tourings

training for collaborative robotics integration

Analysis and Report on the European Situation of Collaborative Robotics in Manufacturing Sectors

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Abstract

The present report seeks to answer to the question: What are the current uses of collaborative robotics in the different European Union countries?

To answer to this question, the present report will first, analyse the current use of collaborative robotics in manufacturing sectors, worldwide and then focusing the attention on the European Union, to draw a parallel between the two tendencies, passing by the regulation provided by the ISO standards. Secondly, the report will examine the main advantages, disadvantages and challenges faced by the European companies while implementing or using collaborative robotics in their production line. Finally, the report will present the jobs and skills required for the use of collaborative robotics, analysed, together with the training and educational system in Europe.

This report is the result of the analysis of the information provided by 63 case studies identified in five different countries, 52 interviews and 36 national reports. Furthermore, this report has been reviewed and validated by 57 experts. By consequence, this report is not an exhaustive representation of the European Union situation in its use of collaborative robotics but tends to give the general tendencies of the collaborative robotics implementation and use in manufacturing companies and its reading can be adapted to both beginners and experts.

This report reveals a lack of skilled workforce as well for the use of collaborative robotics and is the base for the TOURINGS project, which will develop a training content within 2 years.

Summary

Figures' summary

Tables' summary

Appendices' summary

Other

Acknowledgements

Before getting into the issue, we must warmly thank all the people who have participated in the writing and the review of the present report making its delivery possible. Especially, we want to thank all the experts who have taken the time to answer our numerous questions and surveys in their busy agenda helping us to provide the most accomplished version of this report for you, readers.

To the readers, we hope that this report's reading will help you to better understand the current use of collaborative robotics and we thank you for reading this document, we wish you to enjoy it.

Thank you again,
The TOURINGS' team

Introduction

In popular imagination robots were something incredibly complicated and far from the everyday life. In the recent decades, they became a viable part of our workforce and nowadays, everybody is assisted by a robot. During the preparation of a dinner or while parking a car, robots are present assisting and helping in completing the tasks. Today robots can assemble, sort, select, package, etc., all kind of products. Therefore, the robotic area is getting more and more relevant in our society.

This report aims to present the "collaborative robotics" also known as "cobots", a specific area of robotics that is growing since 2008 when Universal robots[1] sold their first model. Before that year, the term "cobot" did not even exist. Unlike traditional industrial robots, collaborative robots are not placed behind guards or in cages: they can help the operator to perform his tasks, or it can perform tasks autonomously by working alongside him.

During the last decade, the use of collaborative robotics is more and more widespread in industry. **According to the numbers provided by the INRS[2], 3 million** collaborative robotics **are currently working worldwide**. This element underlines the fact that the use of collaborative robotics is more than a simple trend: currently they are **the most advanced robots for the industry**. By consequence, knowing what the current uses of collaborative robotics in industries are is the touchstone for the countries to evaluate their technological position at an international scale.

What is a cobot? The standard definition of collaborative robotics is given by the first article of the ISO 10218: "*The difference between collaborating robots (so-called cobots) and classical industrial robots is that they do not have to work behind a safety fence but enable direct cooperation with humans*". This definition is completed by the Technical Specification ISO/TS 15066 "*The objective of collaborative robots is to combine the repetitive performance of robots with the individual skills and ability of people. People have an excellent capability for solving imprecise exercises; robots exhibit precision, power and endurance*".

The present report focuses its attention on the European Union current use of collaborative robotics and aims to give an overview of cobots, which can be used by newcomers and/or more advanced knowledge persons to be aware of:

1. what is "collaborative robotics",
2. the current use of cobots worldwide in the manufacturing sector, with a specific focus on Europe,
3. the opportunities and challenges to face while putting in place collaborative robotics in production lines, as identified in Europe,
4. the jobs, competences required while putting in place collaborative robotics in production lines as identified in Europe.

To cover the point mentioned above, this document has been structured into three parts:

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[1] https://www.universal-robots.com/fr/%C3%A0-propos-duniversal-robots/actualit%C3%A9s-universal-robots/histoire-des-cobots/

[2] Institut National de recherche et de sécurité – A french state organization which works for the improvement of employees' health and security

- **Part 1:** analyses the current use of collaborative robotics in manufacturing sectors, first worldwide and then focusing on the European Union, in order to draw a parallel between the two tendencies, passing by the regulation provided by the ISO standards.
- **Part 2:** examines the main advantages and main disadvantages faced by the European companies while implementing collaborative robotics in their production line. Then this part will examine challenges faced (technical and related to human resources) by the companies during the installation of collaborative robotics in manufacturing sectors.
- **Part 3:** will present the jobs and skills required for the use of collaborative robotics, analysed together with the training and educational system in Europe.

The report has been written thanks to the collaboration among the Tourings partners coming from five different countries **(Estonia, France, Germany, Italy, Spain)** lead by French partners**.** The present report has been based on the information provided by 63 case studies identified in five different countries, 52 interviews (mainly conducted in Germany) and 36 national reports identified by the six partners in the five different countries. Furthermore, this report has been reviewed and validated by 57 experts.

1. The current use of Collaborative Robotics within Manufacturing Sectors (Europe and Worldwide)

Before digging deeper into this topic, it is important to present and define what collaborative robotics is. Then we will be able to present the current use of collaborative robotics through the European Union companies. To do so, and to provide a benchmark, the current use of collaborative robotics worldwide will be presented.

1.1 Definition and presentation of the Collaborative Robotics

1.1.1 Definitions

As seen in the introduction of this report, in 2008, the first “cobot” was sold by Universal robots[3] while the terminology of “cobots” did not even exist at that time. However, since this specific date, cobots have revolutionised the industry. The collaborative robotics area uses different terminologies such like “cobots”, “cobotics”, “cooperative robotics”, “robotic cell” and so on, as shown on the following **Figure 1**.

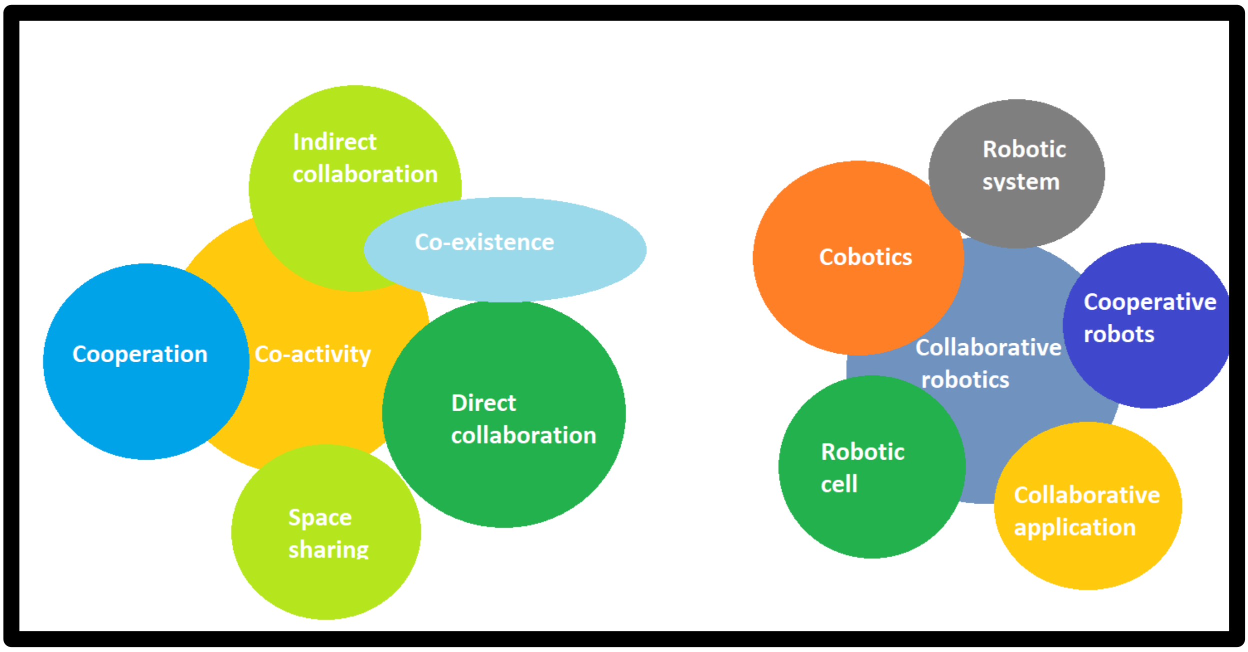


Figure 1. The different terminologies used by the collaborative robotics field[4]

As shown in the previous figure (**Figure 1**), the field of collaborative robotics presents a collection of terms. But fortunately, the ISO 10218 standard provides a precise definition of

[3] https://www.universal-robots.com/fr/%C3%A0-propos-duniversal-robots/actualit%C3%A9s-universal-robots/histoire-des-cobots/

[4] Translation of a presentation made by INRS Robots collaboratifs :l quels enjeux pour la prevention ? (04.06.2018)

collaborative robotics. Thanks to this work, the definition of collaborative robotics tends to be normalized. Concerning robotics, the ISO 10218 defines a **robot** as "a *manipulable arm, which is programmable destinated to be used in multiple different application cases. This robot might at least evolute on three axes and can be fix or mobile*". If the robot is used in an industrial environment, it is called "***industrial robot***". Then this industrial robot is completed by multiple equipment such as tools, axes, etc. In this way, it becomes an industrial robotic system. Finally, it is completed by some means of prevention which allow a safe use of the robot. The robot is isolated into a grid as shown in the next figure (**Figure 2**). By doing so, we get an industrial robotic cell. This robotic cell can either use traditional application as we know them since decades, or it can use collaborative applications. All those steps are summarised in the **Figure 2**.

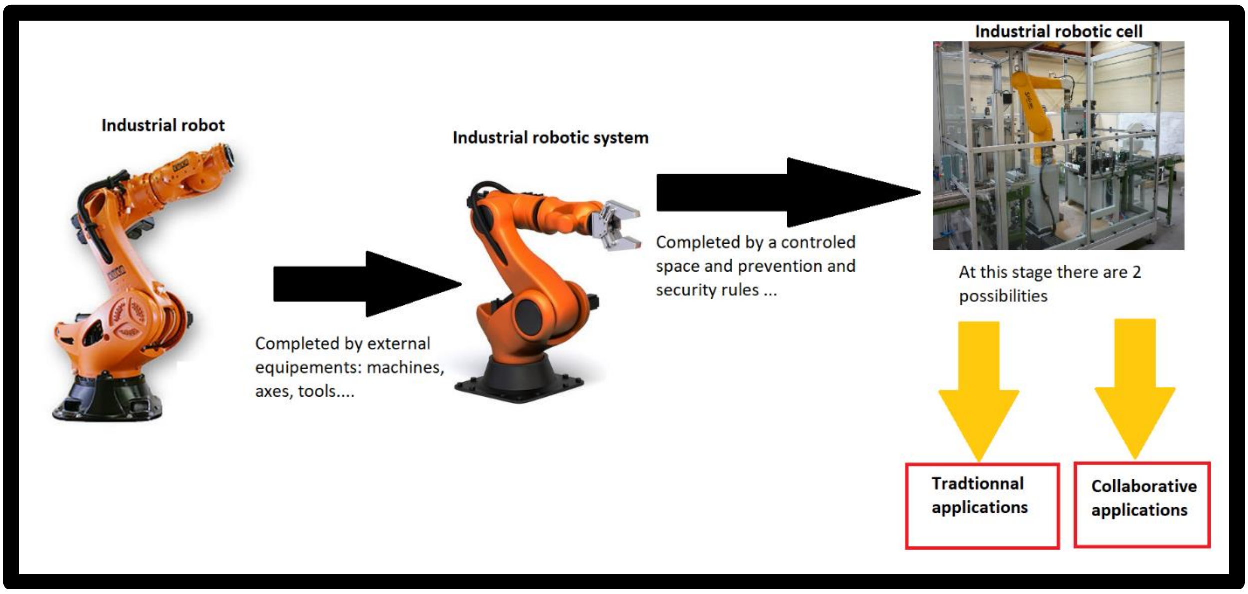


Figure 2. Steps to transform an industrial robot into an industrial robotic cell using collaborative applications[5]

Technological evolutions made it possible to go from traditional applications to collaborative applications. It is important to underline that the goal of collaborative robotics is to combine the human actions with the robot's one. Previously, working spaces were separated for the robot and the operator while **in the collaborative context, the robot and the operator share the same working space and work on same tasks at the same time**.

