source: Own representation

Figure 12: Pairwise comparison results form a smart clothes project leader

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0,5	1	1	0,5	1	1	1	1	1	0,5	9	14,88%
Reduction of Running Costs	0,5	0,5	1	1	1	1	1	0,5	0,5	1	0,5	8,5	14,05%
Increase the Overall Equipment Effectiveness	0	0	0,5	0	0,5	1	0,5	0	0,5	1	0,5	4,5	7,44%
Reduction of Ramp-up Costs	0	0	1	0,5	0,5	1	1	0,5	0,5	1	0,5	6,5	10,74%
Increase of Flexibility	0,5	0	0,5	0,5	0,5	1	1	0,5	1	1	1	7,5	12,40%
Reduction of Investment Costs	0	0	0	0	0	0,5	0	0	0	0,5	0	1	1,65%
Reduction of Required Space	0	0	0,5	0	0	1	0,5	0	0	0,5	0	2,5	4,13%
Reduction of Planning Costs	0	0,5	1	0,5	0,5	1	1	0,5	0,5	1	0,5	7	11,57%
Reduction of Energy and Resource Costs	0	0,5	0,5	0,5	0	1	1	0,5	0,5	1	0	5,5	9,09%
Maturity of a technology	0	0	0	0	0	0,5	0,5	0	0	0,5	0	1,5	2,48%
User Acceptance	0,5	0,5	0,5	0,5	0	1	1	0,5	1	1	0,5	7	11,57%
												60,5	100%

Source: Own representation

Figure 13: Pairwise comparison results form an innovation consultant

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	1	0	0	1	0	0	0	1	0	4,5	7,44%
Reduction of Running Costs	0	0,5	1	1	0	1	0	1	1	1	0	6,5	10,74%
Increase the Overall Equipment Effectiveness	0	0	0,5	1	1	1	0	1	1	1	0	6,5	10,74%
Reduction of Ramp-up Costs	1	0	0	0,5	0	0	0	0	0	0	0	1,5	2,48%
Increase of Flexibility	1	1	0	1	0,5	1	0	0	1	0	0	5,5	9,09%
Reduction of Investment Costs	0	0	0	1	0	0,5	0	0	0	0	0	1,5	2,48%
Reduction of Required Space	1	1	1	1	1	1	0,5	1	1	1	0,5	10	16,53%
Reduction of Planning Costs	1	0	0	1	1	1	0	0,5	0	1	0	5,5	9,09%
Reduction of Energy and Resource Costs	1	0	0	1	0	1	0	1	0,5	0,5	0	5	8,26%
Maturity of a technology	0	0	0	1	1	1	0	0	0,5	0,5	0	4	6,61%
User Acceptance	1	1	1	1	1	1	0,5	1	1	1	0,5	10	16,53%
												60,5	100%

Source: Own representation

Figure 14: Pairwise comparison results form a production planner

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	0,5	1	0,5	0	0,5	0,5	1	0	1	6,5	10,74%
Reduction of Running Costs	0	0,5	0	1	0	1	0,5	1	0,5	0	0	4,5	7,44%
Increase the Overall Equipment Effectiveness	0,5	1	0,5	1	0	1	1	1	1	0,5	0,5	8	13,22%
Reduction of Ramp-up Costs	0	0	0	0,5	0	1	1	1	1	0	0,5	5	8,26%
Increase of Flexibility	0,5	1	1	1	0,5	1	1	1	1	0,5	0	8,5	14,05%
Reduction of Investment Costs	1	0	0	0	0	0,5	0,5	1	0	0	0	3	4,96%
Reduction of Required Space	0,5	0,5	0	0	0	0,5	0,5	0	0,5	0	0	2,5	4,13%
Reduction of Planning Costs	0,5	0	0	0	0	0	1	0,5	1	0	0,5	3,5	5,79%
Reduction of Energy and Resource Costs	0	0,5	0	0	0	1	0,5	0	0,5	0	0	2,5	4,13%
Maturity of a technology	1	1	0,5	1	0,5	1	1	1	1	0,5	1	9,5	15,70%
User Acceptance	0	1	0,5	0,5	1	1	1	0,5	1	0	0,5	7	11,57%
												60,5	100%

