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THE BARRIERS OF IMPLEMENTING THE INDUSTRY 4.0 TECHNOLOGY - COLLABORATIVE ROBOTS

Rita Margarida Silva Costa

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Dissertation

Master in Management

Supervised by
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Biographic Note

Rita Margarida Silva Costa born on 27th of June 1994, in Braga.

Concluded the bachelor's degree in economics in 2015, at University of Minho. In 2016 went to England to enter the professional world, doing an internship of 6 months in the finance department. Returned in that same year and started the Master in Management at the Faculty of Economics in University of Porto.

While studying, was able to do another internship of 6 months in international consulting. After that, worked for more than a year in one of the biggest Portuguese companies as Supply Chain Manager.

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Abstract

The industrial sector has already been through three major revolutions that have come to improve and optimize the performance, with the adaptation to new technologies and discoveries. These events had an impact not only economically but also socially.

Currently, we are in the fourth industrial revolution. Industry 4.0. was triggered essentially by the use of internet, a constant these days. With the increasing digitalization, the need to invest in tools and solutions capable of meeting the needs of consumers was created. As a result, we were introduced to a new generation of technologies: Collaborative Robots. These, in turn, aim to combine the qualities of each stakeholder: robot and worker; and to create a safe common space where both can perform their tasks at the same time by collaborating with each other.

The purpose of this study is to understand what barriers companies encounter when implementing collaborative robots. Additionally, it is intended to understand what developments are necessary to be able to overcome these same barriers.

Keywords: Industry 4.0; Collaborative Robots; CoBots; Barriers; Developments.

Resumo

O setor industrial já conta com três grandes revoluções que vieram melhorar e otimizar a performance das empresas com a adaptação a novas tecnologias e descobertas. Estes eventos impactaram não só a nível económico como também a nível social.

Atualmente, encontramo-nos na quarta revolução industrial. A Indústria 4.0. foi acionada essencialmente pelo uso da internet, uma constante nos dias que correm. Com a crescente digitalização, foi criada a necessidade de investir em ferramentas e soluções capazes de responder às necessidades dos consumidores. Como resultado, fomos introduzidos a uma nova geração de tecnologias: os Robots Colaborativos. Estes, por sua vez, têm como objetivo combinar as qualidades de cada interveniente: robot e trabalhador; e criar um espaço comum seguro onde ambos possam realizar as suas tarefas ao mesmo tempo, colaborando um com o outro.

O objetivo do presente estudo é averiguar quais as barreiras que as empresas encontram ao implementar os robots colaborativos. Adicionalmente, pretende-se entender quais os desenvolvimentos necessários para ser possível superar essas mesmas barreiras.

Palavras chave: Industry 4.0; Collaborative Robots; CoBots; Barriers; Developments.

1. Introduction

The world has been adapting to the different inventions and technologies throughout its existence. It impacted both individuals and businesses. The Industry sector is no different. Since the steam machines' appearance in the 18th century, the Industry sector has been progressively growing and adapting to new technologies and discoveries in science (Belvedere, Grando, and Bielli, 2013).

In more recent years, a drastic evolution has been registered as a result of the introduction of new generation technologies such as Robotics, Big Data, 3D printing, Collaborative Robots, among others. These technologies have been powering the development of a new digital paradigm (Ferreira, Faria, Azevedo and Marques, 2016). The Industry 4.0. (I4.0) was triggered by the internet, allowing an easy communication between humans and machines, marking the beginning of the Fourth Industrial Revolution (Brettel, Friederichsen, Keller and Rosenberg, 2014). We live an era where everything is digital and interconnected (Alcácer and Cruz-Machado, 2019). The focus became a higher level of automatization in order to achieve a greater level of productivity and efficiency (Alcácer and Cruz-Machado, 2019; Peruzzini, Grandi, and Pellicciari, 2017). This production system allows an individualized and customized production, adapting to the customer requirements (Rojko, 2017).

According to Nagy, Oláh, Erdei, Máté and Popp (2018) with the accelerated digitalization, companies progressively invest in tools and solutions to respond to the customer's needs which can lead to a significant impact in manufacturing industries. Inventory, logistics and material handling costs, lead times and shortages are some key areas that are impacted by the digital technologies.

Companies may hold on the decision whether to join or not the fourth industrial revolution (Nagy et al., 2018). However, it is only a matter of time to be mandatory to introduce new technologies in their business if they want to stay competitive in the market, mainly in some industries such as automotive and electronics (Nagy et al., 2018). Overall, the investments have been increasing towards I4.0 technologies (Nagy et al., 2018).

One of the priorities of Industry 4.0. is to accelerate the automation and develop collaborative industrial robots (Li, 2018). While in the past the usage of robots meant a clear separation between their workspace and the human workspace, it becomes more important to create a collaborative and non-independent one. This allows a combination of the different skills that each intervenient has to offer (Robla-Gómez, Becerra, Llata, Gonzalez-Sarabia, Torre-Ferrero, and Perez-Oria, 2017). The robots collaborating with human workers, known as CoBots, may lead to an increase of quality and productivity, as well as safety (Cherubini, Passama, Crosnier, Lasnier and Fraisse, 2016).

In the past few years, the interest in collaborative robots has been increasing, taking forward the idea of combining both robots' endurance and strength with humans' flexibility and problem-solving capabilities (Aaltonen and Salmi, 2019).

Despite certain manufacturers have progressively introduced this kind of robots into their human production line (Cherubini et al., 2016), it is still not clear the challenges, difficulties and limitations the company faces throughout the process.

The focus of this master thesis is to understand which challenges and limitations companies face when they start implementing one of the Industry 4.0 key technology - Collaborative Robots -, and the problems they encounter during the adaptation process. Authors such as Kildal, Tellaeche, Fernández and Maurtua (2018) and Aaltonen and Salmi (2019) have studied the barriers companies face when they implement CoBots. There are also other studies that searched the barriers developers find in the design stage for collaborative robots (Villani, Pini, Leali and Secchi, 2018; Zhang and Fang, 2017; Ranz, Hummel and Sihn, 2018). This dissertation intends to understand the different barriers companies face considering the different stages, from design to usage, and the developments needed to overcome such challenges, distinguishing from the studies that already exist on this topic. An insight into the different constraints' companies face will be provided, allowing them to be elucidated about what they may encounter, and to have a wider understanding about it. With that being said, the following research questions will be answered:

R1: What are the main barriers to implement Collaborative Robots?

In order to answer this question, questionnaires will be sent out. The participants will be people with knowledge on CoBots, based on the company they work and/or their personal experience while working with collaborative robots.

The present study is divided into 5 sections, begging with the Literature Review to introduce some important concepts and similar studies already developed. This chapter will be followed by the methodology used to elaborate the study. Afterwards, it will be presented with the results provided by the utilized methods and, at last, the conclusions as well as the main limitations and future research.

2. Literature Review

This chapter will start by briefly describing the Industry 4.0 background (section 2.1), followed by the description of Collaborative Robots (section 2.2), one of the I4.0 technologies. Inside this last section, there will be a literature review on the Enablers/Advantages and Disablers/Disadvantages (section 2.2.1) and impacts of CoBots (section 2.2.2). At last, similar studies (section 2.3) will be presented.

2.1. Industry 4.0 background

An Industrial Revolution has a great impact in the manufacturing and production methods, including the working practices, caused by the technological advances and improvements (Müller and Voigt 2018). The three initial revolutions began with different key factors. The first occurred from the introduction of heavy mechanical manufacturing machines alongside with the buildout of the steam engine, witnessing the emergence of mechanization. The following one focused on steel production and electricity usage, resulting in the development of the combustion engine and mass production. The third Industrial Revolution used electronics and information technology to achieve a high-level of automation in production processes (Barreto, Amaral, and Pereira, 2017).

The current and fourth revolution, known as Industry 4.0, was originated in 2011 at the Hanover Fair in Germany where the German government developed a project supporting the automation and intelligent monitoring usage in manufacturing processes in order to reduce costs and increase competitiveness (Skilton and Hovsepian, 2017). Amid the purpose of connecting both physical and virtual domains, this new revolution comprehends the progression of information and communication technologies (ICTs) and data storage, as well as the increasing products' customization and the added value to the customer (Leyh, Martin, and Schäffer, 2017; Nascimento, Alencastro, Quelhas, Caiado, Garza-Reyes, Rocha-Lona, and Tortorella, 2019).

According to Frank, Dalenogare and Ayala (2019), pp. 15, "Industry 4.0 relies on the adoption of digital technologies to gather data in real time and to analyze it, providing useful information to the manufacturing system". The main characteristic associated with the fourth revolution is the high level of digitalization in the process that allows real-time interconnection along the different stages of the supply chain. This permits a more efficient usage of the organizational processes into the creation of goods and services that enhance customer benefits (Müller and Voigt, 2018; Barreto et al.,2017).

With the integration of intelligent and automated methods, Industry 4.0 showed numerous business benefits regarding the operational and value chain optimization, through the production evolvement of smart and adaptive methods (Alcácer and Cruz-machado 2019; Cezarino, Liboni, Stefanelli, Oliveira and Stocco 2019).

Base technologies such as the internet of things, cloud computing, big data and analytics support Front-end technologies like Smart Manufacturing, Smart Supply Chain, Smart Working and Smart Products (Frank et al., 2019).

Industry 4.0 wishes to accelerate the automation and advance towards collaborative industrial robots, a key technology within this Industrial Revolution (Li, 2018).

2.2. CoBots

During the last century, significant developments of automation in industry rose above different human limitations (Maurice, 2015). Robotic systems are used in highly repetitive and precise assignments, designed to do tasks that humans cannot do in an environment and conditions that may not be suitable for the workers (Djuric, Urbanic and Rickli, 2016). However, as of today, not all tasks can be fully automated due to costs, unpredictability and/or technicality but also because of the need of human expertise in, for example, customization (Maurice, 2015).