Coming back to the definition of collaborative robotics, the first article of the ISO norm 10218 emphasises the fact that: *"The difference between collaborating robots and classical industrial robots is that they do not have to work behind a safety fence but enable direct cooperation with humans*". This definition is completed by the ISO norm 15066 "*The objective of collaborative robots is to combine the repetitive performance of robots with the individual skills and ability of people. People have an excellent capability for solving imprecise exercises; robots exhibit precision, power and endurance*", by consequence explaining more precisely what collaborative robotics are, is relevant.

1.1.2 Four main types of interaction between collaborative robotics and workers

[5] Translated Figure from the webinar of INRS "*Robots collaboratifs : quels enjeux pour la prevention ?"* (04.06.2018)

Basically, there are four types of interactions that exist between a robot and a human, as shown on the following figure (**Figure 3**).

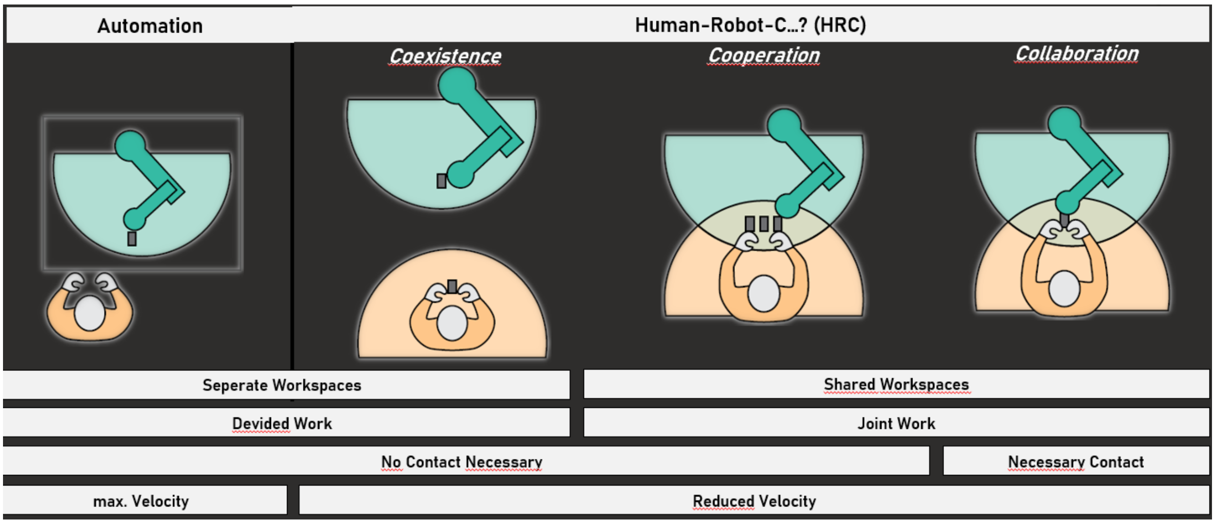


Figure 3. Different interactions between a human and a robot[6]

The previous figure (**Figure 3**) must be completed by the following table (**Table 1**) to be better understood.

Automation	With full automation no human robot collaboration (HRC, stands for Human Robot Collaboration and Human Robot Cooperation in this context) takes place. The robot is spatially separated from humans by a cell / safety fence. This scenario represents the classic safety fence operation, and the robot can act at full speed.
Coexistence	There is no physical separation (safety fence). The working spaces of humans and robots are separated and an interaction between robot and human does not take place in this scenario. Due to the lack of a safety fence, the robot may only act at reduced speed.
Cooperation	Humans and robots share a common workspace. The activity to be performed is coupled, but there is no contact between human and robot. Also, in this scenario the robot may only move with reduced speed.
Collaboration	This scenario is the closest form of interaction between humans and robots. In addition to the common workspace and the coupled work, the contact between humans and robots is necessary. To protect the human, the robot may only move at reduced speed also in this form of interaction. Furthermore, collaborative robotics are adapted to provoke a speed and force limitation when they get into contact with humans.

Table 1. **Chart explaining the different scenarios of human-robot interactions**

Thanks to the addition of the **Figure 3** and the **Table 1**, we can notice that the collaboration between the worker and the robot corresponds to an evolution trend. The collaboration between the human and the robot is in some ways the most advanced interaction system between the worker and the robot while the automation scenario is the first step for the robot industry.

[6] Based on Bauer (2016), Leichtbauroboter in der manuellen Montage – einfach einfach anfangen - Erste Erfahrungen von Anwenderunternehmen" und Otto und Zunke (2015) „Einsatzmöglichkeiten von Mensch-Roboter Kooperationen und sensitiven Automatisierungslösungen. Zukunft der Arbeit – Die neuen Roboter kommen"

1.1.3 Different places and uses in a production system

Those collaborative robotics can be placed at different moments:

- **On assembly lines**: screwing, gluing, welding.
- **On production lines**: polishing, laser marking, durability tests, packaging, palletisation.
- **On a machine**: inserting a part into a machine.
- **Pick-and-Place**: removal of parts from a container and placement on a tray.
- **Easy applications**: moving of a part by the collaborative robotics and termination of the process by the human.

The most popular application areas for collaborative robotics are[7]:

- **Pick and place:** the robot moves apart from the output of one process to the input of another. For example, it could grab parts from a bin and arrange them in order on a tray.
- **Machine tending:** the robot moves parts in and out of a machine for processing. While the robot loads and unloads the part, human operators are free to work on other tasks.
- **Assembly:** the robot performs simple part-assembly tasks that require little dexterity. Conversely, assembly tasks that require high dexterity are a perfect fit for human-robot collaboration: the robot can perform the simplest assembly tasks, then moves parts into an area where the human operator can finish the assembly process.
- **Packaging and palletising:** the collaborative robotics can also perform other lightweight applications. The robot performs basic packaging, finishing, gluing, etc.
- **Quality inspection:** the robot loads products into a quality testing machine and removes them once testing is complete.

By consequence, collaborative robotics can do most of the tasks that humans do, if they do not require great dexterity.

1.1.4 Examples of use of collaborative robotics

Before presenting examples of use of collaborative robotics, we have to underline the fact that collaborative robotics are not destined to replace the traditional conventional robots, they are compatible with their work and only propose alternatives to specific tasks.

To provide a wider view of the application areas in which the collaborative robotics are used, the following sub-part will focus on the examples of use of the collaborative robots in the most popular applications in which they are implemented.

1.1.4.1 *Pick and place*

Manual pick and place jobs require a lot of repetition, it implies that those workers often find their job mundane. When people must perform dull, routine jobs, mistakes often come up, and repetitive motions can inflict workers with strains and injuries. When they are combined with advanced vision systems, collaborative robotics can perform pick and place tasks more efficiently, allowing humans to focus on the parts of their job that require critical thinking. The following figure (**Figure 4**) shows a situation in which a collaborative robot is used to pick and place products.

[7] Those application areas will be better presented in the following sub-part of the report

Co-funded by the Erasmus+ Programme of the European Union

Legend:
Vision system

Figure 4. Pick and place operation with machine vision system

1.1.4.2 *CNC machine tending*

Machine tending is one of those tasks that is ideally suited to collaborative robot-powered automation. Dull, often dirty, and sometimes dangerous, it is unsurprising that over recent years machine tending has emerged as one of the most popular applications for collaborative robotics. Automating machine tending tasks with collaborative robotics also provides important benefits to workers. Cobots' built-in safety systems eliminate the need for caging after risk assessment. And managing collaborative robotics, rather than tending CNC, injection molding and press brake machines, for example, increases worker satisfaction and value. A use of collaborative robotics in machine tending case is represented in the following figure (**Figure 5**).

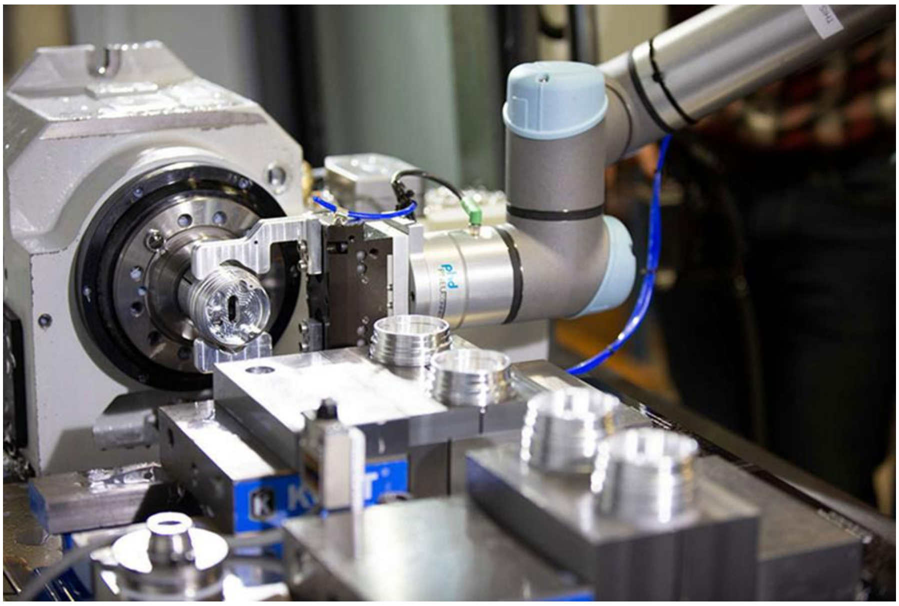


Figure 5. A CNC machine tending with cobot using a mechanical gripper

1.1.4.3 *Assembly*

Assembly is the process of putting together the parts of a machine or structure. collaborative robotics applications are commonly used in assembly tasks because:

- Using collaborative robots allows to automate screw and nut driving tasks, by consequence it provides several benefits (analysed in the second part of this report).
- collaborative robotics can reposition their tools more quickly and accurately than human workers, which means an increase in both production and quality.
- Advancing in force-sensing allows collaborative robotics to 'feel' when tightening is complete, eliminating the problem of over application of torque, which happens all too often when screw driving tasks are manually performed.

The following figure (**Figure 6**) presents the use of a collaborative robotics in an assembly application.

Figure 6. Picture of a collaboration between a worker and a cobot in assembly process

1.1.4.4 *Packaging and palletising*

Products that leave the assembly line must be prepared for shipping. To keep the production line moving, products must be moved to the shipping floor as quickly as possible. Some tasks involved in the process include shrink-wrapping, boxing and placing products on a pallet; tasks often viewed as very repetitive and tedious for workers. In this case, collaborative robotics are also good candidates for performing heavy lifting tasks, relieving humans of potentially dangerous work.