Source: Own representation

Figure 15: Pairwise comparison results form an innovation manager

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0	1	0	1	0	1	1	1	0	0	5,5	9,09%
Reduction of Running Costs	1	0,5	1	1	1	1	1	1	1	0	0	8,5	14,05%
Increase the Overall Equipment Effectiveness	0	0	0,5	1	1	0	1	1	1	0	0	5,5	9,09%
Reduction of Ramp-up Costs	1	0	0	0,5	1	1	1	1	1	1	0	7,5	12,40%
Increase of Flexibility	0	0	0	0	0,5	0	0	0	1	0	0	1,5	2,48%
Reduction of Investment Costs	1	0	1	0	1	0,5	1	1	1	0	0	6,5	10,74%
Reduction of Required Space	0	0	0	0	1	0	0,5	0	1	0	0	2,5	4,13%
Reduction of Planning Costs	0	0	0	0	1	0	1	0,5	0	0	0	2,5	4,13%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	0	1	0,5	0	0	1,5	2,48%
Maturity of a technology	1	1	1	0	1	1	1	1	1	0,5	1	9,5	15,70%
User Acceptance	1	1	1	1	1	1	1	1	1	0	0,5	9,5	15,70%
												60,5	100%

Source: Own representation

Figure 16: Pairwise comparison results form an automotive innovation's expert

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	1	1	1	1	1	1	1	1	1	10,5	17,36%
Reduction of Running Costs	0	0,5	1	1	0	1	1	1	0,5	1	1	8	13,22%
Increase the Overall Equipment Effectiveness	0	0	0,5	1	0	0	1	0	1	0	0	3,5	5,79%
Reduction of Ramp-up Costs	0	0	0	0,5	0	1	1	1	1	1	1	6,5	10,74%
Increase of Flexibility	0	1	1	1	0,5	0	1	1	1	0	0	6,5	10,74%
Reduction of Investment Costs	0	0	1	0	1	0,5	1	0	1	0	0	4,5	7,44%
Reduction of Required Space	0	0	0	0	0	0	0,5	0	0	0	0	0,5	0,83%
Reduction of Planning Costs	0	0	1	0	0	1	1	0,5	1	1	0	5,5	9,09%
Reduction of Energy and Resource Costs	0	0,5	0	0	0	0	1	0	0,5	0	0	2	3,31%
Maturity of a technology	0	0	1	0	1	1	1	0	1	0,5	0	5,5	9,09%
User Acceptance	0	0	1	0	1	1	1	1	1	1	0,5	7,5	12,40%
												60,5	100%

Source: Own representation

Figure 17: Pairwise comparison results form a smart gloves' project leader

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	1	1	1	1	1	1	1	1	1	10,5	17,36%
Reduction of Running Costs	0	0,5	0,5	1	0	1	1	1	0	0,5	1	6,5	10,74%
Increase the Overall Equipment Effectiveness	0	0,5	0,5	1	0	1	1	1	0,5	1	1	7,5	12,40%
Reduction of Ramp-up Costs	0	0	0	0,5	0	0	0	0,5	0	1	1	3	4,96%
Increase of Flexibility	0	1	1	1	0,5	1	1	1	1	1	1	9,5	15,70%
Reduction of Investment Costs	0	0	0	1	0	0,5	0	1	0	1	1	4,5	7,44%
Reduction of Required Space	0	0	0	1	0	1	0,5	1	0,5	1	1	6	9,92%
Reduction of Planning Costs	0	0	0	0,5	0	0	0	0,5	0	0	0,5	1,5	2,48%
Reduction of Energy and Resource Costs	0	1	0,5	1	0	1	0,5	1	0,5	1	1	7,5	12,40%
Maturity of a technology	0	0,5	0	0	0	0	0	1	0	0,5	0,5	2,5	4,13%
User Acceptance	0	0	0	0	0	0	0	0,5	0	0,5	0,5	1,5	2,48%
												60,5	100%

Source: Own representation

Figure 18: Pairwise comparison results form a smart logistics' project leader

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	0,5	0,5	1	1	1	1	0,5	1	0,5	8,5	14,05%
Reduction of Running Costs	0	0,5	0,5	0,5	0,5	1	0,5	1	0,5	0,5	0	5,5	9,09%
Increase the Overall Equipment Effectiveness	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	5,5	9,09%
Reduction of Ramp-up Costs	0,5	0,5	0,5	0,5	0	0,5	0	0,5	0,5	0,5	0	4	6,61%
Increase of Flexibility	0	0,5	0,5	1	0,5	1	0,5	0,5	0,5	0,5	0	5,5	9,09%
Reduction of Investment Costs	0	0	0,5	0,5	0	0,5	0	1	0,5	0,5	0,5	4	6,61%
Reduction of Required Space	0	0,5	0,5	1	0,5	1	0,5	0,5	0,5	0,5	0	5,5	9,09%
Reduction of Planning Costs	0	0	0,5	0,5	0,5	0	0,5	0,5	0,5	1	0	4	6,61%
Reduction of Energy and Resource Costs	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	5,5	9,09%
Maturity of a technology	0	0,5	0,5	0,5	0,5	0,5	0,5	0	0,5	0,5	0,5	4,5	7,44%
User Acceptance	0,5	1	0,5	1	1	0,5	1	1	0,5	0,5	0,5	8	13,22%
												60,5	100%