Throughout the years there has been a growing interest in CoBots, short term for Collaborative Robots (Schou, Andersen, Chrysostomou, Bøgh and Madsen, 2018) The main goal of this technology is to allow a close collaboration between human and robot, in both service and industrial tasks, in order combine the worker's skills such as expertise, decision making and adaptability with the robots' high performance like accuracy, speed, repeatability and payload (Cherubini et al., 2016; Maurice, 2015). The combination of the benefits of both human and robot performances leads to the development of the human-robot collaboration (Charalambous, Fletcher and Webb, 2015). Moreover, the strategy is to develop a workspace for a safe collaboration between the two parts, to create an interaction between human and robot by exchanging information among them (Vysocky and Novak, 2016; Papanastasiou, Kousi, Karagiannis, Gkournelos, Papavasileiou, Dimoulas, Baris, Koukas, Michalos and

Makris, 2019). The target is also to design and determine a communication criterion, so that the robot can understand the intentions and necessities of the human throughout the distinctive stages of the collaborative task (Ajoudani, Zanchettin, Ivaldi, Albu-Schäffer, Kosuge and Khatib, 2018).

CoBots are considered as a practical industrial solution with the potential to become standard in production systems (Djuric et al., 2016). This technology is a trend in the area of industrial and service robotics as a part of the Industry 4.0 strategy (Vysocky and Novak, 2016).

2.2.1. Enablers/Advantages and Disablers/Disadvantages

The possibility to use collaborative robots is among the greatest advantages of employing an Industry 4.0 system (Bragança, Costa, Castellucci, and Arezes, 2019). One of the most common usage is the replacement or assistance to the physical work previously attributed to an employee (Kleindienst, Wolf, Ramsauer, and Pammer, 2016; Bragança et al., 2019). Likewise, they can be used to create prohibited regions or suitable routes to perform the task efficiently (Bragança et al., 2019).

CoBots can generate multiple advantages by balancing the ergonomic problems that arise due to physical and cognitive loading with the safety, quality and efficiency improvement (Cherubini et al., 2016). There is a need for a more advanced collaboration between humans and ergonomic tools (Cherubini et al., 2016). The usage of collaborative robots, a more flexible and agile manufacturing equipment, can address the growing number of musculoskeletal disorders (physical problems) in industry, by allowing a joint operation between robots and workers to create a more dynamic environment (Maurice, 2015; Schou et al., 2018).

As a support for the worker, it can be distinguished in physical work where the robot can assist with tasks that require a great amount of strength and prevent injuries or it can also be used to automate the process by adapting different aspects that may be a restriction for the worker, such as mobility, repeatability, visualization and hearing (Kleindienst et al., 2016); and it can also be a support of the cognitive work for a more knowledge intensive work as the example of reducing biased decisions due to the visualization of alternative decisions and information storage (Kleindienst et al., 2016).

The progress in operation efficiency, the innovation, progresses in physical and intellectual ergonomics, new assembly processes and reduced assembly time, lower level of monotony, better quality and flexibility are considered reasons for the implementation of collaborative robots (Aaltonen and Salmi, 2019).

Although the previous factors enable the usage of CoBots, there are also some risks associated with this implementation (Bragança et al., 2019). Companies may be reluctant to adopt CoBots due to the payback period (Aaltonen and Salmi, 2019). Adding to it, an incompatibility can arise from the collaboration, making it not feasible. As the robot has a higher reaction time when compared to the human, it can get quite frustrating for the worker because the machine cannot respond to the rapid approach. (Khalid, Kirisci, Ghrairi, Thoben, and Pannek, 2017). Besides, the worker can misuse the system and obstruct the workspace intended for the robot.

2.2.2. Impacts of adopting CoBots

The introduction of human-robot collaboration in production lines intends to improve productivity as well as the product quality (Charalambous et al., 2015). If implemented successfully it can also increase the production output and reduce production costs (Charalambous et al., 2015). The increase of competitiveness is also a reason why new manufacturing technologies are implemented (Charalambous et al., 2015; Charalambous, Fletcher and Webb, 2017).

Taking into consideration a study carried by Kildal et al (2018), it is believed that the hypothetical adoption of CoBots was expected to be positive for the company in different aspects. Most of the respondents thought the productivity quality, competitiveness, safety and working conditions would improve with the adoption of the collaborative robots. On the downside, jobs were a concerning aspect as the participants believed they would be negatively impacted by this (Kildal et al, 2018).

With the allocation of tasks that require a more physical aspect to the CoBots, injuries and fatigue can be prevented on the worker's side, by also reducing the physical stress associated with those kinds of chores (Pearce, Mutlu, Shah and Radwin, 2018).

2.3. Similar Studies: challenges and limitations

The current section reviews similar studies that explore what are the barriers companies face when designing or implementing CoBots. An investigation on different authors was carried and, in Table 1, it is possible to see what they conclude to be the challenges.

Author, Year	Phase	Type of Challenge	Challenges
Villani et al, 2018	Design	Operational	Safe Interaction
			Intuitive Interfaces
			Design Methods
Zhang and Fang, 2017	Cell Design	Operational	Proper configuration for task
			Manual operation skill learning and translation
			Collaborative design toolchain
			Cell layout optimization and scheduling
			Optimal tooling design
Kildal et al, 2018	Implementation	Operational	Safety
		Financial	Cost
		Human Resources	Training
			Lack of Knowledge
			Workers' Acceptance
		Legal	Legislation
Ranz et al, 2017	Design	Operational	Task allocation between human and robot
Charalambous et al., 2015	Implementation	Human Resources	Workers' Acceptance
Aaltonen and Salmi, 2019	Implementation	Operational	Safety
			Inability to meet human skills
			CoBot's technical properties
			Lack of system integrators
			Difficulties in deployment
		Financial	Costs
		Human Resources	Lack of Knowledge
			Training
			Workers' Acceptance
		Legal	Legislation

Table 1 - Barriers of implementing CoBots

The implementation of new technologies leads to an organizational change, where challenges rise not only from a technical and production perspective but also from a human side (Charalambous et al., 2015; Charalambous et al., 2017).

Implementing this technology requires an effective usage and acceptance by the worker. It is important to pay attention to the human element, otherwise it can become a major barrier to the successful implementation of CoBots (Charalambous et al., 2015). Previously, robots and workers had two separate workspaces (Robla-Gómez et al., 2017), but with the increasing collaboration between them and the share of a common space leads to the overall safety of the employee as a priority in the industrial plant (Khalid et al., 2017). According to Villani et al. (2018), when designing a collaboration between humans and robots, the main concern and challenge to be tackled first is the safety of this interaction. Furthermore, it is important the robot programming system is properly designed and intuitive so that operators can easily interact with the new "peers". This will enable the worker to be more focused on his task instead of concerning how to interact and communicate with the robot (Villani et al., 2018). Adding to it, the exchange of information should be suitable to enable the intervention in dynamic and unpredicted situations (Villani et al., 2018). Citing Villani et al (2018), pp. 250, "Achieving these goals requires that proper design methods should be addressed, which means control laws, sensors and task allocation and planning approaches, that allow the human operator to safely stand close to the robot, actively sharing the working area and tasks and providing the interaction system with the required flexibility."

Another challenge when implementing a CoBot is how to distribute the workload among the two parties. Understanding where the human can be replaced by the robot, keeping the first one as a need for complex assembly operations, so that more repetitive and ergonomic tasks can be passed to the robot (Malik and Bilberg, 2019).

When designing the cell, the most significant aspect is to assure human safety (Zhang and Fang, 2017). Nevertheless, as studied by Zhang and Fang (2017), there are some challenges to obtain an optimal robotic solution. Beginning with the selection of the proper robot for the operation, where different attributes are taken into consideration such as cost, load capability, maximum speed, among others, creating a wide range of possibilities depending on the application intended for the robot. Another challenge is the translation of the manual job into an automatic/robotized solution, meaning that when designing the cell and the operating parameters, the tasks performed by humans need to be converted into a programmed task done by a robot, creating also the necessity for the robot to learn from the human. Adding to it, the collaborative design toolchain should have a clear communication channel between different function extensions. However, the current dilemma is that this implementation still requires numerous low-level activities to share tools, models and information. It is usually necessary to rebuild the virtual environment repetitively after any design changes. An optimal cycle time should be created by design with an optimal scheduling as it mostly represents productivity. It is important to analyze and test, to take into consideration different aspects to create the ideal solution that enhances the effectiveness of the collaborative work. Besides the space itself, the robot must be developed to maximize the robotic cell productivity. Still, designing a trustworthy and cost-efficient tool, capable of imitating the flexibility of the human movements and senses, is a huge task (Zhang and Fang, 2017).

Zhang and Fang (2017), pp. 2921, conclude that three factors should be taken into consideration when designing the collaborative robot cell: "risk assessment on the collaboration safety, optimized task distribution, human–robot interaction and adaptive control."

All the previously mentioned challenges refer to the CoBot design. After that stage and starting with the implementation, the concerns are different.

According to a study carried by Kildal et al. (2018), the barriers in the adoption of CoBots can diverge between two potential users of collaborative robots in industry: professionals from industry and students in vocational training. Both groups believe that costs, legislation, training, safety, lack of knowledge and workers' acceptance are the main barriers for the technology. However, the importance that each of them attributes to the difficulties varies (Kildal et al., 2018). The lack of knowledge is the main concern for the companies whereas students believe costs is the main impediment to implement the I 4.0 technology. However, the industry also sees this last factor as an important factor that can constrain the implementation process (Kildal et al., 2018).