Figure 7. Picture of a collaborative robotics in a packaging and palletising application [8]

1.1.4.5 *Quality inspection*

Businesses and consumers demand that products are shipped without factory defects, but inspection is sometimes tiresome for workers. Potential mental fatigue can cause inspectors to miss problems, but collaborative robotics can inspect finished parts by comparing images against CAD models[9]. Multiple high-resolution cameras can capture all angles of a part simultaneously for even faster results, and end effectors equipped with high-resolution cameras further increase efficiency, as shown on the following figure **(Figure 8).**

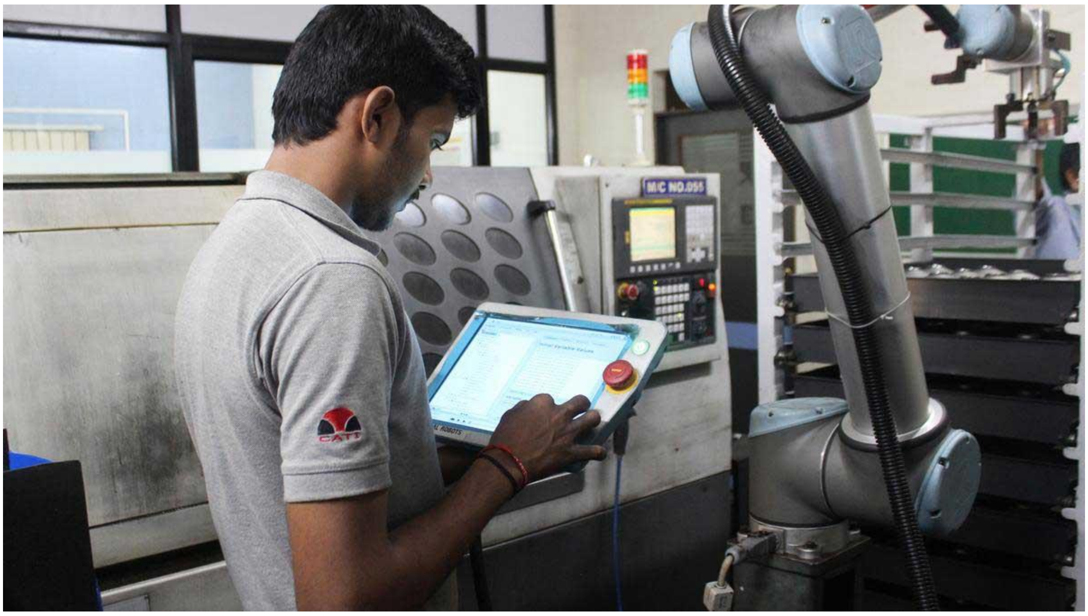


Figure 8. Picture of a cobot being used in a quality inspection application [10]

[8] Cobot produced by the brand Clearpack being used in a packaging application.

[9] CAD stands for Computer Aided Design. CAD brings together the software and geometric modeling techniques that make it possible to design, virtually test and produce manufactured products.

[10] collaborative robotics produced by the Brand Universal Robot being used to inspect the quality of the products.

By consequence, we can affirm that collaborative robotics can be used in many different areas of application ranging from the simple packaging task to the quality inspection. collaborative robotics are therefore, very flexible and adaptable in function of the tasks to perform.

1.1.6 The importance of standards

Finally, we will see later in this report that the collaborative robotics area is ruled by different standards to ensure safety. Those standards are:

- DIN EN ISO 12100 for the safety of machinery, general principles for design, risk assessment and risk reduction,
- DIN EN ISO 10218-1 concerns the safety requirements for industrial robots (in its Part 1. Robots),
- DIN EN ISO 10218-1 linked to the safety requirements for industrial robots, part 2 is dedicated to robot systems and integration,
- and the DIN ISO/TS 15066 which is specifically dedicated to robots and robotic devices - collaborating robots

To conclude this presentation of the collaborative robotics, we can highlight that cobots, or collaborative robots, are robots intended for direct human robot interaction within a shared space, or where humans and robots are in close proximity. Cobot applications contrast with traditional industrial robot applications in which robots are isolated from human contact.[11] Cobot safety may rely on lightweight construction materials, rounded edges, and inherent limitation of speed and force, or on sensors and software that ensures safe behavior. [12] [13]

[11] “I, Cobot: Future collaboration of man and machine" The Manufacturer (2015-11-15). Retrieved on 2016-01-19

[12] https://ifr.org/downloads/papers/IFR_Demystifying_Collaborative_Robots.pdf

[13] ISO 10218-1:2011, ISO 10218-2:2011, ISO/TS 15066:2015

1.2 Overview of the current use worldwide and in Europe

1.2.1 Current use worldwide

1.2.1.1 Density of use of collaborative robotics at a worldwide scale

Even after checking that the use of collaborative robotics in the industry is more and more important at a worldwide scale, as shown on the following figure (**Figure 10**), we may notice that the countries and continents have undergone different growth levels of their use and equipment of collaborative robotics. In 2020, there is an overall estimation of **3 million of industrial** collaborative robotics **being used** worldwide[14]. And following the previsions, this tendency will keep on increasing as shown on the following figure (**Figure 9**).

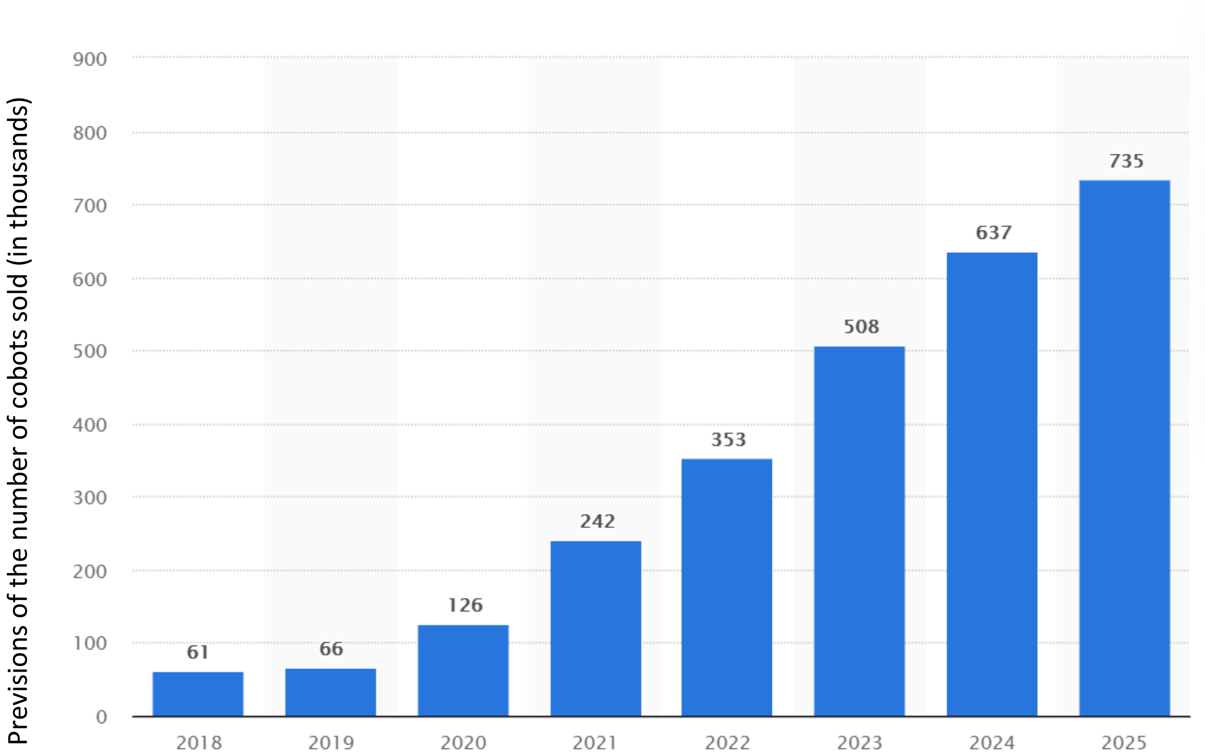


Figure 9. Sells previsions of collaborative robotics between 2018 and 2025[15] at a worldwide scale

As shown on the previous figure, sell estimations are exponential for collaborative robotics for industry and other areas of activity. Therefore, in the following section we will learn how those industrial collaborative robotics are distributed following the continent or the country that uses them or even the sector of use. The following table (**Table 2**) presents the quantity of collaborative robotics used from 2013 to 2019 per continent.

[14] webinar of INRS "*Robots collaboratifs : quels enjeux pour la prévention?"* (04.06.2018)
[15] https://fr.statista.com/statistiques/1022275/cobots-ventes-prevues-monde/

Geographical region	2013	2014	2019[16]
America	**226 071**	**248 430**	**377 400**
Northern America (Canada, Mexico, United-States)	215 817	236 891	362 100
Asia/ Australia	**689 349**	**785 028**	**1 164 000**
Europe	**392 227**	**411 062**	**580 000**
Total worldwide	**1 332 218**	**1 480 778**	**2 162 900**

** Estimated and recorded quantity of collaborative robotics which were not affected to specific countries (e.g., spaces not politically recognised as "countries")

Table 2. **Quantity of industrial collaborative robotics used following by continent** [16]

Based on the previous table (**Table 2**) we can notice that Asia was the first user of collaborative robotics in 2013, followed by the European Union using three times fewer collaborative robotics in industry. In order to resume this fact, the following map (**Figure 10**) provides a visualisation of the situation of the use of collaborative robotics in 2014.

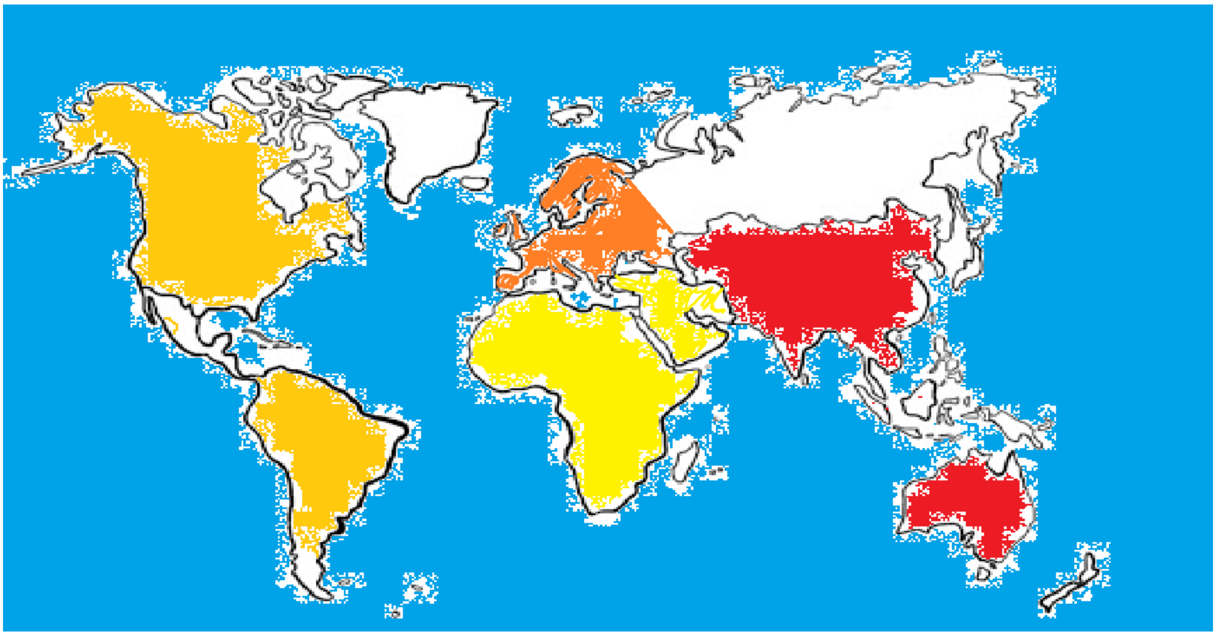


Figure 10. Map resuming the use of collaborative robotics in industries in 2014 worldwide

Legend of the map
• Red: countries with the most important number of operational robots
• Orange: countries where the number of robots is medium
• Yellow: countries where the number of robots is low
• White: countries for which the data available data is insufficient

[16] https://ifr.org/downloads/press/French_Press_Release_IFR_World_Robotics_Report_2017-09-27.pdf

Based on **Figure 10,** we can represent the growth trend of use of collaborative robotics in the industry following the continent. The following figure (**Figure 11**) allows us to evaluate the different growth trends and the gap between continents about their use of collaborative robotics in the industry.