Source: Own representation

Figure 19: Pairwise comparison results form a smart gloves' product owner

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0,5	0,5	1	1	1	1	0,5	1	1	0,5	8,5	14,05%
Reduction of Running Costs	0,5	0,5	0,5	0,5	1	0	1	0,5	1	1	1	7,5	12,40%
Increase the Overall Equipment Effectiveness	0,5	0,5	0,5	0	1	0	1	0,5	1	1	1	7	11,57%
Reduction of Ramp-up Costs	0	0,5	1	0,5	1	0,5	1	0,5	1	1	1	8	13,22%
Increase of Flexibility	0	0	0	0	0,5	0	1	0	0	1	1	3,5	5,79%
Reduction of Investment Costs	0	1	1	0,5	1	0,5	1	1	1	1	1	9	14,88%
Reduction of Required Space	0	0	0	0	0	0	0,5	1	0,5	1	1	4	6,61%
Reduction of Planning Costs	0,5	0,5	0,5	0,5	1	0	0	0,5	0,5	1	1	6	9,92%
Reduction of Energy and Resource Costs	0	0	0	0	1	0	0,5	0,5	0,5	0,5	0	3	4,96%
Maturity of a technology	0	0	0	0	0	0	0	0	0,5	0,5	1	2	3,31%
User Acceptance	0,5	0	0	0	0	0	0	0	1	0	0,5	2	3,31%
												60,5	100%

Source: Own representation

Figure 20: Pairwise comparison results form a smart gloves' product owner

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0,5	0,5	1	1	1	1	1	1	0,5	0,5	8,5	14,05%
Reduction of Running Costs	0,5	0,5	0,5	1	1	1	1	1	1	0,5	0,5	8,5	14,05%
Increase the Overall Equipment Effectiveness	0,5	0,5	0,5	1	1	1	1	1	1	0,5	0,5	8,5	14,05%
Reduction of Ramp-up Costs	0	0	0	0,5	0	1	1	1	0,5	1	0	5	8,26%
Increase of Flexibility	0	0	0	1	0,5	1	1	1	1	1	0	6,5	10,74%
Reduction of Investment Costs	0	0	0	0	0	0,5	1	0,5	1	0	0	3	4,96%
Reduction of Required Space	0	0	0	0	0	0	0,5	0	0,5	0	0	1	1,65%
Reduction of Planning Costs	0	0	0	0	0	0,5	1	0,5	1	0	0	3	4,96%
Reduction of Energy and Resource Costs	0	0	0	0,5	0	0	0,5	0	0,5	0	0	1,5	2,48%
Maturity of a technology	0,5	0,5	0,5	0	0	1	1	1	1	0,5	1	7	11,57%
User Acceptance	0,5	0,5	0,5	1	1	1	1	1	1	0	0,5	8	13,22%
												60,5	100%

Source: Own representation

Figure 21: Pairwise comparison results form an innovation manager

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	0,5	1	0	1	1	1	1	1	0	8	13,22%
Reduction of Running Costs	0	0,5	1	1	0	1	1	1	1	1	0	7,5	12,40%
Increase the Overall Equipment Effectiveness	0,5	0	0,5	0,5	0	0,5	1	0,5	1	0,5	0	5	8,26%
Reduction of Ramp-up Costs	0	0	0,5	0,5	0	0,5	0,5	0	1	0,5	0	3,5	5,79%
Increase of Flexibility	1	1	1	1	0,5	1	1	0,5	1	1	0,5	9,5	15,70%
Reduction of Investment Costs	0	0	0,5	0,5	0	0,5	0,5	0,5	1	0,5	0	4	6,61%
Reduction of Required Space	0	0	0	0,5	0	0,5	0,5	0	0,5	0,5	0	2,5	4,13%
Reduction of Planning Costs	0	0	0,5	1	0,5	0,5	1	0,5	1	0,5	0	5,5	9,09%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	0,5	0	0,5	1	0	2	3,31%
Maturity of a technology	0	0	0,5	0,5	0	0,5	0,5	0,5	0	0,5	0	3	4,96%
User Acceptance	1	1	1	1	0,5	1	1	1	1	1	0,5	10	16,53%
												60,5	100%