A similar study was carried by Aaltonen and Salmi (2019), where they analyzed the replies of two different groups: the "experts" – people well informed about CoBots and know robotics; "less knowledgeable" – people that have a reasonable knowledge about robotics and have heard about CoBots. The main difference between the two lays on the fact that "experts" predict less barriers than the "less knowledgeable". The results showed that lack of knowledge was perceived as a major barrier. Besides that, some other concerns as the consciousness of risks and safety regulations amongst end-users, preconceptions against CoBots and the lack of courage of trying new applications were mentioned. CoBot's technical properties, legislation, lack of integrators, safety, inability to meet human skills, and costs create the rest of barriers considered by the interviewees. Although most respondents do not consider training, workers' acceptance, and difficulties in deployment as a barrier, those who do consider give them a high importance. Moreover, developments mentioned as needed for

CoBots were new ways of allocating work between human workers and CoBots and safety technology (Aaltonen and Salmi, 2019).

As previously mentioned, the implementation of new technologies leads to organizational changes. Such changes can be in the social environment, leading to an uncertainty among the employees, which can be translated in a lack of acceptance from the workers, creating a barrier to the success of the process and leading to failure. Reasoning from this fact, it is important to take into consideration the human factor as it can be a great challenge by creating higher levels of stress and deterioration of job satisfaction (Charalambous et al., 2015).

3. Methodology

The current study intends to analyze the barriers companies face when implementing collaborative robots and how those difficulties can be lessened.

This chapter aims to describe and explain the research methodology used throughout the execution of this study.

Scientific research can be qualified as quantitative, qualitative or mixed (Oliveira and Ferreira, 2014). With that being said, we can reveal that our study features a quantitative research. In section 3.1. it will be presented methodological aspects of similar studies. The following section 3.2. describes in what quantitative research consists. Section 3.3. shows the research hypotheses that the study will confirm or refute and section 3.4. will describe the used method to answer those same hypotheses, which is the questionnaire.

3.1. Methodological aspects of similar studies

In Table 2, it is presented the methodological aspects each study has used. It is possible to see that two of them used the literature review to understand what the barriers were while the used survey and complemented the study with an additional method. However, the ones that used surveys, only analyzed the data through a descriptive analysis and with that came to some conclusions. In the current study, it was opted to also use a survey to understand the barriers of CoBots but the statistical analysis will go further than just a descriptive analysis.

Author	Country	Sample Size	Industrial Sector	Data Collection	Response Rate (%)	Statistical Analysis
Villani et al., 2018	N/A	N/A	N/A	Literature Review	N/A	Qualitative Analysis
Zhang and Fang, 2017	N/A	N/A	N/A	Literature Review	N/A	Qualitative Analysis
Charalambous et al., 2015	United Kingdom	12	Aerospace	Interview		Qualitative Analysis
Kildal et al., 2018	N/A	51 professionals from industry 38 students	N/A	Workshop and Survey	63,57%	Descriptive Analysis
Ranz et al., 2017	N/A	15 robot manufacturers 14 system integrators 5 companies	N/A	Survey and Interview	N/A	Descriptive Analysis
Aaltonen and Salmi, 2019	Finland	75	Multiple	Survey	23%	Descriptive Analysis

Table 2 - Research method in similar studies

3.2. Quantitative Research

According to Aliaga and Gunderson (2000), quantitative research is "explaining phenomena by collecting numerical data that are analyzed using mathematically based methods (in particular statistics)". This method considers that all data is quantifiable, even if it does not naturally appear in quantitative form. This allows the measurement of opinions, habits, attitudes and reactions through a statistical sample that represents the researched universe (Freitas and Jabbour, 2011; Reis, 2010). It creates the possibility to generalize the sample findings through the interaction of variables, events' shape and outcomes to a broader group (Newman, Benz and Ridenour, 1998; Winter, 2000; Antwi and Hamza, 2015).

Quantitative research focuses on hypotheses and theory testing through empirical data (Antwi and Hamza, 2015). The current research intends to confront those research hypotheses. In the following section, the research hypotheses will be presented.

3.3. Research Hypotheses

The research hypotheses are propositions that aim to express the anticipation of results or consequences of a certain phenomenon. Once formulated, they must be tested (Martins and Theóphilo, 2009).

Below, it is possible to find the research hypotheses that were raised during the literature review process, which we now describe.

The lack of understanding of collaborative robots is seen as the most significant barrier among studies such as Aaltonen and Salmi (2019) and Kildal et al. (2018). Our aim is to understand if, comparing all barriers already studied, the lack of knowledge is the biggest barrier companies face when adopting CoBots. With that, the following research hypothesis was formulated:

H1: The Human Resources factor lack of knowledge is the most significant barrier among industry professionals.

The determination of task allocation between humans and robots of the planning phase was considered one of the biggest challenges in the implementation according to Ranz et al. (2017). This task is a challenge even for experienced people in the area of robotics technology. Robots and humans have unique aptitudes, but they also have overlapping capabilities, it is important to adapt the collaboration between them according other variables like costs, time and quality, for example (Ranz et al., 2017). In order to understand if this perception goes according to our study, the following hypothesis was formulated:

H2: Determine the task allocation between humans and robot, an operation design factor, is one of the biggest planning challenges.

As humans and robots work together, the first aspect to take into consideration is how safe the interaction will be for the human. With collaborative robots, the fences between both will disappear so the direct contact between the intervenient must be done in a safe manner, being a requirement for a Human-Robot collaboration (Villani et al., 2018; Kildal et al., 2018). According to Villani et al. (2018), pp. 249, "(…) safety issues are the primary main challenge that must be tackled (…)". To understand if the current study perceives it the same way, the resulting research hypothesis was framed:

H3: The operational user factor worker's safety is the main challenge when adopting a CoBot. OpU1 versus todos

Having an optimal tool design is a big challenge. Having a reliable and cost-efficient robot that can perform the task according to the needs will influence the productivity. In order to create an optimal cell layout design and according to Zhang and Fang (2017). The following hypothesis was formulated in order to understand if the barrier is as big as Zhang and Fang (2017) consider when compared to the other barriers:

H4: Creating an optimal tooling design is a massive challenge.

According to Aaltonen and Salmi (2019) research, new ways of allocating work between humans and robots is the most emphasized development need. It is perceived that the level of collaboration between both sides is still low, so creating new collaborative tasks should be a focus area (Aaltonen and Salmi, 2019). Based on this study, the below hypothesis was created:

H5: New ways of allocating work between human workers and CoBots was the most highlighted development need.

Usually, companies from different sizes face different challenges. An exploratory research hypothesis was created to understand if there is a difference between the importance small and micro companies give to the barriers versus to what medium and large companies range as big or small barriers.

H6: The perception of the importance of barrier depends on the size of the company.

Adding it, it was decided to understand if there is a different awareness of barriers if the company has or not a collaborative robot. As their experience is different, there could be a different opinion on the level of each barrier. So, the following hypothesis will be tested:

H7: The perception of the importance of barriers depends on whether the company has CoBots or not.

3.4. Data collection

Quantitative research is strongly associated with survey techniques (Brannen, 2017). For this study, the investigation method considered most appropriate was the questionnaire, which will allow us to confirm or refute the research hypotheses.

The questionnaire is a measuring tool that transforms the objectives of the study with quantifiable variables and helps to consolidate and standardize the data so that the information sought can be collected in a rigorous approach (Fortin, 2009)

The types of measurements in a questionnaire can be categorized into objective and subjective. Objective measures are associated with facts, individuals' characteristics, their knowledge and behavior. Subjective measures refer to what people think, feel, the judgments they make and the level of satisfaction, opinion, values and intentions of behavior (Freixo, 2011)

The questionnaire was based on studies similar presented throughout the literature review (see Section 2). The survey was structured with the aim of obtaining an answer to various research hypotheses that were raised during the process of reviewing the existing studies. The questionnaire comprises 9 sections, with a total of 27 questions of multiple-choice questions and free text comment fields. In the first section of the questionnaire, the purpose is to validate the respondent's willingness to participate in the study and their understanding of the consequences of doing it. The section 2 consists of 6 questions aiming to understand the background information about the participant, like demographic facts such as age, gender and nationality as well as their academic background. Adding to it, some questions were made to understand the knowledge and role regarding collaborative robots which can be found through sections 3 and 4, among 5 different questions. Section 5 and 6 comprise 8 questions with the purpose of understanding the company where que respondent works and the level of adoption, they have of CoBots. Section 7 showed different barriers found through the literature review that should be classified from 0 to 5 if they were considered a barrier or not (being 5 the highest rate which means very large barrier and 1 the lowest rate, meaning very low barrier; the classification 0 was meant for those that may not know or do not find it applicable). In Section 8 they had to choose what they believe to be the three most important between the barriers previously shown. Lastly, the section 9 presents different developments' needs, also selected through the literature review, where the participant had to select those he found to be necessary to overcome the barriers mentioned throughout the survey.

The Table 2 shows the detailed structure of the questionnaire, the purpose of each section and the studies that inspired those questions.

In order to get replies from different nationalities, the language used in the survey was the English. Google Forms was the platform used to create the form and LinkedIn was the main social network to get in contact with possible respondents. The target population of the study were people who had knowledge about collaborative robots and/or Industry 4.0. The selection was mainly based on their job description.

During the process, 216 people were contacted through LinkedIn where 30 responded to the questionnaire, which means a response rate of approximately 13,9%. In the next section, the population that responded to the questionnaire will be analyzed as well as their responses.