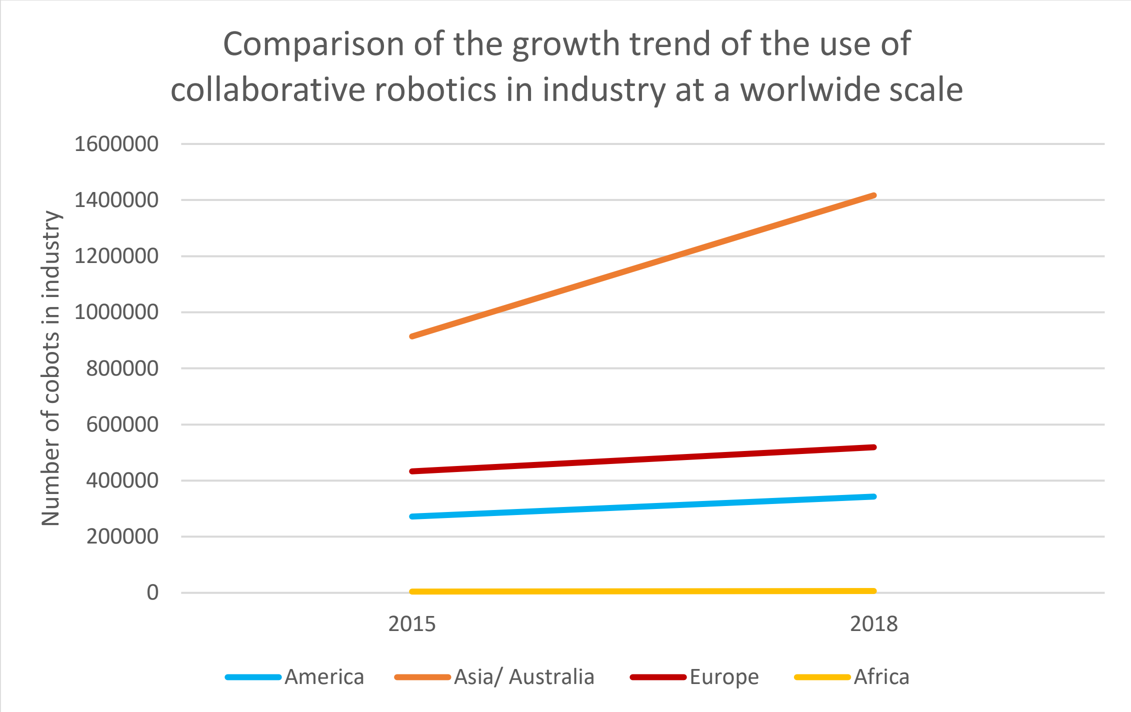


Figure 11. Graph presenting the number of collaborative robotics per continent and the growth trend of their use per continent[17]

Based on the previous figure (**Figure 11**), we can evaluate the general trend of use of the collaborative robotics between continents and analyse the gap existing between the continents. As we can see on this figure, there are huge gaps between all those continents. We can notice that Asia and Australia are the most equipped continent of the world using more than one million of collaborative robotics while Africa only uses 6 500 collaborative robotics units. By looking at the graph we may also notice that this trend will not diminish, the gaps between the most equipped (Asia/Australia) and the less equipped one (Africa) will widen in the next few years if the trend progresses in the same proportions.

The growth rate percentage of use of collaborative robotics in Asia and Australia is higher than 55% since 2015, this rate in America is about 27%, in Europe is lower than 20% and in Africa is about 44%; however, even if the African growth rate is high, this continent seems to be too late to be able to catch up with the progress shown by other continents. If we elaborate this thought, we may notice that: if the growth trend of those continents remains steady in those proportions during the next few years, Asia will solidify as the first user of collaborative robotics in the world in 2036 and America will use more collaborative robotics than European Union countries as presented on the following figure (**Figure 12**) which represents the estimated quantities of collaborative robotics sold in the next decades if the growth rate stays the same.

[17] Based on the information provided by the **Figure 11** available at: https://ifr.org/downloads/press/French_Press_Release_IFR_World_Robotics_Report_2017-09-27.pdf

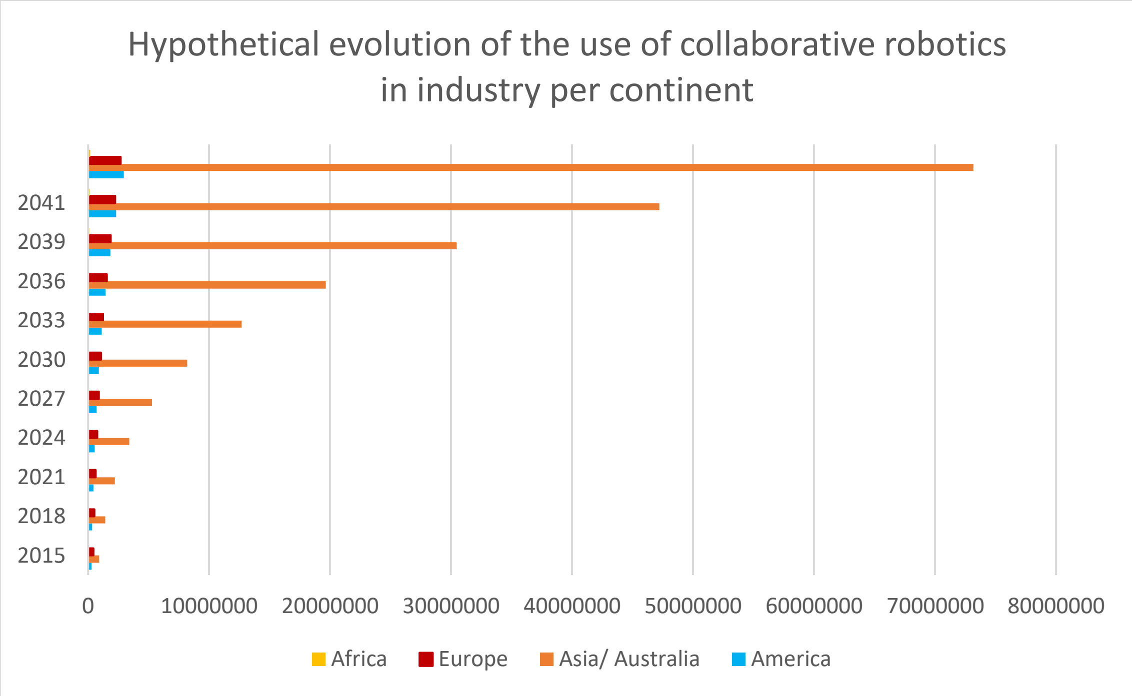


Figure 12. **Hypothetical evolution of the use of collaborative robotics in industry per continents (based on the current growth rate[18])**

1.2.1.2 Activity sector of use of collaborative robotics

Now that we have learned about the trend of use of collaborative robotics per continent, we focus on the industrial sectors that use collaborative robotics, as shown on the following figure (**Figure 13**).

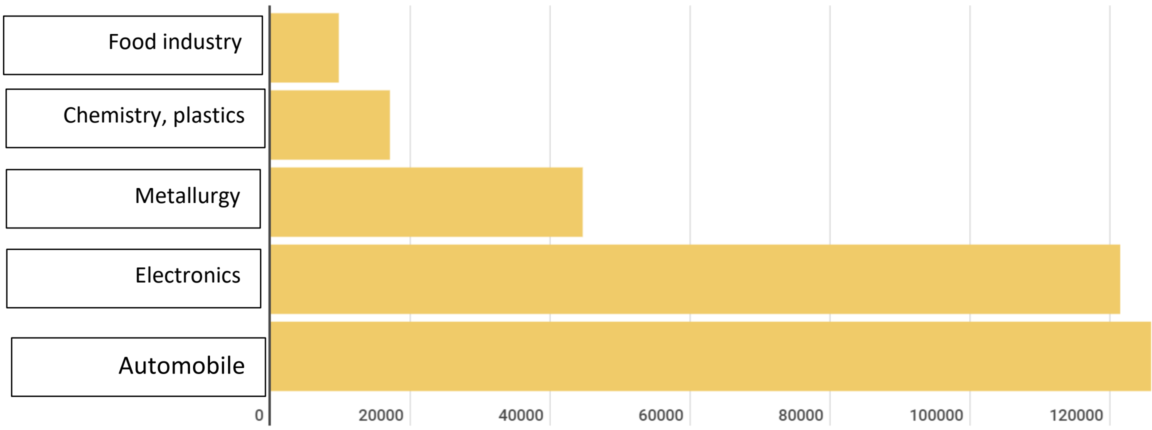


Figure 13. **Number of collaborative robotics used per industry sector at a worldwide scale in 2017[19]**

[18] Based on the information provided by the **Figure 11** available at : https://ifr.org/downloads/press/French_Press_Release_IFR_World_Robotics_Report_2017-09-27.pdf
[19] http://www.irsst.qc.ca/media/documents/PubIRSST/R-974.pdf

We can notice that the first sector using collaborative robotics at a worldwide scale is the automotive sector followed by the electronics sector.

1.2.1.3 *Examples of collaborative robotics use following the activity sector*

1.2.1.3.1 Automobile

The automobile activity sector is the sector with the highest number of collaborative robots in use at a worldwide scale. By consequence, we delve into the example of the PSA group (the first French automobile group) which uses collaborative robots in its Sochaux centre. The PSA group is the second automobile European constructor, selling 3 million automobiles at a worldwide scale. One third of their production is carried out in France, and 400 000 cars are produced in the Sochaux factory. The implementation of a collaborative robotics in their production and assembly line is linked to the project "Projet Usine future"[20] whose objective is to compact their production line and to decrease the cost of production of an automobile. The PSA Group has chosen the Universal Robots brand of collaborative robotics to integrate their assembly line at the Sochaux plant producing the Peugeot 3008 models. To improve economic performance of factories and ergonomics of workstations, two UR10 robotic arms take care of complex screwing operations. The job of the collaborative robotics is to screw in the bottom of the vehicle's fenders, while operators around them can work on other screwing operations, as shown on the following figure (**Figure 14**). Completely unique, the template created on the basis of Universal Robots UR10 collaborative robotics has been patented nationally and internationally.