Source: Own representation

Figure 22: Pairwise comparison results form a production supervisor

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	0	1	1	1	1	1	1	1	0	8,5	14,05%
Reduction of Running Costs	0	0,5	0	1	1	1	1	1	0	1	0	6,5	10,74%
Increase the Overall Equipment Effectiveness	1	1	0,5	1	1	0	1	0	0	1	0	6,5	10,74%
Reduction of Ramp-up Costs	0	0	0	0,5	1	0	0	0	1	0	0	2,5	4,13%
Increase of Flexibility	0	0	0	0	0,5	1	0	0	0	0	0	1,5	2,48%
Reduction of Investment Costs	0	0	1	1	0	0,5	0	1	1	1	0	5,5	9,09%
Reduction of Required Space	0	0	0	1	1	1	0,5	0	1	0	0	4,5	7,44%
Reduction of Planning Costs	0	0	1	1	1	0	1	0,5	0	0	0	4,5	7,44%
Reduction of Energy and Resource Costs	0	1	1	0	1	0	0	1	0,5	0	0	4,5	7,44%
Maturity of a technology	0	0	0	1	1	0	1	1	1	0,5	0	5,5	9,09%
User Acceptance	1	1	1	1	1	1	1	1	1	1	0,5	10,5	17,36%
												60,5	100%

Source: Own representation

Figure 23: Pairwise comparison results form a smart gloves' product owner

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0	1	1	0	1	1	1	1	0	0	6,5	10,74%
Reduction of Running Costs	1	0,5	1	1	0	1	1	1	1	1	0	8,5	14,05%
Increase the Overall Equipment Effectiveness	0	0	0,5	1	0	0	1	1	0	0	0	3,5	5,79%
Reduction of Ramp-up Costs	0	0	0	0,5	0	0	1	1	0	0	0	2,5	4,13%
Increase of Flexibility	1	1	1	1	0,5	1	1	1	1	1	0	9,5	15,70%
Reduction of Investment Costs	0	0	1	1	0	0,5	1	1	1	0	0	5,5	9,09%
Reduction of Required Space	0	0	0	0	0	0	0,5	1	0	0	0	1,5	2,48%
Reduction of Planning Costs	0	0	0	0	0	0	0	0,5	0	0	0	0,5	0,83%
Reduction of Energy and Resource Costs	0	0	1	1	0	0	1	1	0,5	0	0	4,5	7,44%
Maturity of a technology	1	0	1	1	0	1	1	1	1	0,5	0	7,5	12,40%
User Acceptance	1	1	1	1	1	1	1	1	1	1	0,5	10,5	17,36%
												60,5	100%

Source: Own representation

Figure 24: Pairwise comparison results form a production planner

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	0,5	1	1	1	1	1	1	1	1	1	10	16,53%
Reduction of Running Costs	0,5	0,5	1	1	1	1	1	1	1	1	1	10	16,53%
Increase the Overall Equipment Effectiveness	0	0	0,5	1	1	0,5	1	0,5	1	0,5	1	7	11,57%
Reduction of Ramp-up Costs	0	0	0	0,5	0,5	0	1	0	1	0,5	1	4,5	7,44%
Increase of Flexibility	0	0	0	0,5	0,5	0	1	0	1	0	0,5	3,5	5,79%
Reduction of Investment Costs	0	0	0,5	1	1	0,5	1	0,5	1	0,5	0,5	6,5	10,74%
Reduction of Required Space	0	0	0	0	0	0	0,5	0	0,5	0	0	1	1,65%
Reduction of Planning Costs	0	0	0,5	1	1	0,5	1	0,5	1	0,5	1	7	11,57%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	0,5	0	0,5	0	0	1	1,65%
Maturity of a technology	0	0	0,5	0,5	1	0,5	1	0,5	1	0,5	1	6,5	10,74%
User Acceptance	0	0	0	0	0,5	0,5	1	0	1	0	0,5	3,5	5,79%
												60,5	100%

Source: Own representation

Figure 25: Pairwise comparison results form a production supervisor

	Reduction of Rework Cost	Reduction of Running Costs	Increase the Overall Equipment Effectiveness	Reduction of Ramp-up Costs	Increase of Flexibility	Reduction of Investment Costs	Reduction of Required Space	Reduction of Planning Costs	Reduction of Energy and Resource Costs	Maturity of a technology	User Acceptance	Score	Weight
Reduction of Rework Cost	0,5	1	0	1	0	1	1	1	1	1	0	7,5	12,40%
Reduction of Running Costs	0	0,5	0	1	1	1	1	1	1	1	0	7,5	12,40%
Increase the Overall Equipment Effectiveness	1	1	0,5	1	0	1	0	0	1	1	0	6,5	10,74%
Reduction of Ramp-up Costs	0	0	0	0,5	0	1	1	0	1	0	0	3,5	5,79%
Increase of Flexibility	1	0	1	1	0,5	1	0	0	1	0	0	5,5	9,09%
Reduction of Investment Costs	0	0	0	0	0	0,5	0	1	1	1	0	3,5	5,79%
Reduction of Required Space	0	0	1	0	1	1	0,5	0	1	0	0	4,5	7,44%
Reduction of Planning Costs	0	0	1	1	1	0	1	0,5	0	0	0	4,5	7,44%
Reduction of Energy and Resource Costs	0	0	0	0	0	0	0	1	0,5	0	0	1,5	2,48%
Maturity of a technology	0	0	0	1	1	0	1	1	1	0,5	0	5,5	9,09%
User Acceptance	1	1	1	1	1	1	1	1	1	1	0,5	10,5	17,36%
												60,5	100%