Section 1 - Consent		
1.1. I agree to participate in this study, confirming that I was informed about the conditions of the study and that I have no doubts.	Have the participant consent in being part of the study	
Section 2 - Demographic Information		
2.1. Gender	Understand who is replying to the survey	
2.2. Age		
2.3. Nationality		
2.4. Level of Education		
2.5. Field of Education		
2.6. Professional Activity		
Section 3 - Knowledge about CoBots		
3.1. Have you heard about CoBots?	Understand the knowledge of the person replying to the questionnaire regarding CoBots	Aaltonen and Salmi, 2019; Türkeş, Oncioiu, Aslam, Marin-Pantelescu, Topor and Căpuşneanu, 2019
3.2. Do you know what CoBots are?		
3.3. Have you ever worked with CoBots?		
3.4. My role in working with CoBots (example: programmer, user)		
3.5. For how long have you been working with CoBots? (in months)		

Section 4 - Company		
4.1. Industry 4.2. Size of the company 4.3. Does the company have CoBots? 4.4. How many CoBots does the company has? 4.5. Since when does the company have CoBots? (year) 4.6. Does the company plan on acquiring more CoBots? 4.7. What is the application of the CoBots in the company?	Understand the company the person works in and the level of adoption of CoBots; Besides that, in what activity is the CoBot used.	Kildal et al., 2018
Section 5 - Barriers of CoBots		
5.1. Human Resources Lack of knowledge Worker's training Workers' acceptance Fear of job losses 5.2. Operational Design/Development Lack of system integrators Design Methods Proper configuration for a task Collaborative design toolchain Cell layout optimization and scheduling Security (data exchange) Task allocation between human and robot Optimal tooling design Difficulty in selecting the right robot Direct work with humans Workers' safety Inability to meet human skills CoBot's technical properties Manual operation skill learning and translation Dependency on other technologies Communication between humans and robots Intuitive interfaces 5.3. Legal Civil Law rules in Robots Ethnical Perpective Safety Legislation Lack of clear laws Bureaucracy 5.4. Financial Acquisition Costs Maintenance Costs Fixed Costs Variable Costs Lack of financial resources Lack of government support	Understand what the participants feel as a barrier in the adoption of CoBots » rating them from 1 (very small) to 5 (very large), and 0 in case it is unknown or not applicable	Aaltonen and Salmi, 2019; Kildal et al., 2018; Villani et al., 2018; Zhang and Fang, 2017; Ranz et al., 2017
Section 6 - Barriers of CoBots		
6.1. Define 3 most important barriers of CoBots	Understand what the most important/biggest barriers are	

Section 7 - Developments need		
7.1. Select the options you consider to be necessary developments to overcome the barriers of CoBots	Understand what the necessary developments in order are to overcome the barriers mentioned throughout the survey	Aaltonen and Salmi, 2019
New ways of allocating work		
Safety technology		
Mobile robot cells		
Programming methods		
Design methods for safety		
Utilization of machine vision		
Utilization of artificial intelligence		
New kinds of interfaces (gestures, speech)		
Flexibility of material handling devices		
Mobility		
Developing performance (speed, accuracy)		
Comprehensive solutions taking advantage of the best of robots and humans		
Integration, process and interpretation of raw data from different sensors		
Retraining and reskilling (or uptraining) workers		
Greater communication between employees and managment		
Government programs that support this type of innovation		

Table 3 - Questionnaire sections

4. Discussion

In this chapter, the results obtained through the surveys are described and evaluated. Firstly, in section 4.1 a descriptive analysis of the responses to the questionnaire will be done. In Section 4.2. we proceed to the empirical validation of the raised research hypotheses. Lastly, in section 4.3. the main results are discussed and in section 4.4. the theoretical and practical implications.

4.1. Descriptive Analysis

As mentioned in the previous section, the questionnaire was delivered to 216 people and the response rate was 13,9%, which means 30 answers.

In order to understand who replied to the questionnaire, a descriptive analysis of the participants will be provided.

Demographically, out of all participants, 93,3% belong to the male gender whereas only 6,7% belong to the female gender. Moreover, the average age of the respondents is approximately 36 years old, being the maximum is 56 and the minimum 22 years old. When it comes to the nationality of the individuals, there is a great diversity considering 17 different nationalities from 3 different continents, which enriches the study since the similar studies like Aaltonen and Salmi (2019) do not provide such diversity. Nevertheless, the most prominent continent is Europe, concentrating 63,3% of the replies, followed by Asia (30%) and Americas (6,7%). Related to education, the level that stands out between the contributors is the master's degree, whereas the field is Mechanical Engineering. The professional activity is quite diverse, not being able to highlight one. However, it is possible to say that most of them are related to the engineering department.

An important aspect to comprehend if the participants could respond to the questionnaire is the knowledge on CoBots they have. Through the responses, it is possible to conclude that all participants have heard about and know what CoBots are, but only 83,3% have worked with them. It was given the option to the participants to select their role working with CoBots, it could be more than one. Among them, the most common role is robot programmer and system designer (15 out of 30 have that role). The average time they have worked with CoBots is 29,4 months.

Furthermore, the questionnaire intended to understand the company the participants work for and their level of adoption of CoBots.

Firstly, the approach was related to information about the industry they belong to, the size and the location. Taking into consideration the industry, the responses are very diverse, going from robotics and automation to health, aerospace, automotive, textile and shoes, among others. Taking into consideration the companies' size, 33,3% of the participants work in a large company, followed by 26,7% who work in a small company, then 23,3% work in a micro company and, finally, 16,7% work in a medium-sized company. Once again, the companies' site is quite diverse as it happens with the nationality of the participants. The number of different countries is 17. The continent that concentrates the highest percentage is Europe, weighting 70%, followed by Asia (20%) and the Americas (10%).

Secondly, the approach focused on understanding the level of adoption of CoBots companies have. Out of the 30 responses, 23 confirm the company they currently work for has CoBots. Among those, the quantity is a little dispersed, while some have only one, others have more than 200, which is a big difference. However, 18 companies have between 1 and 10 robots. The year of adoption does not go further than 2010, so all of them CoBots were acquired in the last 10 years. When looking into the role the CoBot takes within the company, most companies use it for more than one application, highlighting Material handling, Packaging and palletizing, Quality inspection and Assembly, where at least half of the companies use the CoBot for that purpose. Some other tasks such as welding, screwing and drilling were mentioned but at a lower level. Concluding the analysis about this topic, 73,9% intend to acquire more collaborative robots, 4,4% do not think the company has intentions of acquiring more CoBots and 21,7% do not know where the company stands on that matter.

The barriers faced during the implementation of collaborative robots were divided into sections: Human resources; Operational factor development and design; Operational usage factor; Legal; Financial. In Table 4, it is possible to find the main statistic description of all barriers. Within those categories, the companies' financial factor of acquisition costs is considered the largest barriers, with a mean of 3,4, which goes against what literature perceive as being the biggest barrier, which according to Ranz et al. (2017) is the lack of knowledge. After that, we can find the Lack of financial resources (mean = 3,07) and safety legislation (mean = 3,00). Ethnical perspective (mean = 1,47), Civil Law rules in Robots (mean = 1,53) and risk of Data Security problems (mean = 1,77) are considered to be the smallest barriers.

Besides safety legislation, we can conclude that the remaining factors on legal section are unknown or not applicable as a barrier to many participants.

		Mean	Median	Mode	Standard Deviation	Kurtosis	Min	Max
Human Resources	HR1 Lack of workers' knowledge	2,37	2,00	2	1,43	-0,79	0	5
	HR2 Need for workers' training	2,57	2,00	2	1,45	-0,75	0	5
	HR3 Lack of workers' acceptance	2,80	3,00	2	1,61	-0,84	0	5
	HR4 Fear of job losses	2,63	3,00	3	1,50	-0,69	0	5
Operational - Design/Development	OpD1 Lack of system integrators	1,93	1,50	1	1,64	-0,80	0	5
	OpD2 Lack of appropriate design methods	2,43	2,00	2	1,57	-1,04	0	5
	OpD3 Difficulty in creating an optimal tooling design	2,60	2,50	2	1,43	-0,81	0	5
	OpD4 Difficulty in creating a proper configuration for a task	2,53	2,50	2	1,53	-0,82	0	5
	OpD5 Difficulty in creating a collaborative design toolchain	2,30	2,00	2	1,49	-0,64	0	5
	OpD6 Difficulty in creating a cell layout optimization and scheduling	2,27	2,00	2	1,39	-1,14	0	4
	OpD7 Risk of Data Security problems	1,77	1,00	1	1,52	-0,47	0	5
	OpD8 Difficulty in task allocation between human and robot	2,10	2,00	1	1,47	-0,74	0	5
	OpD9 Difficulty in selecting the right robot	1,90	2,00	1	1,37	0,09	0	5
Operational - Usage	OpU1 Risk of workers' safety	2,53	2,50	1	1,61	-1,52	0	5
	OpU2 Inability to meet human skills	2,63	2,50	1	1,65	-1,24	0	5
	OpU3 CoBot's technical properties	2,63	2,50	2	1,52	-0,68	0	5
	OpU4 Manual operation skill learning and translation	2,50	3,00	4	1,48	-1,02	0	5
	OpU5 Dependency on other technologies	2,73	3,00	4	1,57	-1,16	0	5
	OpU6 Difficult communication between humans and robots	2,33	2,00	1	1,35	-0,78	0	5
	OpU7 Lack of intuitive interfaces	2,63	3,00	1	1,59	-1,30	0	5
Legal	L1 Civil Law rules in Robots	1,53	1,00	0	1,55	-1,17	0	4
	L2 Ethnical Perspective	1,47	1,50	2	1,20	-0,49	0	4
	L3 Safety Legislation	3,00	3,00	4	1,53	-0,87	0	5
	L4 Lack of clear laws	1,97	2,00	0	1,56	-1,20	0	5
	L5 Bureaucracy	1,90	2,00	2	1,56	-0,75	0	5
Financial	F1 Acquisition Costs	3,40	3,00	3	1,25	-1,25	1	5
	F2 Maintenance Costs	2,23	2,00	2	1,25	-0,65	0	5
	F3 Fixed Costs	2,27	2,00	2	1,44	-0,67	0	5
	F4 Variable Costs	2,00	2,00	2	1,20	-0,79	0	4
	F5 Lack of financial resources	3,07	3,00	3	1,39	-0,61	0	5
	F6 Lack of government support	2,53	3,00	3	1,48	-0,60	0	5

Table 4 - Descriptive analysis of CoBots' barriers

In Table 5, it is presented the mean of each barriers by company size and also by adoption. Between company sizes, it is possible to highlight two barriers small and micro companies find to be smaller than large and medium-sized companies: Lack of appropriate design methods (mean large and medium = 3,00; mean small and micro = 1,87) and Difficulty in creating a collaborative design toolchain (mean large and medium = 2,87; mean small and micro = 1,73). However overall, large and medium companies find legal factor to be larger barriers than the small and micro companies. Regarding the differences between adoption or not, the variance in opinions is not as evident. Nevertheless, companies that do not have CoBots consider that Lack of system integrators (mean Yes = 1,56; mean No = 2,86) and Lack of appropriate design methods a bigger barrier than companies who have CoBots (mean Yes = 2,09; mean No = 3,57).