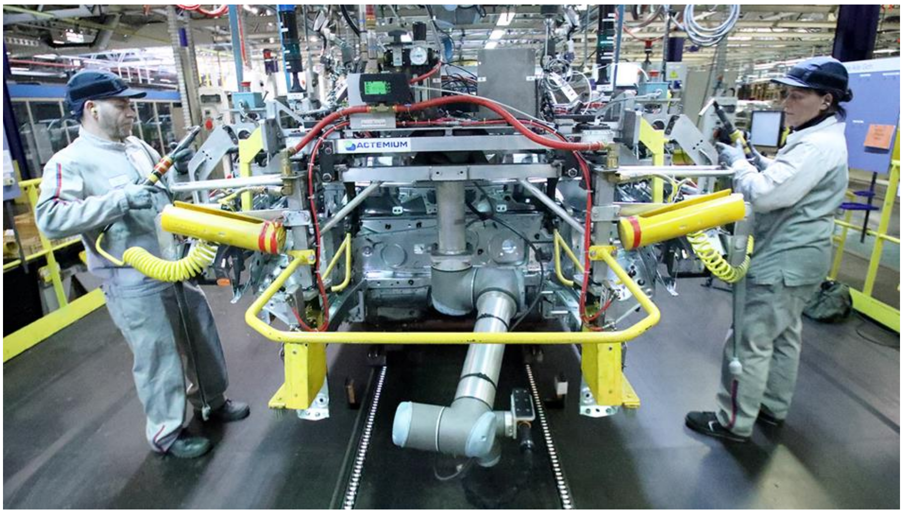


Figure 14. Picture showing the UR10 (Collaborative robot made by the brand Universal Robots) in a screwing application for the Sochaux PSA group factory[21]

1.2.1.3.2 Electronics

[20] Translated as « Future factory project »

[21] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/usine-de-sochaux-du-groupe-psa/

The electronics activity sector resort to and use also collaborative robotics in its production lines. For example, the Flex company[22] or even the electronics constructor ASM[23] use KUKA collaborative robotics to produce electronics components. In the ASM case, ASM assembly systems illustrate how networked production enables optimisation of SMT chains. The KUKA's collaborative robotics used by ASM is shown on the following figure (**Figure 15**).

Figure 15. Picture showing LBR iiwa cobot produced by KUKA and used by the ASM company [24]

1.2.1.3.3 Metallurgy

Likewise, the metallurgy activity sector resorts to collaborative robotics. In this context, the example of Airbus Aero may prove instructive. For the company Airbus Aero, collaborative robotics have been implemented through the prism of the Asimov project. This project has led to solve issues linked to the precision, even errors, in the printing of holes for the assembly of certain aerostructure elements of the A380. Automating their marking also allowed them to improve their production rate.[25] The collaborative robotics used by Airbus aero is shown in the following figure (**Figure 16**).

[22] https://www.kuka.com/fr-fr/presse/nouvelles/2016/09/industry-4,-d-,0-goes-global-with-kuka-and-flex
[23] https://www.kuka.com/fr-fr/production-du-futur/industrie-4-0/industrie-4-0-cases/industry-4-0-asm
[24] https://www.kuka.com/fr-fr/production-du-futur/industrie-4-0/industrie-4-0-cases/industry-4-0-asm
[25] https://www.basystemes.com/fr/projets-rd/asimov/

Figure 16. Mobile cobot used by Airbus Aero [26] to produce some parts of A380

1.2.1.3.4 Chemistry, plastics

The chemistry and plastics activity sectors use collaborative robotics as well. In this context, we can take the example of the company Sanofi, the medicine chemistry company. Sanofi has implemented 7 UR10 collaborative robotics in its Tours' factory mainly for palletisation tasks. The cobots are in the production line and intervene at the time of the packaging of the drugs on the packaging line, as shown in the following figure (**Figure 17**). The first Sanofi cobot implementation has been a success. As a result, the company has planned a next collaborative robotics integration, this implementation is planned for the loading cases on their assembly lines.[27]

Figure 17. UR10 used by Sanofi for palletising drugs[28]

[26] https://irt-jules-verne.fr/projets/cobot-mobile-pour-operations-d-assemblage/
[27] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/
[28] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/

1.2.1.3.5 Food industry

The food industry also uses collaborative robotics. For example, the company Mademoiselle Desserts (based in France, Bretagne) uses collaborative robots to prevent their operators from practicing risky tasks (e.g. heat related) as shown in the following figure (**Figure 18**). For this reason, Mademoiselle Desserts was rewarded with the prize “Marque employeur & responsabilité sociale” at the occasion of “Trophées de l'industrie durable 2020”. [29]

Figure 18. Picture of the production line of Mademoiselle Desserts using a cobot to prevent their employees from working on “risk determined tasks”[30]

Therefore, we can claim once more that collaborative robots are flexible concerning both the task they must perform and the activity sector in which they will operate.

1.2.1.4 Main brands at a worldwide scale

[29] Which can be literally translated as “Employer brand & social responsibility award” at the occasion of “Sustainable Industry Trophies 2020 ”.

[30] https://www.usinenouvelle.com/article/prix-marque-employeur-responsabilite-sociale-2020-mademoiselle-desserts-des-cobots-aux-fourneaux.N1004134

There is a large number of different brands producing collaborative robots and their equipment like feeders or palletisers. The following chart (**Table 3**) gathers the main known brands producing collaborative robotics and their equipment at a worldwide scale.

Brand
KUKA
COMAU
STAUBLI
YASKAWA
UNIVERSAL ROBOTS
SCOTT
ELITE ROBOT
COBOTS SOLUTIONS
NIRYO
EASY ROBOTICS
HANWHA TECHWIN
ABB
MILACRON
DENSO
FRANKA
ARC
DESMASA
YUANDA
SIASUN
SINTERPACK
TECCRON
ROZUM ROBOTICS
RETHINK ROBOTICS
TM ROBOT
PRODUCTIVE ROBOTICS
FETCH ROBOTICS
INDEVA
ZOLLER
FUYU
MG TECH
FANUC
RNA
DOOSAN ROBOTICS

Table 3. **List of the most well-known brands of collaborative robotics**

1.2.1.5 Maintenance of *collaborative robotics*

Concerning the maintenance of collaborative robotics, the task may be performed by collaborative robotics constructors or by independent companies located in different countries. Maintenance can be predictive with distanced maintenance of the cobot or linked to a need of repair in the company's fabric. This system of maintenance leads to different advantages and disadvantages which will be developed in the following part. But whichever the company performing the maintenance of the collaborative robotics will be, they will focus maintenance on 4 axes:

- Repairing, by asking the question: What to do when the collaborative robotics has suffered a shutdown?
- Optimisation, by asking the question: How could the collaborative robotics be more productive?
- Anticipation, by asking the question: What are the risks for the collaborative robotics and when might it be likely to experience a risk of breakdown?
- Innovation, by asking the question: What elements can be included in the collaborative robotics to diminish the risks of breakdown?

As a conclusion, concerning the worldwide use of collaborative robotics, we can point out that even the phenomenon of collaborative robotics used in industry being recent (2008), continents use them but in different ratios. By consequence, the European Union is well placed in this context and stands out as a land of opportunities for the expansion of the use of collaborative robotics.

1.2.2 Current use in Europe

1.2.2.1 *General trend in the European Union*

As previously mentioned, the European Union is the second region using Collaborative robotics right after Asia/Australia (as represented by the **Figure 10**). However, there are discrepancies among the European Union countries. Before studying those discrepancies, analysing the relevance of industry in the Gross Domestic Product (GDP) of each European Union country is important. As shown in the two following figures (**Figure 19 and 20**) there is a relation between the industrial sector in each country and the total GDP generated by those specific countries.

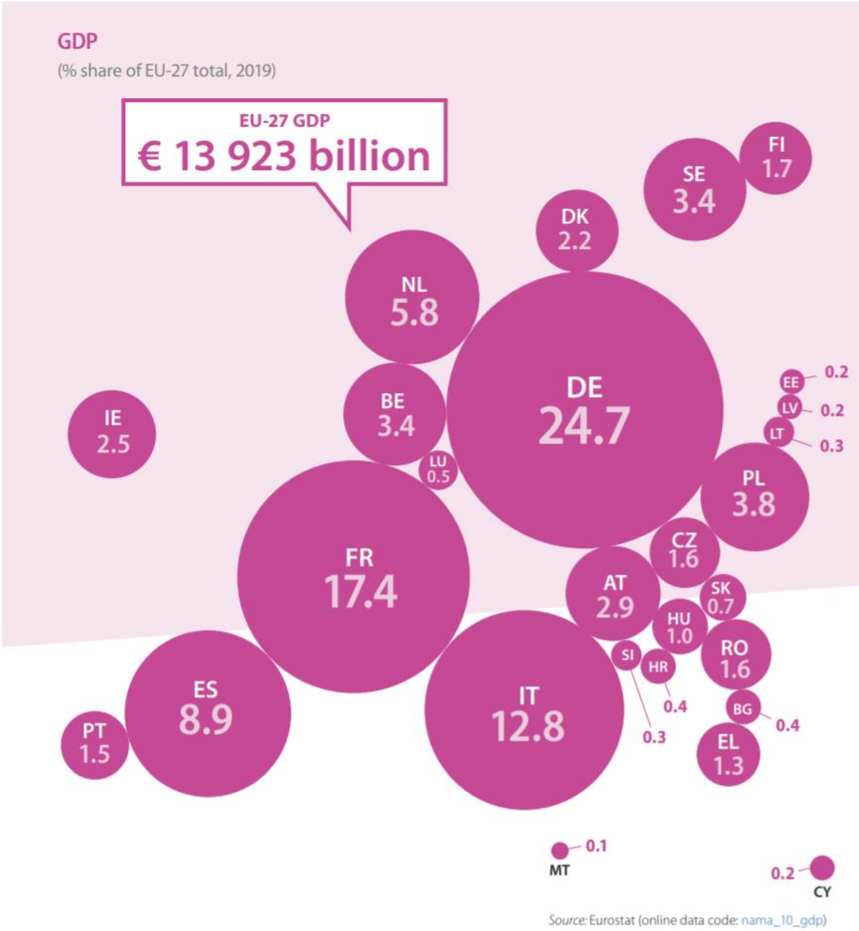


Figure 19. GDP generated by each European Union country and their weight to the general European Union GDP

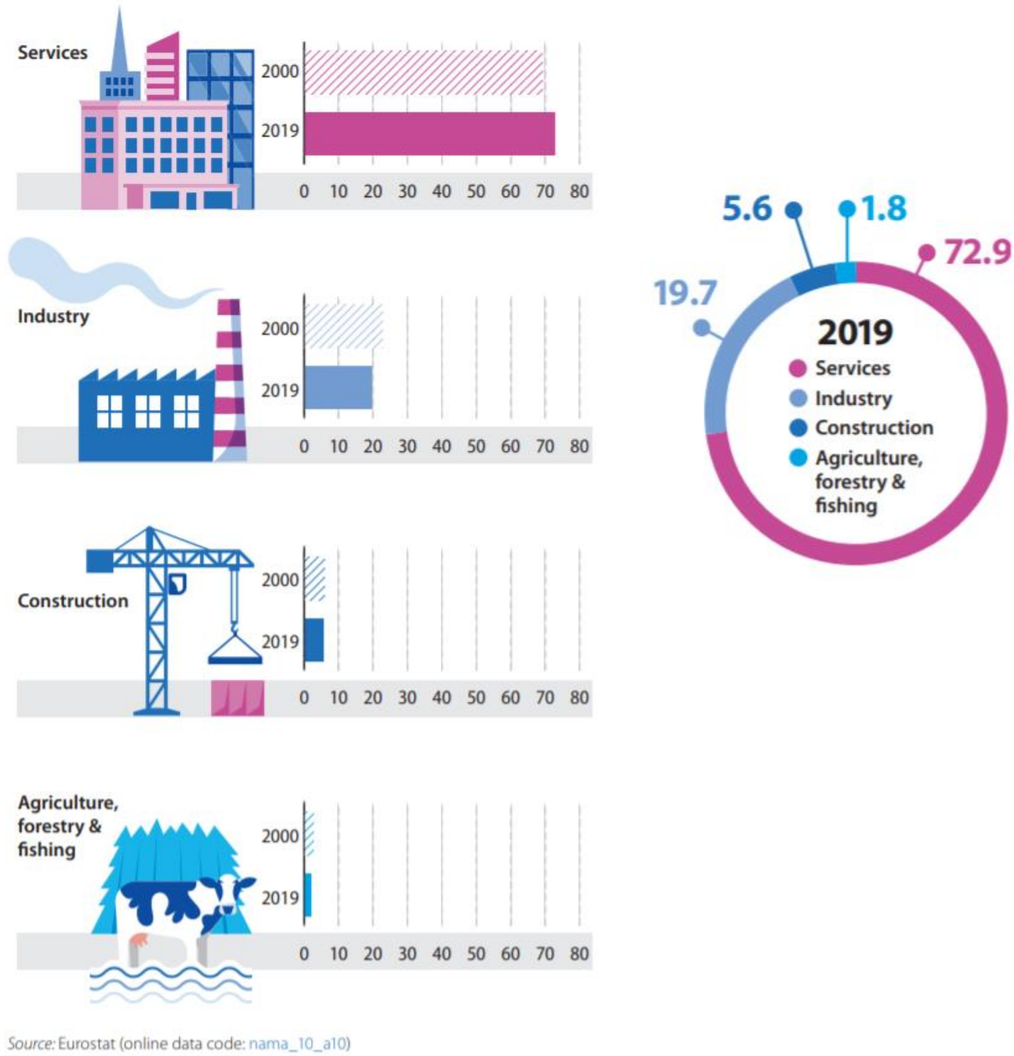


Figure 20. Percentage of value added per sector in the entire European Union

According to this, the industrial sector represents less than 20% of the added value generated by the European Union and it is the second most important sector after services contributing to the general GDP of the European Union. Nevertheless, the fact that European Union countries do not contribute with the same rate to the GDP generated by industrial sector cannot be overlooked as shown by the following figure (**Figure 21**).