Source: Own representation

B Interviews conducted with experts

In this section all the interviews conducted with experts are presented. Each interview had a header which indicate:

[Name of the participant of the interview]

[Responsibility of the participant of the interview]

[Place were the interview was conducted]

[Date of the interview]

[Additional data]

Interview was conducted with:

Frank Pochiro

Project leader exoskeleton at BMW AG

Knorrstr. 147, 80937 Munich, Germany

June 19, 2018

Transcribed from English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Frank Pochiro: "I don't know, I have to think about it, because I have to go through this list a few times, and make sure I understand them. Let me think, so, I mean, ergonomics is very important. When we have an injury, a shoulder injury for example, it comes out of our plan budget. It is different than in Germany. So, there is reducing new investment. But you don't have nothing mention about budget. That might be something that is missing. "

Question: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Frank Pochiro: "That is one of my most important criteria. Yeah, that is one of the highest criteria, one of the highest. One of the number one goals that I had was, that the workers accepted. I mean, it has to be something that they accepted or they won't use it here. They won't use it anywhere. In fact, they will find a million reasons not to use it if they don't like it. So it has to be very comfortable, that was one of my highest goals. It has to be fast to put on and off. Because I don't want it to take a long time to put it on and off, otherwise they won't use it because is to complex and it takes away from their break time. You know, when they have to put this on, or they are not able to do their job, or they are taking to much time to put on an exoskeleton. So it has to be very quick. And Hygiene is a very top criteria, we have to think about sharing it between people. So all of this contributes to them accepting it as a system that they want to use."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don´t consider the societal factor?*

Frank Pochiro: "I think is important, is one of the most important things. I think that maybe is not something on the surface that you seeing on your research, but is definitely one of the highest considerations of all the companies I have worked with. I mean, they evaluate and analyze the human body, as much as they can. They have lots and very detailed analysis of the human body, and all the biomedical side. That where all, most of the companies of exoskeletons come from, is the biomedical side. And they have done a lot of research and developments. It is actually very important for them. So this question maybe not apply here. Are you thinking this questions from the exoskeleton perspective or from collaborative assistance systems."

Question: *The question was more about assistance systems, and try to investigate why the methods do not consider the user acceptance, if, as you have said before, is such an important factor?*
Frank Pochiro: "Well, yeah, I don't know. I can't really answer from everybody else. But at least all the companies that I work with the acceptance has been extremely important. Because all the companies that I work with, they realized, they know that if the person doesn't want to wear it they won't wear it. And that is a priority for them. And they done many studies analyzing the human body, but also analyzing and gathering data from people, as far as their acceptance, their feelings about it. We spend a long time asking from feedback from associates, trying them on, from people. That was a big factor."

Question: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*
Frank Pochiro: "This increase of user acceptance can be done by means of information directed to the associates. So that they understand, what the long term benefit of the system is. One of the biggest problems I have with them accepting it, they are either very young or healthy, so they don't think that they need something like this as an assistance system. But the older they get, the more they work this job, they start to feel the fatigue. And then, maybe, much later they might have an injury. And so, I guess the communication to them and the education of them to understand the long term benefits to this. The fact that this could reduce their chances of injury. Nobody, who is young wants to really wear it, because they are like:" hey I am young, I don't need that, I am not gonna get hurt, I am not gonna wear out". But the thing is that they do. And they are not seeing that, they are not understanding what that could potentially result in. So I think

maybe some sort of better communication and education. How often does shoulder injuries happen, and what is the cause of the results when that happen. So maybe more training, and education and communication, that would help. I think we are focusing in hygiene, making it as much light as it could be, which adds the comfort obviously. Most of the major factors we are already considering. Apart from education, I would probably say like more, like a training are, like a lab where they can try it on, trying to wear it on and off. That could help them understand. So when they first star using them, and they have to do the same job without them, they realize, oh wow, that was really helping me. And then they want to put them on again. So some sort of a lab or a trial area."