		All	Company Size		Adoption of CoBots	
			Micro & Small	Medium & Large	Yes	No
Human Resources	HR1 Lack of workers' knowledge	2,37	2,47	2,27	2,30	2,57
	HR2 Need for workers' training	2,57	2,60	2,53	2,39	3,14
	HR3 Lack of workers' acceptance	2,80	2,73	2,87	2,74	3,00
	HR4 Fear of job losses	2,63	2,40	2,87	2,78	2,14
Operational - Design/Development	OpD1 Lack of system integrators	1,93	1,80	2,07	1,65	2,86
	OpD2 Lack of appropriate design methods	2,43	1,87	3,00	2,09	3,57
	OpD3 Difficulty in creating an optimal tooling design	2,60	2,13	3,07	2,39	3,29
	OpD4 Difficulty in creating a proper configuration for a task	2,53	2,13	2,93	2,39	3,00
	OpD5 Difficulty in creating a collaborative design toolchain	2,30	1,73	2,87	2,13	2,86
	OpD6 Difficulty in creating a cell layout optimization and scheduling	2,27	2,00	2,53	2,35	2,00
	OpD7 Risk of Data Security problems	1,77	1,80	1,73	1,52	2,57
	OpD8 Difficulty in task allocation between human and robot	2,10	2,40	1,80	2,09	2,14
	OpD9 Difficulty in selecting the right robot	1,90	1,93	1,87	1,78	2,29
Operational - Usage	OpU1 Risk of workers' safety	2,53	2,53	2,53	2,30	3,29
	OpU2 Inability to meet human skills	2,63	2,40	2,87	2,39	3,43
	OpU3 CoBot's technical properties	2,63	2,67	2,60	2,61	2,71
	OpU4 Manual operation skill learning and translation	2,50	2,40	2,60	2,39	2,86
	OpU5 Dependency on other technologies	2,73	2,47	3,00	2,57	3,29
	OpU6 Difficult communication between humans and robots	2,33	2,13	2,53	2,13	3,00
	OpU7 Lack of intuitive interfaces	2,63	2,20	3,07	2,52	3,00

Legal	L1 Civil Law rules in Robots	1,53	1,47	1,60	1,43	1,86
	L2 Ethnical Perspective	1,47	1,40	1,53	1,35	1,86
	L3 Safety Legislation	3,00	2,73	3,27	2,83	3,57
	L4 Lack of clear laws	1,97	1,67	2,27	1,78	2,57
	L5 Bureaucracy	1,90	1,67	2,13	1,78	2,29
Financial	F1 Acquisition Costs	3,40	3,47	3,33	3,48	3,14
	F2 Maintenance Costs	2,23	2,20	2,27	2,13	2,57
	F3 Fixed Costs	2,27	1,93	2,60	2,30	2,14
	F4 Variable Costs	2,00	1,73	2,27	2,04	1,86
	F5 Lack of financial resources	3,07	3,47	2,67	3,04	3,14
	F6 Lack of government support	2,53	2,80	2,27	2,61	2,29

Table 5 - Means of CoBots' barriers by company size and by adoption

The participants had to select what they considered to be the three most important barriers companies face when implementing collaborative robots. In Table 6 it is possible to see how many times each barrier was considered to be one of those barriers. When compared to the other barriers, the acquisition costs among the three most important barrier multiple times, 40,0% of the respondents believe it to be at least the third most important barrier. Furthermore, this same barrier was the most mentioned barrier as the most important barrier. The risk of workers’ safety is also among the most important barriers, where 8 out of 30 participants (26,67%) consider it to be on the Top3. Ethnical perspective, bureaucracy, maintenance and variable costs were not considered by any participant to be among the three most important barriers.

		Number of times in TOP3	**% of times in TOP3**
Human Resources	HR1 Lack of workers' knowledge	4	13,33%
	HR2 Need for workers' training	2	6,67%
	HR3 Lack of workers' acceptance	4	13,33%
	HR4 Fear of job losses	2	6,67%
Operational - Design/Development	OpD1 Lack of system integrators	2	6,67%
	OpD2 Lack of appropriate design methods	2	6,67%
	OpD3 Difficulty in creating an optimal tooling design	3	10,00%
	OpD4 Difficulty in creating a proper configuration for a task	4	13,33%
	OpD5 Difficulty in creating a collaborative design toolchain	3	10,00%
	OpD6 Difficulty in creating a cell layout optimization and scheduling	5	16,67%
	OpD7 Risk of Data Security problems	2	6,67%
	OpD8 Difficulty in task allocation between human and robot	2	6,67%
	OpD9 Difficulty in selecting the right robot	0	0,00%

Operational - Usage	OpU1 Risk of workers' safety	8	26,67%
	OpU2 Inability to meet human skills	5	16,67%
	OpU3 CoBot's technical properties	1	3,33%
	OpU4 Manual operation skill learning and translation	1	3,33%
	OpU5 Dependency on other technologies	2	6,67%
	OpU6 Difficult communication between humans and robots	1	3,33%
	OpU7 Lack of intuitive interfaces	3	10,00%
Legal	L1 Civil Law rules in Robots	4	13,33%
	L2 Ethnical Perspective	0	0,00%
	L3 Safety Legislation	3	10,00%
	L4 Lack of clear laws	1	3,33%
	L5 Bureaucracy	0	0,00%
Financial	F1 Acquisition Costs	12	40,00%
	F2 Maintenance Costs	0	0,00%
	F3 Fixed Costs	2	6,67%
	F4 Variable Costs	0	0,00%
	F5 Lack of financial resources	5	16,67%
	F6 Lack of government support	2	6,67%

Table 6 - Most important barriers

Taking into consideration the developments needed to overcome the barriers, the participants could select all the developments they felt necessary to overcome the barriers. In Table 5, it is possible to see how many times each development was selected. Out of all developments, it is possible to highlight new ways of allocating work and design methods for safety, where the first was selected by 46,67% of the participants to be one of the developments needed, which is the same conclusion as Aaltonen and Salmi (2019) have in their study . The second one is Design methods for safety with 40,0%. Right after that, it is possible to find Comprehensive solutions taking advantage of the best of robots and humans, Safety technology and Government programs that support this type of innovation with 36,67% of the participant considering them to be a development needed to overcome some barriers.

	Number of times selected	% of times selected
Dev_HR1 Retraining and reskilling (or uptraining) workers	8	26,67%
Dev_HR2 Communication between employees and management	6	20,00%
Dev_OpD1 New ways of allocating work	14	46,67%
Dev_OpD2 Programming methods	9	30,00%
Dev_OpD3 Design methods for safety	12	40,00%
Dev_OpD4 Utilization of artificial intelligence	9	30,00%
Dev_OpD5 Developing performance (speed, accuracy)	8	26,67%
Dev_OpD6 Comprehensive solutions taking advantage of the best of robots and humans	11	36,67%
Dev_OpD7 Integration, process and interpretation of raw data from different sensors	7	23,33%
Dev_OpU1 Safety technology	11	36,67%
Dev_OpU2 Mobile robot cells	7	23,33%
Dev_OpU3 Utilization of machine vision	9	30,00%
Dev_OpU4 New kinds of interfaces (gestures, speech)	9	30,00%
Dev_OpU5 Flexibility of material handling devices	7	23,33%
Dev_OpU6 Mobility	4	13,33%
Dev_F1 Government programs that support this type of innovation	11	36,67%

Table 7 - Developments needed to overcome barriers in CoBots implementation

4.2. Validation of research hypotheses

This section evaluates the research hypotheses that were raised during the literature review process. With the data collected by the questionnaires, we tested these same hypotheses, using the RStudio software.

Firstly, the option for non-parametric tests was dictated by the fact that the data are not normally distributed (completion of the Shapiro-Wilk test).

Before testing each defined research hypotheses (defined in Section 3.3), we tried to understand if there is any significant difference among the barriers within each group. Those groups are: Human Resources (HR1 to HR4), Operational – Development/Design (OpD1 to OpD9), Operational – Usage (OpU1 to OpU7), Legal (L1 to L5) and Financial (F1 to F6).

The appropriate test, according to Maroco (2018) is the Friedman, given that the barriers are factors where companies have to express their opinion on a 6-point scale of importance (ordinal variable) and it is intended to test whether there are differences in the choice of barriers by group, as mentioned before. Besides, data is not normally distributed which is another reason to choose this test. This works by testing the null hypothesis that there is no preference between k possible choices (in this case barriers), when these choices are marked on an ordinal scale. For example, for the Human Resources factor, the null hypothesis is that there is no preference between HR1, HR2, HR3 and HR4. The other ones are built in the same way. The results of the Friedman test performed for each group, are shown in Table 8.