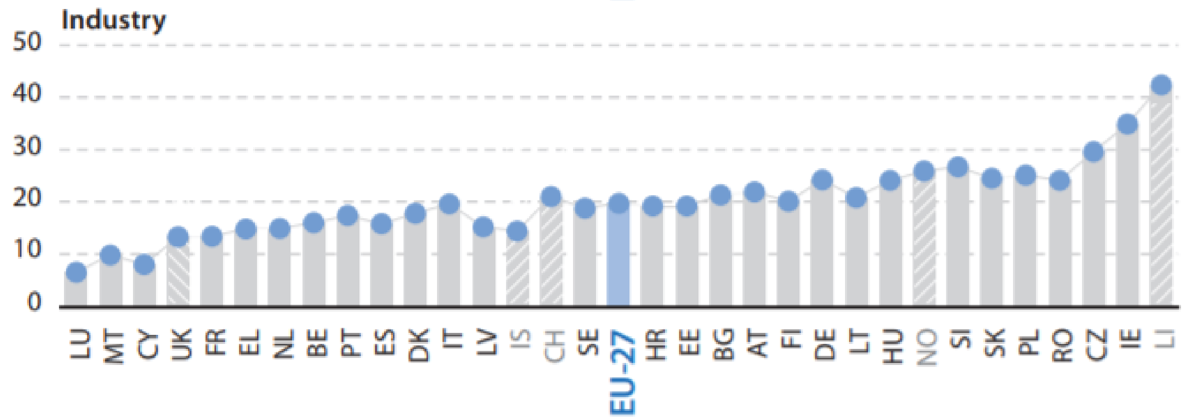


Figure 21. Added value of GDP generated by the industrial sector in each European Union country

Comparing the GDP generated by the industrial sector in each European Union country (**Figure 19**) with the number of employees of the industrial sector in each country, the number of employees of the industrial sector does not match the weight of the industry in the general GDP of the country as shows the following figure (**Figure 22**).

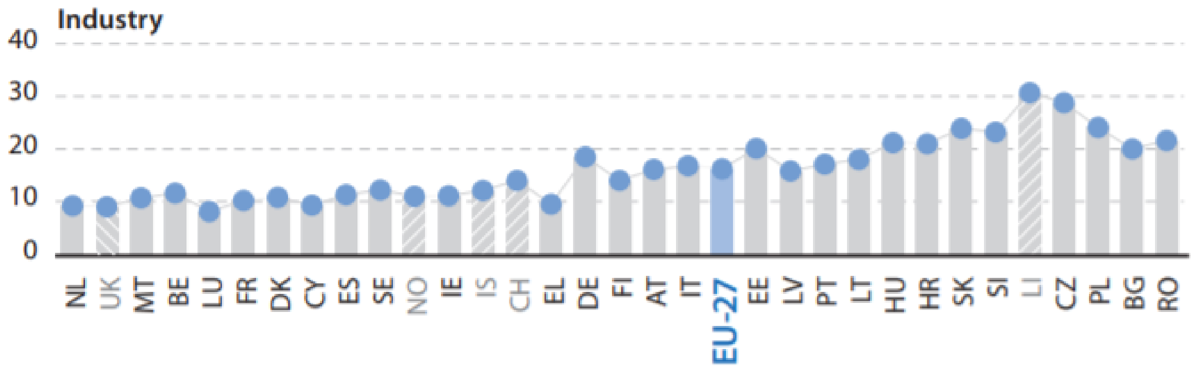


Figure 22. Percentage of the active population working in the industrial sector per country of the European Union

Serving as a reminder, the following figure (**Figure 23**) shows the most important industrial sectors in European Union.

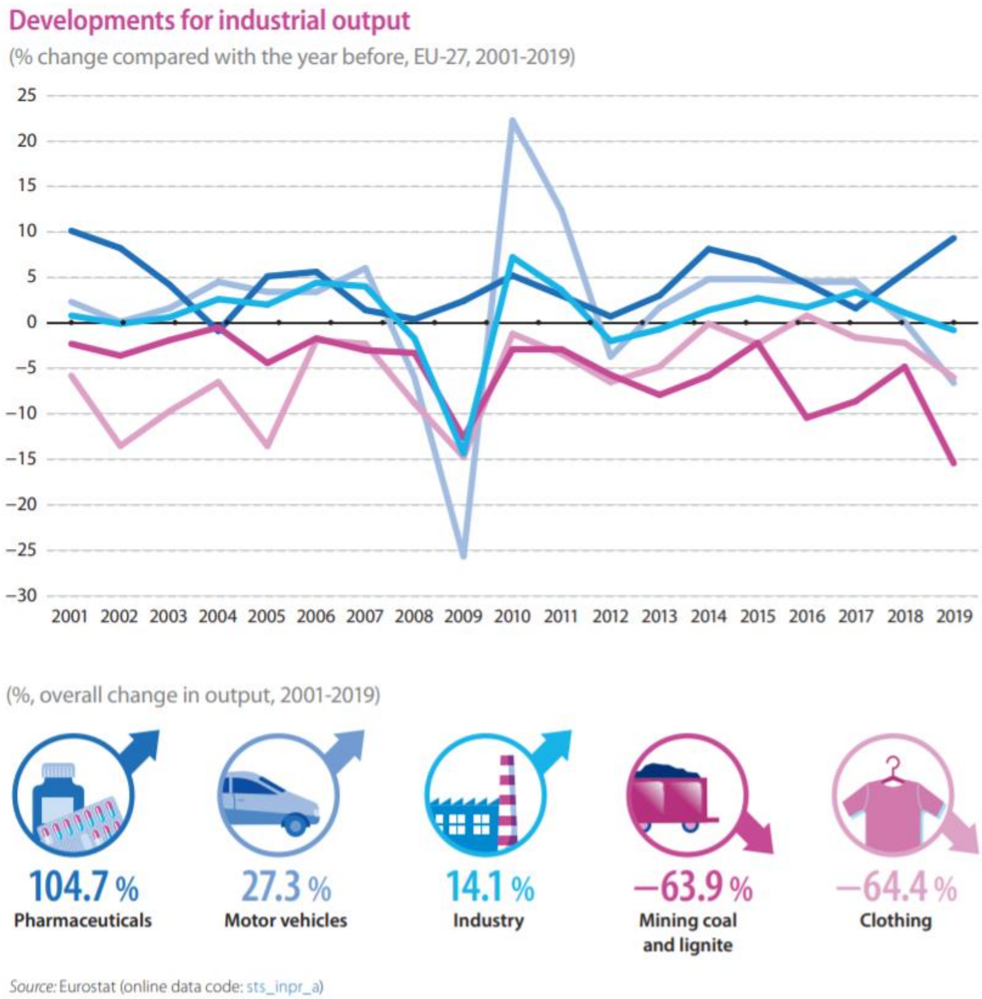


Figure 23. Main important industrial sectors in the European Union and their evolution compared with previous years between 2001 and 2019 [31]

Once the relation that links industry to the general GDP per country has been explored, we can analyse the presence of collaborative robotics in those industries. The following figure (**Figure 24**) shows the density of industrial robots per 10 000 employees and per country of the European Union.

[31] www.europarl.europa.eu/RegData/etudes/IDAN/2019/644201/EPRS_IDA(2019)644201_EN.pdf

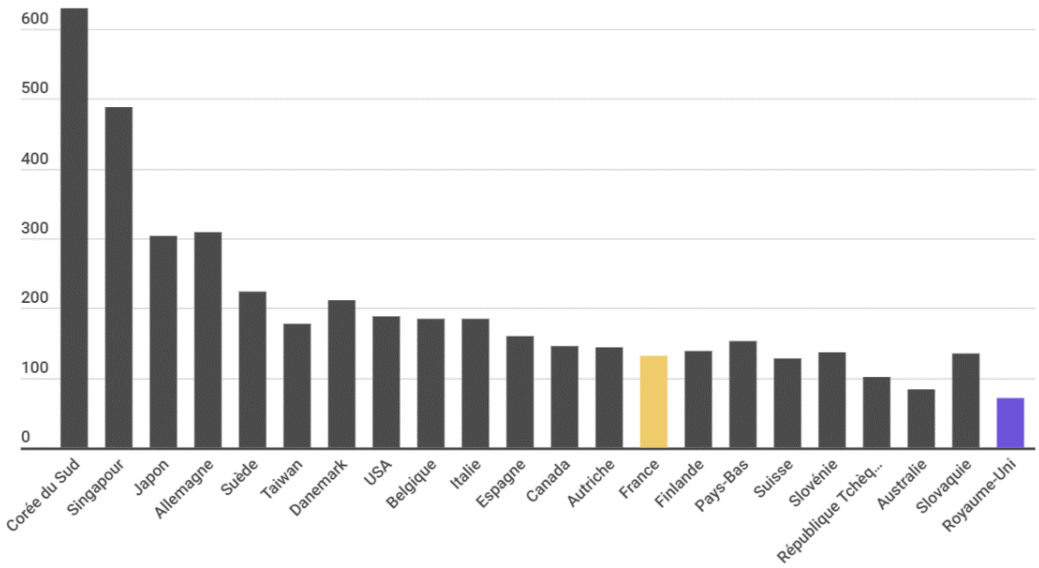


Figure 24. **Density of Industrial robots for 10 000 employees of the industrial sector per country**[32]

Considering the fact that collaborative robotics belong to the category of "industrial robots" we can infer that the previous figure (**Figure 24**) reflects the same tendency for the collaborative robotics.

Now we want to create a ratio to compare the rate of robotization in industries with the importance of industry for the European Union countries. We can draw a typology of the countries of the European Union as presented in the following part.

1.2.2.2 *Proposition of a typology*

Using all the previous elements gathered, the European Union can be divided into 4 types of countries as shown in **table 4,** which is a typology proposing levels of robotization in the European Union countries.