Interview was conducted with:
Verena Wagner
Project leader smart watch at BMW AG
Knorrstr. 147, 80937 Munich, Germany
June 20, 2018
Transcribed from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*
Verena Wagner: " I find, that the criteria are not the problematic here, but the person who evaluate those criteria. For me, because of the things that I want to improve in production, the OEE is the most important criteria, but if you speak with Christian or Elisabeth, that they are focus on ergonomics, then the ergonomics are more important."

Question 2*: There are reasons to believe that the different assistance systems should not be treated equally. Do you agree with this statement, that for each technology it should be done a different kind of evaluation with probably different criteria?*
Verena Wagner:" Not only that, but it is as well important who evaluate those technologies. It is people from management who are going to evaluate those systems, or a person that is in contact with users that are going to use those systems?"

Question: *This is exactly my point of view. Therefore, I am trying to conduct those comparison with experts of different areas, so that I have a better overview of the assistance systems. Moving on, from your experience, how important is the perceived*

user acceptance of an assistance system, in order that this system has a successful implementation in production?

Verena Wagner: "Really important, really really important. If you see my evaluation then you will realize that I put a lot of 1. Because if the system that I am developing is not accepted, the user will never use it."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don´t consider the societal factor?*

Verena Wagner: "Yes, I think is a mistake if the people don't consider the user acceptance. The human is now more important than ever. There is a trend towards improving the quality of work of each worker. In my parents' generation, the main concerned was numbers, facts, what this system is able to do, what is the use for it, without much thinking in the human component."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Verena Wagner: "I think the most important is, from the very beginning, to involve the end user in the development of the product. I can not develop an assistance system, and then when it is ready, give it to the user and say: "now work with it". So I think is important, to involve the user from the beginning, so that they can say what is good what is wrong, what could be improved. And from my experience, to give the possibility to the user to try the new assistance system. To discover improvements. And when, by trying this system, they realize that this systems add value to what they are doing, then they wil choose to use it."

Interview was conducted with:
Fabian Grad
Innovation manager at BMW AG
Knorrstr. 147, 80937 Munich, Germany
June 20, 2018
Transcribed from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Fabian Grad: "I think, in general, I mean the pairwise comparison, and how to evaluate the criteria I find it really good. I think is a good method, I have myself already use it in the past. Do you talk about the criteria in particular? "

Question*: when I was asking that question, I was referring to criteria rather than the method itself*

Fabian Grad: "In this aspect, then I find that the criteria is good. The only thing that maybe I don't picture in this criteria is the maturity of the technology. I have the feeling that doesn't belong here… why do I say that? Because it is obvious for me that when a technology is not mature enough so that we can adopt this technology, is then a KO criterion. I decide between ergonomics or maturity, only that with the maturity I make the very first decision, and that happens even before starting evaluating this technology. So if the product is not mature enough I will not even evaluate the OEE for example."

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Fabian Grad: "For me, really really important. I have that evaluated as my fourth criteria in the pairwise, but the user acceptance, when I want to implement something, is the most important factor. To decide what product is cheap, then hear we must consider things like OEE, quality, and so on, but that we can implement the user acceptance experience is really really important."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don't consider the societal factor?*

Fabian Grad: " The reason for that I don't know right now. But, as you have already said, the user acceptance is definitely the most important criteria. The are criteria to decide whether I want to implement this product or not, but in order that this product will successfully be implemented, the user acceptance is the most important criteria. The assistance system have gained relevancy through the past few years. Because the worker now has to face more complex tasks, forty to fifty different possibilities, and with every new model of car, they will be even more important."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Fabian Grad: "Yes, of course. When I think about the tasks that our colleagues in production must to do, then it is important that assistance systems are easy to use, robust, that it doesn't fail from time to time, and as well really important, that tolerate mistakes. That is something that is missing in many software products. That means that when I do a mistake while using the system, it automatically guides me again to the right path. Therefore, I would say, easy, robust, and tolerant towards mistakes."

Interview was conducted with:
Thomas Lorisch
Innovation consultant at BMW AG
Knorrstr. 147, 80937 Munich, Germany
June 20, 2018
Transcribed from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Thomas Lorisch: "I think, that there are considered lots of criteria. And I cannot think of any situation not covered with these criteria. As well, they are good balanced. "

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Thomas Lorisch: "I find it extreme relevant, especially in final stages. When I take a look at the innovation process, from the moment that someone has an idea until this idea is implemented in production, the user acceptance has a huge impact on the development of this concept. That is the reason why I think, that the user acceptance is a sensitive topic, because if you forget to consider it at the very beginning then you could have implementations problems at the end. You will have created a product that no one is willing to use. For that is important to integrate the user in the process, from the very beginning, to have their minds in consideration."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don´t consider the societal factor?*