Group	Chi-squared	p-value	Decision
Human Resources	2,8537	0,4147	Not Reject H0
Operational – Development/Design	19,076	0,0145	Reject H0 at 5%
Operational – Usage	3,9034	0,6897	Not Reject H0
Legal	37,713	1,284e-07	Reject H0 at 1%
Financial	41,676	6,849e-08	Reject H0 at 1%

Table 8 - Friedman test results

It is possible to conclude that for the Human Resources group and for the Operational – Usage group of barriers, there is no significative differences among the HR barriers and OpU barriers (p-value=0,4147 and p-value=0,6897, respectively). Consequently, in these two groups, there is no predominant barrier inside each one.

Regarding the Operational – Development/Design, there are significant differences between the barriers inside this group (OpD1 to OpD9) as the p-value is ≤5%. However, the Eisinga, Heskes, Pelzer and Grotenhuis (2017) test with Bonferroni correction, does not allow the identification of which pairs have significant differences. In Appendix 2, there is the result table from this test.

Finally, in both Legal and Financial groups there are significant differences between barriers in each group; both have a p-value≤1%. The Eisinga et al. (2017) test with Bonferroni correction, allows the identification of pairs with significant differences, shown in Table 9 for Legal group and in Table 10 for Financial group.

	L1	L2	L3	L4
L2	1,00000	-	-	-
L3	0,00016	7e-05	-	-
L4	0,94178	0,65954	0,12282	-
L5	1,00000	0,94178	0,05851	1,0000

Table 9 - Eisinga et al. (2017) test with Bonferroni correction p-value results for legal barriers

	F1	F2	F3	F4	F5
F2	0,00056	-	-	-	-
F3	0,00805	1,00000	-	-	-
F4	7,4E-06	1,00000	1,00000	-	-
F5	1,00000	0,03674	0,25231	0,00144	-
F6	0,04644	1,00000	1,00000	0,86202	0,86202

Table 10 - Eisinga et al. (2017) test with Bonferroni correction p-value results for financial barriers

Considering the results above, we can state that there is a significance level of ≤1% between different barriers. Safety Legislation (L3) (median = 3) is considered a bigger barrier than

Civil Law rules in Robots (L1) (median = 1) and Ethnical Perspective (L2) (median = 1,5). At a lower p-value≤10%, we can say that Safety Legislation (L3) is a larger barrier than Bureaucracy (L5) (median = 2). Among legal barriers, it is possible to conclude that Safety Legislation, in the Legal group of barriers, is the biggest for the surveyed companies.

At last, the p-values results for Financial barriers show that there are significant differences among them. At a significance value of ≤1%, it is possible to conclude that Acquisition Costs (F1) (median = 3) is a larger barrier than Maintenance Costs (F2) (median = 2), Fixed Costs (F3) (median = 2) and Variable Costs (F4) (median =2). Besides that, at the same significance level, we can identify Lack of Financial Resources (F5) (median = 3) as a bigger barrier than Variable Costs (F4) (median = 2). Among financial barriers, it is possible to conclude that Acquisition Costs, in the Financial group of barriers, is the biggest for the surveyed companies.

The first set of hypotheses comprehends those that refer to what the literature suggests as the biggest barriers for CoBots.

To analyze and test the hypotheses generated from the literature, we used Wilcoxon's non-parametric test, which allows us to assess whether there is evidence of statistically significant differences between the median of responses to each barrier and the median of responses to:

1. Lack of workers' knowledge (HR1) (H1)
2. Difficulty in creating an optimal tooling design (OpD3) (H2)
3. Difficulty in task allocation between human and robot (OpD8) (H3)
4. Risk of workers' safety (OpU1) (H4)

The Wilcoxon test was chosen because the sample is relatively small and the data is not normally distributed, and it is well-known that the Wilcoxon test is closely as efficient as its parametric counterpart even under normality.

Based on the test previously described, follows the results and interpretation of the results to each hypothesis.

H1: The Human Resources factor lack of knowledge is the most significant barrier among industry professionals.

For testing hypothesis 1, as mentioned before, the Wilcoxon test will be used, so it was defined the null hypothesis (H0) as *Lack of workers' knowledge (HR1) is not different than all other barriers, among industry professionals.*

In Table 11, it is shown the statistics from Wilcoxon test for n=30 and a p-value α ≤10%. The barriers that do not appear in the table were not included because all of them have a p-value higher than 10% and, consequently, the final decision is to not reject H0.

HR1 Lack of workers' knowledge *versus*	**W**	**p-value**	**Decision**
HR3 Lack of workers' acceptance	51	0,06833	Reject H0 at 10%
OpD7 Risk of Data Security problems	208,5	0,08944	Reject H0 at 10%
L1 Civil Law rules in Robots	265	0,06572	Reject H0 at 10%
L2 Ethnical Perspective	234,5	0,01391	Reject H0 at 5%
F1 Acquisition Costs	60,5	0,01007	Reject H0 at 5%
F5 Lack of financial resources	65	0,0448	Reject H0 at 5%

Table 11 - H1: Wilcoxon test results for rejected H0

With the results presented it is possible to conclude that there are barriers considered to be larger than the lack of knowledge at a significance level ≤10% and even at a significance level of ≤5%. Acquisition Costs (median = 3) and lack of financial resources (median = 3) are assumed to be larger barriers than Lack of workers' knowledge (median = 2), with a p-value ≤5%. Lack of workers' acceptance (median = 3) is also considered to be a bigger barrier but at a significance level ≤ 10%. This result is not in line with what is suggested by Ranz et al. (2017). However, since the null hypothesis considers that *Lack of workers' knowledge is not different than all other barriers, among industry professionals*, it is possible to state that there are also barriers considered to be smaller than the lack of knowledge. Risk of Data Security problems (median = 1), Civil Law rules in Robots (median = 1) and Ethnical Perspective (median = 1,5) are smaller barriers when compared to lack of knowledge, the first two at a significance level of ≤10% and the last one at a level of ≤5%. Although lack of knowledge is of the biggest barriers for the surveyed companies, it is not the biggest one according to our analysis, corroborating the results of Ranz et al. (2017).

H2: Determine the task allocation between humans and robot, an operation design factor, is one of the biggest planning challenges.

To test hypothesis 2, it was defined the null hypothesis (H0) as *Difficulty in task allocation between human and robot (OpD8) is not different than all other barriers.*

In Table 12, it is presented the statistics from Wilcoxon test for n=30 and α≤10%. The barriers that do not show up in the table, were not included because all of them have a p-value >10% and, therefore, the final decision is to not reject H0.

OpD8 Difficulty in task allocation between human and robot *versus*	W	p-value	Decision
HR3 Lack of workers' acceptance	83	0,05331	Reject H0 at 10%
L2 Ethnical Perspective	199,5	0,04894	Reject H0 at 5%
L3 Safety Legislation	31,5	0,005579	Reject H0 at 1%
F1 Acquisition Costs	35,5	0,0009902	Reject H0 at 1%
F5 Lack of financial resources	56,5	0,007224	Reject H0 at 1%

Table 12 - H2: Wilcoxon test results for rejected H0

As the previous hypothesis test, the results show that there are barriers considered to be larger than the difficulty in task allocation between human and robot. Safety Legislation (median = 3) and acquisition Costs (median = 3) and Lack of financial resources (median = 3) are assumed to be larger barriers than the difficulty in task allocation between human and robot (median = 2), at a significance level of ≤1%. Moreover, lack of workers' acceptance (median = 3) is also a bigger barrier than OpD8 but at a significance level of ≤10%. Besides that, Ethnical Perspective (median = 1,5) is considered a smaller barrier, with a p-value=0,04894. We can conclude that there is no barrier in the planning phase of CoBots statistically significant bigger than the difficulty in determine the task allocation between humans and robot.

H3: Creating an optimal tooling design is a massive challenge.

Before testing he hypothesis 4, it was defined the null hypothesis (H0) as *Difficulty in creating an optimal tooling design (OpD3) is not different than all other barriers.*

In Table 13, the statistics from Wilcoxon test for n=30 and α≤10%. The barriers that do not appear in the table are explained by the fact that the final decision was to not reject H0, with a p-value > 10%.

OpD3 Difficulty in creating an optimal tooling design *versus*	W	p-value	Decision
OpD1 Lack of system integrators	153	0,07326	Reject H0 at 10%
OpD7 Risk of Data Security problems	202,5	0,01232	Reject H0 at 5%
OpD9 Difficulty in selecting the right robot	143,5	0,05095	Reject H0 at 10%
L1 Civil Law rules in Robots	233	0,0175	Reject H0 at 5%
L2 Ethnical Perspective	205,5	0,00165	Reject H0 at 1%
L5 Bureaucracy	178	0,09503	Reject H0 at 10%
F1 Acquisition Costs	60,5	0,03154	Reject H0 at 5%

Table 13 - H4: Wilcoxon test results for rejected H0

The outcome confirms that Acquisition Costs (median = 3) is the only barriers considered to be bigger than the Difficulty in creating an optimal tooling design (median = 2,5), with a p-value ≤5%. The remaining six barriers in the table are considered to be reduced smaller barriers compared to the difficulty in creating an optimal tooling design, all with a significance level of at least <10%. In more detail, lack of system integrators and bureaucracy were rejected at the level of ≤10%; risk of data security problems and civil law rules in Robots at a level of ≤5%; finally, , difficulty in selecting the right robot and ethnical perspective at a level of ≤1%. Based on these results, it is possible to confirm that difficulty in creating an optimal tooling design is in fact a massive challenge, but not the biggest one.

H4: The operational user factor worker's safety is the main challenge when adopting a CoBot.