Type 1	The first category is characterised by countries which are advanced both in the industrial sector and in their level of robotization (and therefore on their use of collaborative robotics). **Germany** is a perfect example of this category.
Type 2	The second category is represented by countries which are less advanced both in the industrial sector and in their level of robotization (and use of collaborative robotics) compared with type 1. **Italy** is advanced on the industrial sector and in its use of collaborative robotics, but is one third less advanced than Germany.
Type 3	The third type includes countries, which are advanced on their industrial sector, but not much on their use of collaborative robotics. **Estonia** is an example of this category.

[32] http://www.irsst.qc.ca/media/documents/PubIRSST/R-974.pdf

Type 4	The fourth category is composed by countries which are a bit late in the development of their industrial sector (it can be due either to a lack of development or to a retreat from their industrialisation) and which are a bit late in their use of collaborative robotics compared with the other European Union countries. **France or Spain** will be used as examples for the presentation of this category.

Table 4. **Four types of European countries based on the number of collaborative robotics used in industry and the weight of industry in the GDP**

This proposition of typology will be studied all along this report.

1.2.2.3 *Examples of the typology: Germany (type 1), Italy (type 2), Estonia (type 3), Spain and France (type 4)*

1.2.2.3.1 *Germany (type 1)*

As mentioned above, type 1 is characterised by the countries which are advanced both in the industrial sector in relation to their GDP, and which are advanced on their level of robotization and therefore on their use of collaborative robotics. As an example, we will develop the **German** case.

The study of the German case is important because it is the most robotised country of the European Union. The following table (**Table 5**) presents the main sectors and fields of application of collaborative robotics in Germany.

Sectors which use Collaborative Robotics covered in the case studies[33]	• Metal industry • Electronic and Mechatronic industry • Automotive • Audio Technology • Household Appliances • Food industry • Disc Spring Production • Model and Modul Making • Electro industry • Demonstrator / Competence Centre • Energy Component • Mechanical and Plant Engineering • Developers of Automation Solutions • Agricultural • Space • Medicine
Types of products and services for which cobots are being implemented	▪ Assembly/Handling applications: sensitive joining, gluing, soldering, fastening, adjustment, bin-picking,

[33] The case studies identified for the report are available in the appendices (**Appendix 4**)

	one piece flow, collaborative robotics removes part and places it in a second holder. ▪ Welding applications: metal working/processing, smart welding, cutting. ▪ Packaging applications: handling of packaging units, pick-and-place tasks. ▪ Loading/unloading application: palletising/depalletising, holding and moving heavy parts, mobile robotics holds and transfer parts to the worker. ▪ Grinding application: cleaning and painting, sealing. ▪ Inspection: check correctness, verification, optical inspection, collaborative function tests. ▪ Healthcare: sterilization and decontamination process, operations.
Types of HRC that are implemented	▪ Collaboration ▪ Cooperation ▪ Coexistence

Table 5. **Sectors and fields of applications of collaborative robotics in Germany**

As shown in the **Table 5**, Germany has a high proportion of robotization in its industry. This observation is linked to the fact that Germany has many different fields of industry. We could resort to the CHRISTALLER model to explain the German situation as presented in the following figure **(Figure 25)**:

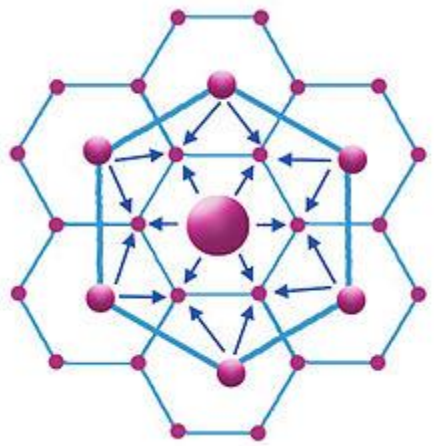


Figure 25. Simplified CHRISTALLER's model[34]

Figure 25 represents a simplified version of the CHRISTALLER's model. This theory explains the fact that if there is a central place to any geographical space, and that the area surrounding it will benefit from this central place (taking advantage from scale savings for example). Purple bulbs represent either cities or activity sectors. Therefore, to explain the high level of robotization in German industrial sectors, we can claim that it is due to the diversity of industrial sectors in the area, each sector taking advantage from the rest. So, Germany would be in a kind of *"virtuous circle"* auspicious to an increase of the number of collaborative robotics used in the industry.

1.2.2.3.2 Italy (type 2)

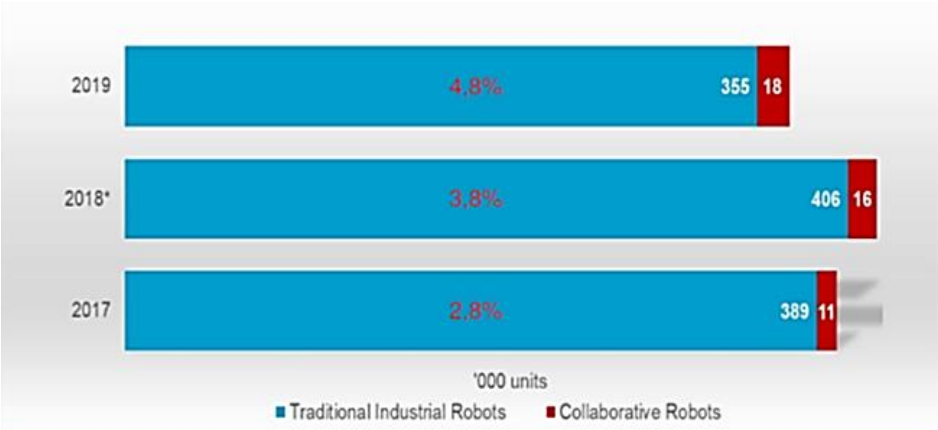
As mentioned above, Italy may represent the type 2 of our typology. Type 2 presents the countries, which are less advanced both in the industrial sector and in their level of robotization (and use of collaborative robotics) in comparison to type 1, but which are, nevertheless, advanced on those subjects.

Type 2 of this typology presents countries which are advanced as well both in the industrial sector compared with their GDP, and which are advanced on their level of robotization and therefore on their use of collaborative robotics, but much less than type 1. We will take the example of Italy.

In Italy, the use of Human Collaborative Robotics is one of most relevant aspects of the industry 4.0 and a major part of the company's digital transformation process. Robots are becoming essential in production: continuous technological development is turning these machines into important allies for improving quality and safeguarding the health of operators. Thanks to collaborative robots, production workers will be able to avoid the riskiest tasks, repetitive and exhausting activities, and errors that can cause fatal damage to end users, and concentrate on those tasks where humans are, and will remain, irreplaceable.

[34] CHRISTALLER Walter, *Die zentralen Orte in Süddeutschland, Iena University, 1933*

According to the latest data released by IFR[35] (International Federation of Robotics) in 2019, the number of industrial robotics' sales slightly decreased compared to the previous years (as shown in **Figure 26**), however, the most surprising performance was related to the collaborative robot segment, in the same period they recorded an increase of 11% compared to the previous year.



Year	Cobot installations	Total industrial robot installations	Cobot share	Growth year-over-year
	units	units	%	%
2017	11,107	399,640	2.78%	
2018*	16,217	422,271	3.84%	+46%
2019	18,049	373,240	4.84%	+11%

*revised
Sources: IFR, JARA, KAR

Figure 26. Industrial robot sales over the last three years in Italy. Percentages indicated in red show the percentage of newly installed collaborative robotics compared with the traditional robots

Although collaborative robotics are still a niche in the vast ocean of the automation world, the statistical analysis reports about 400 installations of collaborative robots throughout Italy: of this total, **most have found a home in Lombardy (with 29% of installations) and in Emilia-Romagna (with 24%)[36].** By consequence, in Italy two areas concentrate more than 50% of the total number of collaborative robotics. Considering this fact, once more, the CHRISTALLER's model would be adequate to explain the Italian situation of robotization.

1.2.2.3.3 Estonia (Type 3)

Type 3 of this typology presents countries which are advanced on their industrial sector, but not much on their use of collaborative robotics. To present this type of European Union countries, we will take the example of **Estonia**.

More than 71% of the Estonian GDP is derived from the service sectors, industrial sectors yield 25% and primary branches (including agriculture) approximately 4% of the overall output. The important sectors of the Estonian economy are the processing industry (approximately

[35] https://ifr.org/ifr-press-releases/news/record-2.7-million-robots-work-in-factories-around-the-globe
[36] https://www.alumotion.eu/2019/06/robotica-collaborativa-da-record-in-lombardia-ed-emilia-romagna/

14.5% of the overall production), transport, warehousing and communications (10%), commerce (13.5%) and estate, rental and letting, as well as business services (21%). Agriculture and forestry amount to 2.2% of the overall production, construction approximately represents 7%, and government, education and health care to more than 17%. [37]

The most important branches among processing industries in Estonia **are the mechanical industry (about 25% of manufacturing production), timber and paper industry are next in importance (20%, see Forestry), then the food industry (15%, see Agriculture), the chemical industry (about 10%), the metal industry (13%) and the light industry (less than 5%).** There have been rapid changes in manufacturing: a little more than ten years ago, the timber and paper industries were the leading sectors. For more than ten years, the mechanical and metal industries have seen extensive growth. At the same time, light industry is producing less and less. The electronics industry has increased eightfold in a couple of years. The labor force is becoming more expensive, but increased skills and investments are some of the reasons for the changes.

As shown on the following figure (**Figure 27**) it is not strongly anchored in the digital economy.

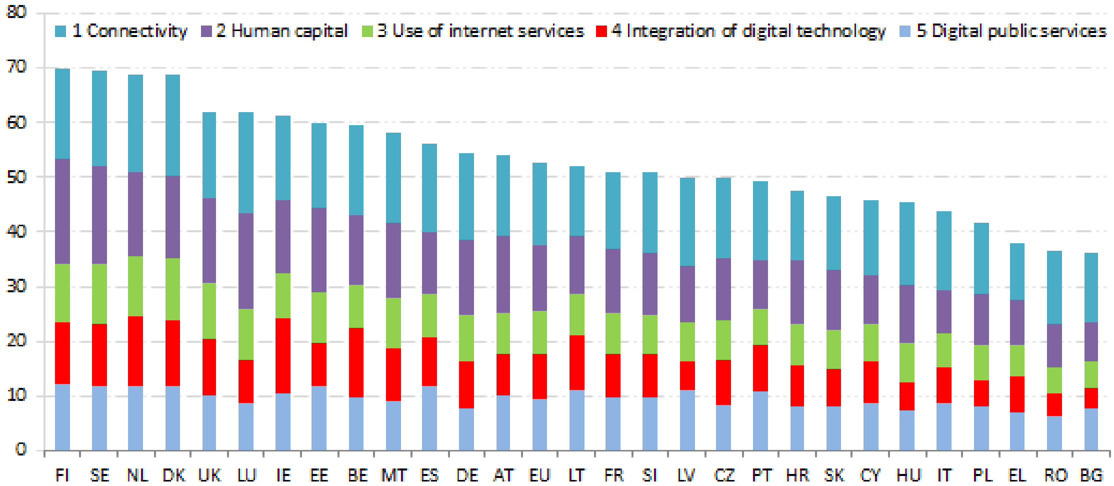


Figure 27. Digital Economy and Society Index (DESI) 2019 ranking

On the one hand, Estonia (EE) is strong in connectivity, human capital and digital public services. On the other hand, not so strong in digital technologies and using internet services, as shown in the previous figure (**Figure 27**).[38]

The Digital Agenda 2020 for Estonia[39] is a document describing the activities for society for increasing the digital era of economy. Digital Agenda for Estonia were based on the two key strategic objectives established in the competitiveness strategy “Estonia 2020”: to achieve growth of productivity through higher value-added goods and services, to increase total

[37] Estonian Entrepreneurship Growth Strategy 2014-2020
Tööstuspoliitika Roheline Raamat (Green Book of Estonian Industry – in Estonian)
IKT Valdkonna arenguprogramm (in Estonian)
Digital Economy and Society Index – Country Report 2019 - Estonia
[38] Digital Economy and Society Index – Country Report 2019 - Estonia
[39] [36] Tööstuspoliitika Roheline Raamat (Green Book of Estonia)

employment. In the Digital Agenda 2020 the main output is the digitalisation of society, and less attention has been paid to the topic of digitalisation of the industry.