Thomas Lorisch: "The problematic here, is that the assessment of user acceptance is really difficult. I would suggest to considered, without any doubt about it, but it is difficult to find a way to evaluate this factor. This is not a criteria, which someone can evaluate like the efficiency, with a formula or some objective values. Therefore, methods have a huge challenge there. Again, I would consider the user acceptance, and then the question that arise her is: what options do I have to evaluate the acceptance? Do I stick with interviews or I speak directly with the users, it depends really on each situation. So I think, there is a great difficulty to find a method that evaluate this acceptance. But I find user acceptance extreme important. But, If I can say a last thing, one should be consistent with the necessity in production as well. Not only follow what the user wants, but to find a balance. I mean it is not bad to follow the user recommendations, but applying always common sense and trying to develop a system that adds value for production as well. Do not get me wrong, user acceptance should be the factor that drive the development of assistance systems, but analyzing in the same time other factors. As well, one very last thing, then we must decide, which users do we listen to, or how do I select representative users for this innovation. That could be another point of discussion."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Thomas Lorisch: "For me the first measure, that could be adopted, is to consider the user in this developing process. In all the innovation steps, or in the majority of them. A possibility to do that maybe is to received feedback in every innovation stage from the user. This is how it works today for us. But you should differentiate each project. There are times where we already have a prototype that we can try with the users. In that case is easier to gather data. In that case, is easy to involve the user from a early stage, in other cases it is more complex."

Interview was conducted with:
Elisabeth Wolf
Project leader smart clothes at BMW AG
Knorrstr. 147, 80937 Munich, Germany
July 6, 2018

Transcribed from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Elisabeth Wolf: "I found them correct. If you are thinking about assistance system, which is the thing that concern me, then I would put the focus on the user acceptance. I want to do something good for the user, but in the same time trying to improve the productivity, the quality of production, and so on. But as the main factor, I think in changes that affect to the ergonomics of the user. I should be a bit selfish and think about what the priority for my systems is. "

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Elisabeth Wolf: " For the systems that I am developing, that have to do with smart clothes, the improving of ergonomics is what I have in mind all the time. If I develop a smart clothe that any worker want to wear or to use, then they will never be implemented. That is why for me user acceptance is the most important criteria."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don't consider the societal factor?*

Elisabeth Wolf: "I think has to do with the fact, that assistance systems were not that relevant few years ago. If you look at today's production the implementation of assistance systems has increased. Maybe, the methods are trying to evaluate general production systems, but when it is about assistance systems, such as the ones that I am supervising, the acceptance of the user must be considered."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Elisabeth Wolf: "If someone comes to me, and I am a production worker with a new assistance system, then for me, as production worker, what is the most important is that I can easily use the system. And of course, that it is ergonomics. For me those are the most important factors. If I have to improve the acceptance of the user, I would aim to the

improvement of those factors. But as a productions planner or innovator, I must ensure that the necessities of the workers are covered, whatever those necessities are. And that is connected to the acceptance. That is how I see it."

Interview was conducted with:

Nicolai Piller

Product owner Smart Gloves at BMW AG

Knorrstr. 147, 80937 Munich, Germany

July 11, 2018

Transcribed from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Nicolai Piller: "Yes, that is ok"

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Nicolai Piller: "For new technologie I think that the User Accpetance is in fact really important. But if you compare it with the other criteria that you have presented to me, it plays a secondary role. You have to consider that to each particular case. For example, Exoskeleton consider the User Acceptance the most important factor out of all of them. Without this acceptance from the user and if no one would like to use the exoskeleton, then you could never implement those systems in production. But then in comparison with big objective such as reduction of rework or increase the quality, then the user acceptance is a secondary objective. If you want to achieve the objectives in production."

Question: *Form you point of view then, one should design an assistance system prioritizing the reduction of costs, leaving the user acceptance as a secondary objective. Am I correct?*

Nicolai Piller: "That is correct. However, one should differentiate between the functionality of each systems. Is a system made for the user, that he must use it the whole day? Or it is a system that the user uses it from time to time? If it is the first case, then of

course, the user acceptance is the most important factor. In other cases, the savings in production are more important."

Question: *So if it is the case, that we are to evaluate an assistance system, such as smart gloves, smart glasses, exoskeleton, would you priories then the user acceptance?*

Nicolai Piller: " If that is the case, that those systems were to be evaluated, I believe that the user acceptance should be the most important factor. If not, no one will ever use those systems. And consequently, we could never implement those systems in production."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don′t consider the societal factor?*

Nicolai Piller: "As I have said before, if we are evaluating systems in production, then the most important objectives are the reduction of rework, or improvement of the quality. That is the reasons most of the methods put the focus on those parameters. However, as I said, it depends on each technology. It is obvious, that if you have to evaluate an assistance system, the user acceptance must be considered. If not then again no one will use it."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Nicolai Piller: "Things like improving the ergonomics, or safety, in that direction."