Before testing the hypothesis 4, it was defined the null hypothesis (H0) as *Risk of workers' safety is not different than all other barriers.*

Once again, in Table 14, it is presented the statistics from Wilcoxon test. The barriers that do not show up in the table is because the final decision was to not reject H0, with a p-value > 10%.

OpU1 Risk of workers' safety *versus*	**W**	**p-value**	**Decision**
OpD7 Risk of Data Security problems	168	0,01657	Reject H0 at 5%
OpD9 Difficulty in selecting the right robot	224	0,09529	Reject H0 at 10%
L1 Civil Law rules in Robots	129,5	0,01212	Reject H0 at 5%
L2 Ethnical Perspective	201	0,002627	Reject H0 at 1%
L3 Safety Legislation	64	0,06942	Reject H0 at 10%
F1 Acquisition Costs	130	0,0565	Reject H0 at 10%

Table 14 - H3: Wilcoxon test results for rejected H0

By analyzing the results, it is possible to conclude that there are barriers considered to be bigger than the Risk of workers' safety, with a p-value <0,10. Safety Legislation (median = 3) and acquisition Costs (median = 3) are the only barriers considered to be bigger than Risk of workers' safety (median = 2,50), with a significance level <10%. Risk of Data Security problems (median = 1,00) and Civil Law rules in Robots (median = 1,00) are all considered to be smaller barriers at a significance level ≤5% and difficulty in selecting the right robot (median = 2) is smaller at a level of ≤10%. At last, ethnical Perspective (median = 1,5) is a minor challenge compared to the risk of worker's safety at a service level of ≤ 1%.

After analyzing this set of hypotheses, we can conclude that acquisition costs are a bigger barrier compared to the barriers of CoBots considered by other studies, with a p-value ≤ 5%, only excluding risk of workers' safety, which the p-value is ≤10%.

The following hypothesis H5 takes into consideration a different test that will be explained below.

H5: New ways of allocating work between human workers and CoBots was the most highlighted development need.

To analyze and test the hypothesis generated from the literature, we used proportion difference test. As the test mentions, it will test if there is a difference in proportion between the development needs. It is a two-sided analysis since there were only two options (1 – selected; 0 – not selected)

Before testing the hypothesis 5, it was defined the null hypothesis (H0) as *New ways of allocating work between human workers and CoBots (Dev_OpD1) has an equal proportion as all other developments (Dev_HR1 to Dev_HR1, Dev_OpD2 to Dev_OpD7, Dev_OpU1 to Dev_OpU6, Dev_F1).*

In Table 15, it is shown the results of the test.

Results	X-squared	p-value	Decision
	15,001	0,4514	Not reject H0

Table 15 - H5: Proportion difference test results

Based on the results from the proportion test, H0 is not rejected. It is not possible to take any conclusion about the difference among the proportions of answers for each development needed, with a statistical significance of ≤10%. Nevertheless, as observed in Table 7 (included in section 4.1), the development 'New ways of allocating work' has the highest proportion of 46,67%, followed by 'Design methods for safety' with a proportion of 40%.

The following two exploratory hypotheses were tested based on the non-parametric Mann-Whitney test. This test allows to assess whether there is evidence of statistically significant differences between the medians of the companies in each of the groups. It will be used for the differences in barriers between:

1. Medium & large *versus* Micro & small (H6)
2. Adopted CoBots *versus* Has not adopted CoBots (H7)

H6: The perception of the importance of a barrier depends on the size of the company.

To test the hypothesis 6, it was defined the null hypothesis (H0) as *the perception of the importance of barrier does not depend on the size of the company.*

The company size is an information that surveyed participants provided on question #4.2.. 15 participants worked for medium and large companies and 15 worked for micro and small.

Table 16 refers to the results of the Mann-Whitney test. We opted to not include all the outputs of the test; just the ones that have a significant p-value at least 10%. Consequently, the barriers that do not show up in the table are the ones where the corresponding H0 is not rejected, with a p-value > 10%.

Analysis by cluster – company size						
Barriers	All companies median	Micro & Small	Medium & Large	W	p-value	Decision
OpD3 Difficulty in creating an optimal tooling design	2,50	2	3	71	0,08265	Reject H0 at 10%
F5 Lack of financial resources	3	3	3	152,5	0,09318	Reject H0 at 10%

Table 16 - H6: Mann-Whitney test results and median by company size

With the results shown in Table 16, it is possible to conclude that the barrier 'Difficulty in creating an optimal tooling design' is bigger for medium and large companies (m&s median = 2; m&l median = 3) when compared with the micro and small ones whereas 'Lack of financial resources' is a larger barrier for micro and small companies when compared to the other group. Both have a significance value of ≤10%.

H7: The perception of the importance of barriers depends on whether the company has CoBots or not.

In order to test the hypothesis 7, it was defined the null hypothesis (H0) as *the perception of the importance of a barrier does not depend on the company's CoBots adoption.*

The information about whether or not companies have adopted CoBots was provided by the survey participants when they replied to question #4.3. Based on those answers, 23 companies have adopted CoBots and 7 have not.

Table 17 refers to the results of the Mann-Whitney test concerning H7. We opted to not include all the outputs of the test; just the ones that have a significant p-value at least 10%. Consequently, the barriers that do not show up in the table are the ones where the corresponding H0 is not rejected, with a p-value > 10%.

Analysis by cluster – adoption of robots						
Barriers	All companies' medians	Yes	No	W	p-value	Decision
OpD1 Lack of system integrators	1,5	1	3	41,5	0,05331	Reject H0 at 10%
OpD2 Lack of appropriate design methods	2	2	4	37	0,03209	Reject H0 at 5%

Table 17 - H7: Mann-Whitney test results

The outcome confirms that both 'Lack of system integrators' ('yes' median = 1; 'no' median = 3) and barrier 'Lack of appropriate design methods' ('yes' median = 2; 'no' median = 4) are seen as bigger barriers of CoBots for companies who are yet to adopt CoBots. However the significance level is lower for the second barrier with p-value ≤5%, compared to the p-value≤10%.

We can conclude that barrier 'Difficulty in creating an optimal tooling design' is bigger for medium and large companies when compared with the micro and small ones whereas 'Lack of financial resources' is a larger barrier for micro and small companies when compared to the other group. This last result is expected because large companies have easier access to investment.

We can conclude that the barriers 'Lack of system integrators' and 'Lack of appropriate design methods' are larger barriers for companies who are yet to adopt CoBots. We may conclude that the experience has an impact on how they perceive the barriers.

4.3. Practical and theoretical implication

The current study complements the body of literature on this topic by providing an insight on the different barriers companies face when implementing CoBots. It also provides a perception on what developments' need this technology faces in order to reduce the challenges.

A highlight point about this study is the fact it is not based on one location but rather on multiple countries, which gives a broader vision on the topic. Adding to it, the majority of studies reviewed analyze the barriers on the design or development of the robot while this research intended to understand what the barriers throughout the whole process are.

The conclusions reached elucidate companies who want to adopt CoBots of the barriers they will face, also providing an understanding on the development's companies should focus to successfully implement CoBots. Companies will understand what the biggest barriers are but also what are the most important. As seen, the safety legislation is considered to be one of the largest barriers whereas risk of workers' safety one of the most important barriers. As a result, design methods for safety and safety technology have a direct impact on those barriers, being developments considered necessary that companies should take into consideration.

Another topic to have into consideration is how challenges vary according to the company size. With that, large and medium-sized companies will understand what barriers they face that small and micro companies do not in the same degree, the reverse is also true. It is possible to conclude that small and micro companies will face bigger challenges when it comes to the acquisition costs.

Summing up, companies aiming to adopt CoBots or already using it should:

1. invest in developing design methods for safety and safety technology for risk of workers' minimization;
2. research on new ways of allocating work;
3. develop solutions to take advantage of the best of robots and the best of humans.

Moreover, governments together with other Research & Development organizations should develop a strategic plan for supporting companies in:

1. programs for training and reskilling workers for dealing with CoBots;
2. promoting the utilization of artificial intelligence;
3. researching innovative technologies;
4. financial sponsoring as CoBots acquisition costs and other related costs are very high.

5. Conclusion

The industry sector has been evolving through the years, adapting to new technologies and findings, being currently in the Fourth Industrial Revolution (Belvedere et al., 2013). The investment concerning its technologies has been increasing and one of the priorities is to develop and advance towards collaborative industrial robots (Nagy et al., 2018; Li, 2018).

Challenges and barriers arise when a new technology in implemented in an organization, CoBots is no exception (Charalambous et al., 2015; Charalambous et al., 2017). The current study aimed to understand what those barriers and the developments needed to overcome then. In order to do that, a questionnaire was delivered to people who worked with or understood the topic.

After analyzing the answers, we can conclude that acquisition costs are the largest and most important barrier when implementing a CoBot. Nevertheless, new ways of allocating work between human workers and CoBots was the most stressed development need amongst the respondents.

The main limitation of this study was the low number of answers to the questionnaire. Having a bigger sample size could have generated could more accurate results. With that being said, the recommendation is to repeat this type of questionnaire to get a broader sample.

It would be interesting to focus on each phase of the implementation process, from the development to the usage of the CoBot. The barriers change depending on the stage or position a person occupies. During this study, it was not possible to differentiate and study the phases independently, it was a global study on the implementation of CoBots. However, the knowledge of the participants on each phase and their experience is not the same, which can lead to misleading results about the biggest barriers in implementing a CoBot. Adding to it, future research could focus on testing the exploratory research hypothesis presented in this study.

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Appendix

1. Questinnaire

Barriers of implementing cobots

Dear participant,

This survey is part of a research project developed within Master in Management at Faculty of Economics of the University of Porto. The study aims at understanding the barriers companies face when implementing Collaborative Robots (Cobots*).

The questionnaire is intended for people who know and have worked with Cobots.

There are no right or wrong answers, we appreciate honest answers. Total confidentiality and anonymity will be guaranteed during the entire data collection and treatment process. The information is for research purposes only and will be handled only by the team's investigators.

The questionnaire lasts around 7-8 minutes to be answered.

In the case of using a mobile device, be aware that all options may not appear on the screen, having to slide it to the left to be able to view it.

In case of doubt, please contact me at: up201600316@fep.up.pt

* Cobots, short term of Collaborative robots, are complex machines that work alongside with human beings. Contrary to the traditional industrial robots, both humans and Cobots share a work space.They support and relieve the human operator.

*Obrigatório

I agree to participate in this study, confirming that I was informed about the conditions of the study and that I have no doubts. *

- ◯ Yes
- ◯ No

Demographic Information

Gender *

- ◯ Female
- ◯ Male
- ◯ Prefer not to say

Age *

A sua resposta

Nationality *

- ◯ Danish
- ◯ French
- ◯ German
- ◯ Norwegian
- ◯ Polish
- ◯ Portuguese
- ◯ Romanian
- ◯ Spanish
- ◯ Swedish
- ◯ British
- ◯ American
- ◯ Outra:

Level of Education *

- ◯ High School
- ◯ Bachelor's Degree
- ◯ Master's Degree
- ◯ Doctoral's Degree
- ◯ Outra:

Field of Education *

A sua resposta

Professional Activity *

A sua resposta

Knowledge on Cobots

This section intends to understand the knowledge the participant has regarding Collaborative Robots.

Have you heard about Cobots? *

- ◯ Yes
- ◯ No

Do you know what Cobots are? *

- ◯ Yes
- ◯ No

Have you ever worked with Cobots? *

- ◯ Yes
- ◯ No

My role in working with Cobots

- ☐ Robot system designer
- ☐ Robot programmer
- ☐ End User
- ☐ Consultant
- ☐ Field Engineer
- ☐ Distributor
- ☐ System implementation
- ☐ Production manager
- ☐ Outra: ____________

For how long have you been working with Cobots? (in months)

A sua resposta

Company

This section intends to understand the company you work and the level of adoption of Cobots

Industry *

A sua resposta

Company Location *

- ○ Denmark
- ○ France
- ○ Germany
- ○ Norway
- ○ Poland
- ○ Portugal
- ○ Romania
- ○ Spain
- ○ Sweden
- ○ United Kingdom
- ○ United States of America
- ○ Outra: ______

Size of the Company *

- ○ Micro company: (< 10 workers) AND (Turnover ≤ 2 M OR Balance sheet total ≤ 2M)
- ○ Small Company: (<50 workers) AND (Turnover < 10 M OR Balance sheet total < 10 M)
- ○ Medium-sized company: (< 250 workers) AND (Turnover ≤ 50 M OR Balance sheet total ≤ 43M)
- ○ Large company: (≥ 250 workers) AND (Turnover > 50 M OR Balance sheet total > 43M)

Does the company have Cobots? *

- ◯ Yes
- ◯ No

How many Cobots does the company has? *

A sua resposta

Since when does the company have Cobots? (year) *

A sua resposta

Does the company plans on acquiring more Cobots? *

- ◯ Yes
- ◯ No
- ◯ Maybe

What is the application of the Cobots in the company? *

- ☐ Material handling
- ☐ Welding
- ☐ Assembly
- ☐ Packaging and Palletizing
- ☐ Quality Inspection
- ☐ Screwing
- ☐ Drilling
- ☐ Outra: ______

Barriers of Cobots

This section intends to understand what the participants feel as a barrier in the adoption of Cobots

Please evaluate each topic from very small barrier (1) to very large barrier (5). You also have the option Don't know/Not applicable (0) if you don't know or don't have the information about it.

Human Resources (HR) *

	0 (Don't know/Not applicable)	1 (Very small)	2	3	4	5 (Very large)
Lack of workers' knowledge	○	○	○	○	○	○
Need for workers' training	○	○	○	○	○	○
Lack of workers' acceptance	○	○	○	○	○	○
Fear of job losses	○	○	○	○	○	○

Financial (F) *

	0 (Don't know/Not applicable)	1 (Very small)	2	3	4	5 (Very large)
Acquisition Costs	○	○	○	○	○	○
Maintenance Costs	○	○	○	○	○	○
Fixed Costs	○	○	○	○	○	○
Variable Costs	○	○	○	○	○	○
Lack of financial resources	○	○	○	○	○	○
Lack of government support	○	○	○	○	○	○

Operational - Development/Design (Op - D) *

	0 (Don't know/Not applicable)	1 (Very small)	2	3	4	5 (Very large)
Lack of system integrators	○	○	○	○	○	○
Lack of appropriate design Methods	○	○	○	○	○	○
Difficulty in creating an optimal tooling design	○	○	○	○	○	○
Difficulty in creating a proper configuration for a task	○	○	○	○	○	○
Difficulty in creating a collaborative design tool-chain	○	○	○	○	○	○
Difficulty in creating a cell layout optimization and scheduling	○	○	○	○	○	○
Risk of Data Security problems	○	○	○	○	○	○
Difficulty in task allocation between human and robot	○	○	○	○	○	○
Difficulty in selecting the right robot	○	○	○	○	○	○

Operational - Usage (Op - U) *

	0 (Don't know/Not applicable)	1 (Very small)	2	3	4	5 (Very large)
Risk of workers' safety	○	○	○	○	○	○
Inability to meet human skills	○	○	○	○	○	○
Cobot's technical properties	○	○	○	○	○	○
Manual operation skill learning and translation	○	○	○	○	○	○
Dependency on other technologies	○	○	○	○	○	○
Difficult communication between humans and robots	○	○	○	○	○	○
Lack of intuitive interfaces	○	○	○	○	○	○

Legal (L) *

	0 (Don't know/Not applicable)	1 (Very small)	2	3	4	5 (Very large)
Civil Law rules in Robots	○	○	○	○	○	○
Ethnical Perspective	○	○	○	○	○	○
Safety Legislation	○	○	○	○	○	○
Lack of clear laws	○	○	○	○	○	○
Bureaucracy	○	○	○	○	○	○

Please select the 3 more important barriers of Cobots (select 1 barrier per column)

	Most important	2nd Most important	3rd Most important
Lack of workers' knowledge (RH)	☐	☐	☐
Need for worker's training (RH)	☐	☐	☐
Workers' acceptance (RH)	☐	☐	☐
Fear of job losses (RH)	☐	☐	☐
Lack of system integrators (Op - D)	☐	☐	☐
Lack of appropriate design Methods (Op - D)	☐	☐	☐
Difficulty in creating an optimal tooling design (Op - D)	☐	☐	☐
Difficulty in creating a proper configuration for a task (Op - D)	☐	☐	☐
Difficulty in creating a collaborative design tool-chain (Op - D)	☐	☐	☐
Difficulty in creating a cell layout optimization and scheduling (Op - D)	☐	☐	☐
Risk of Data Security problems (Op - D)	☐	☐	☐
Difficulty in task allocation between human and robot (Op - D)	☐	☐	☐
Difficulty in selecting the right robot (Op - D)	☐	☐	☐
Risk of workers' safety (Op - D)	☐	☐	☐

Inability to meet human skills (Op - U)	☐	☐	☐
Cobot's technical properties (Op - U)	☐	☐	☐
Manual operation skill learning and translation (Op - U)	☐	☐	☐
Dependency on other technologies (Op - U)	☐	☐	☐
Difficult communication between humans and robots (Op - U)	☐	☐	☐
Lack of intuitive interfaces (Op - U)	☐	☐	☐
Civil Law rules in Robots (L)	☐	☐	☐
Ethnical Perspective (L)	☐	☐	☐
Safety Legislation (L)	☐	☐	☐
Lack of clear laws (L)	☐	☐	☐
Bureaucracy (L)	☐	☐	☐
Acquisition Costs (F)	☐	☐	☐
Maintenance Costs (F)	☐	☐	☐
Fixed Costs (F)	☐	☐	☐
Variable Costs (F)	☐	☐	☐
Lack of financial resources (F)	☐	☐	☐
Lack of government support (F)	☐	☐	☐

Developments need

This section intends to understand what are the necessary developments in order to overcome the barriers mentioned throughout the survey.

Select the options you consider to be necessary developments to overcome the barriers of cobots *

- [ ] New ways of allocating work
- [ ] Safety technology
- [ ] Mobile robot cells
- [ ] Programming methods
- [ ] Design methods for safety
- [ ] Utilization of machine vision
- [ ] Utilization of artificial intelligence
- [ ] New kinds of interfaces (gestures, speech)
- [ ] Flexibility of material handling devices
- [ ] Mobility
- [ ] Developing performance (speed, accuracy)
- [ ] Comprehensive solutions taking advantage of the best of robots and humans
- [ ] Integration, process and interpretation of raw data from different sensors
- [ ] Retraining and reskilling (or uptraining) workers
- [ ] Communication between employees and management
- [ ] Government programs that support this type of innovation
- [ ] Outra: ____

2. Eisinga et al. (2017) with Bonferroni correction p-value results for operational – development/design barriers

	OpD1	OpD2	OpD3	OpD4	OpD5	OpD6	OpD7	OpD8
OpD2	1,00	-	-	-	-	-	-	-
OpD3	1,00	1,00	-	-	-	-	-	-
OpD4	1,00	1,00	1,00	-	-	-	-	-
OpD5	1,00	1,00	1,00	1,00	-	-	-	-
OpD6	1,00	1,00	1,00	1,00	1,00	-	-	-
OpD7	1,00	1,00	0,35	0,41	1,00	1,00	-	-
OpD8	1,00	1,00	1,00	1,00	1,00	1,00	1,00	-
OpD9	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

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