Interview was conducted with:
Karl-Heinz Bienert
Innovation manager at BMW AG
Knorrstr. 147, 80937 Munich, Germany
July 12, 2018
Transcribed from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Karl-Heinz Bienert: "Mmm yes, looking to this criteria seems good for evaluating assistance systems"

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Karl-Heinz Bienert: "As you can see in the pairwise comparison for me is the most important factor."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don´t consider the societal factor?*

Karl-Heinz Bienert: "I think in the production it has always take into account things such as costs, quality and so on. The fact that nowadays we have assistance systems in production poses new challenges for the evaluation of those systems. And the other models might have not adapted to them."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Karl-Heinz Bienert: "To realize what a technology could offers you, in terms of benefits for your work, then you say, yes I am going to use this technology. Is as well important that this technology is easy to use. Then you should aim for those factors, if you want to increase the acceptance among worker. However, the safety is extremely important, for the whole concept to work. If you don't assure that the system is safe, then it will never be used. Said that, safety is a KO factor. Without safety, the system cannot be implemented. But this is clear to anyone."

Question: *"If I have correctly understood, for you the most important is that the system works good, or that it adds something new, rather than a system with good ergonomics for example?*

Karl-Heinz Bienert: "Of course that this is important. If it is not safe, or the ergonomics are not good then the system is not useful. This is how I see it. But if you ask me, what we should do to increase the acceptance, I would just go directly to the user of each technology and ask them for their opinions."

Interview was conducted with:
Stefanie Schalau
Productions planner at BMW AG

Knorrstr. 147, 80937 Munich, Germany

July 17, 2018

Translated from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

Stefanie Schalau: "Yes, to my point of view I think is good "

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

Stefanie Schalau: "Of course is important, however in comparison with the other production objectives, it is less relevant. If we look at our objectives, here in production, we must prioritize things such as reduction of rework or running costs. If at the same time we could implement as well, a system that has a good acceptance among user, that could be ideal. But again, for me is more important to priories other factors rather that the acceptance of the user."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don´t consider the societal factor?*

Stefanie Schalau: "Maybe because they put the focus on other factors, such as economic factors. Focusing on the reduction of costs, or improving the quality, which tend to be one of the most important things in production lines"

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Stefanie Schalau: "For me the most important factor for a system is, of course, safety. For example, a technology such as the gloves, must prevent from workers to be cut or injured, when they are wearing them. As well the worker must understand what is this glove adding to my work, in terms of benefits for my daily work. It doesn't have to broke immediately if they use it on the second day. It must be, at least, as good as the previous system. If not they will not use it"

Interview was conducted with:

Alexander Schmitz

Product owner Smart Gloves at BMW AG

Knorrstr. 147, 80937 Munich, Germany

July 18, 2018

Translated from German to English

Question 1: *Do you have the impression that the presented criteria is sufficient for the assessment of assistance system in production? If not, could you suggest other criteria to be considered?*

A.Schmitz: " I think that with this criteria one can good enough evaluate a production system such as the assistance system "

Question 2: *From your experience, how important is the perceived user acceptance of an assistance system, in order that this system has a successful implementation in production?*

A.Schmitz: "When we think about Pro Glove or exoskeleton, for example, the user acceptance is the most important factor. If you cannot convince the workers that the technology to be implemented is going to be useful for them, they will never adopt it."

Question 3: *Why do you think most of the evaluating methods, regarding production technologies, don't consider the societal factor?*

A.Schmitz: "That is a difficult question to answer. Mmm…. Maybe could be that the assistance systems are relatively new in production, or because of the difficulty of assessing this acceptance."

Question 4: *Following the topic of the social perception of a system, could you think of any factor that could increase the acceptance of an assistance systems among workers in production?*

Alexander Schmitz: "It really depends on the situation or the technology. For example, for Pro Glove, things like safety or ergonomics are factors that increase the acceptance of this technology. As well, convincing the colleagues that the technology that they are going to use is better than the data logic. Taking that into account, I think this is the most important factor to increase the user acceptance. And maybe the ease of use, take it out and off we go. If it takes too long to take it out, for example 10 min, no worker will use

them. It must be easy to use, have a relative advantage against the previous product and it must be pleasant in the hand. Another think is, if someone use it and find this glove cool, or someone with a strong opinion in the band use this technology, that can motivate the whole group toward using this technology."

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