For digitalisation, the industry government through Enterprise Estonia[40] has organised some supportive actions, oriented directly to the companies. Industry policy development is focused on the Ministry of Economic Affairs and Communication[41].

1.2.2.3.4 Spain and France (type 4)

Type 4 of this typology presents the countries that are a bit late in their industry and their use of collaborative robotics compared to the other European Union countries, such as France or Spain.

- **Spain**

The first electric robot installed in Spain was in 1979 from ASEA (Current ABB). Manufacturing sectors in Spain have been working on the introduction and integration of new industrial processes by the functionalities of industrial robots. Meanwhile, there have been several initiatives concerning the development of collaborative robotics in different processes related to manufacturing, assembly and inspection. The main aim for Spanish companies is to make their facilities as flexible as possible, with the highest possible degree of flexibility. Since high-speed programs are not available, the solutions chosen must be adaptable to different products. In this way, a return of investment will be achieved in line with the different industry standards. From the manufacturing point of view, there are daily progresses to have industrial resources with a higher level of autonomy and which, at the same time, are designed for perfect integration with the people who operate or supervise them. The quality level required for products means that highly specialised means are needed involving many players; robot manufacturers, artificial vision systems, end-effector developers, integrators who often specialise in one of the technologies needed for processes, etc.

From 2014 to 2019, annual robot's installation increased by 10% on average[42] to a record high of 36,700 robots, Spain was ranked 7th in Europe's robot density with 191 units per 10,000 employees[43]. Due to the importance of exports in Spain, the country depends on the evolution of the main markets to ensure the volume of production. This country ended 2020 clearly below initial forecasts. In 2021 the situation is being stabilised, although it is difficult to grow significantly, as the gap caused by the pandemic will recover very slowly in the domestic market.

During the TOURINGS' data collection, different companies with collaborative robotics integrated have been contacted, mainly from the automotive sector, food and dairy products, cosmetics, and metal. **These companies have integrated their robotics cells since 2014 (first in Spain) until nowadays**. These units (between 1 and 8 in the contacted companies) have been used for such different uses as:

- Assembly
- Palletising and depalletising

[40] www.eas.ee
[41] www.mkm.ee/en
[42] CAGR
[43] https://ifr.org/downloads/hidden/200601_World_Robotics_RD_Program_v01.pdf

- Screwing
- End-of-line control
- Quality control
- Placing trays on packaging line
- Load and unload components
- And placing in the filling line

As an industrial philosophy, only operations that generate value should be automated, or non-value-added activities which will allow Spain to focus on other more valuable processes. Technology allows Spain to automate many operations, but the process must be financially sustainable. That is why all the facilities the Spanish industry implement must be governed by the concept of cost-efficiency.

COVID-19 made a new paradigm, Spain is moving more and more towards a contactless society to avoid contracting the virus. **If COVID-19 has served any purpose, it has been to put robotics in the spotlight for those organisations** that were wary of it, when in many cases it is their only solution now or in the short term. In the same vein, the scalability of robotics in terms of investment has also broken-down barriers and many private investors see automation as profitable beyond the long term.

Spain maintains the 4th place in installations in the European robotics market (after Germany, Italy and France), dropping one place in the world ranking from 10th to 11th position. Spain has suffered in 2019 a very sharp decline in robot installations, with a drop of 28%, placing the country with 3.820 new installations at levels of 5 years ago, and interrupting a period 2014-2019 where the average growth rate had been +10%. Robot sales in the Spanish market depend to a large extent on the automotive industry (certainly cyclical) which in 2019 installed 47% of the total number of units, being the second largest European vehicle manufacturer only behind Germany[44].

The Spanish industry hopes that in the next few years, Spain will see the awakening of service robotics and the automation of many of the manual processes it carries out in its day-to-day lives. This will probably make *lato sensu* robotics one of the main drivers of industry in the coming decades, just as the automotive industry has been for all these years in Spain.

- **France**

Concerning France, the use of collaborative robotics follows the general European tendency. Collaborative robotics belongs to the 4.0 industry field. The observation which can be made about France is that France is using more and more collaborative robotics in its industry and thus, whatever the industry is. **It covers a wide range of sectors: automotive, pharmaceutical, cosmetics, food industry, etc.** (List based on the case studies analysed for France presented in the **Appendix 4**). French analysis has identified 16 case studies divided into 9 industrial sectors in the proportions shown in the following chart (**Figure 28**).

[44] https://www.oica.net/category/production-statistics/2019-statistics/

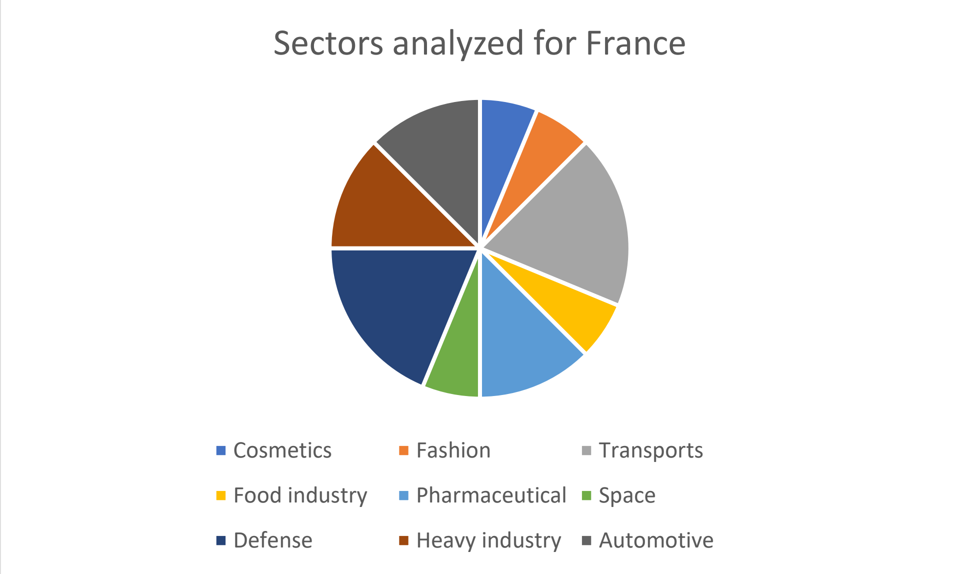
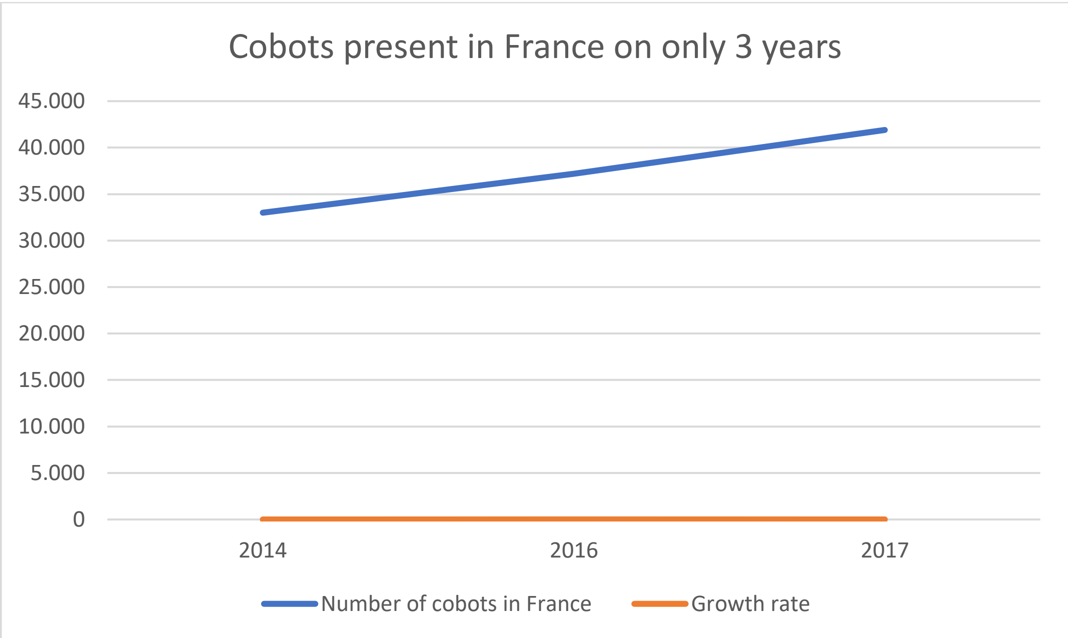


Figure 28. **Distribution of the industrial sectors analysed in France**

In France, the industrial robot density per 10 000 employees is around 130, which is few. In comparison with Germany, French industry uses 5 to 7 times less collaborative robotics [45], which is fewer than Italy and equivalent to the Spanish rate. Following the general estimations in 2014, there were 33,000 industrial collaborative robotics in France. In 2016, 4,200 cobots were sold while in 2017, 4,700.[46] So, the number of collaborative robotics sales is increasing while the part of industry in the general GDP of France does not change. So, France is getting more and more equipped in collaborative robotics compared to its active population working in this sector. Therefore, every year French companies buy the equivalent of 13 % of the whole entire collaborative robots' park of France. This tendency is resumed in the following figure (**Figure 29**).



[45] https://www.youtube.com/watch?v=wATqoTMlqJE
[46] webinar of INRS "*Robots collaboratifs : quels enjeux pour la prévention ?*" (04.06.2018)

Figure 29. Chart representing the number of collaborative robotics being used in France [47]

Thanks to this chart, we can check that during the year 2017, the number of collaborative robotics used in France increased 25 % in comparison with the year 2014. Thus, the use of collaborative robotics is getting more and more important in the French industry and it seems to be exponential.

The first use of collaborative robotics that we have analysed in France concerns the placing system. Thanks to the collaborative robotics help, the operator can precisely assemble the elements of the products. Other companies use collaborative robotics in order to develop their Research and Development area. For example, collaborative robotics can test some products faster than computers. The collaborative robotics are also used to assemble and package the products.

What we have analysed in France thanks to the TOURINGS' project is that there is a fear from the private companies using collaborative robotics to raise their voices for this matter publicly. The reason would be that companies using collaborative robotics would not want to expose this use of human robot collaboration in order to avoid exposing a risk of unemployment. Therefore, we can imagine that in the collective mind, French population could represent a diffidence against collaborative robotics. This fact is surprising, because even if the collaborative robotics are not destinated to replace operators, but to work with them, the population seems to be hostile to their implementation in companies. This unconscious phenomenon could find an explanation in the fact that during the 30 last years, the French industry has fired more that 2 million of employees of the industrial sector. This phenomenon has been so intense in France that it was called the "des-industrialisation". This newly created terminology defines the reallocation of resources initially intended for the manufacturing industry towards alternative activities[48]. Therefore, during a long time, robotization has been considered as an "*employment destruction tool*"[49] while in Germany robotization was considered as a *"tool of employment creation"*. But it appears that nowadays, those French considerations are changing, little by little but notably, since government studies publications, showing that instead of being an "*employment destruction tool*" the implementation of collaborative robotics in industries is more a *"tool for maintaining employment in French territories"* because of the competitiveness that it provides to companies which are more flexible and thus more agile. This newly competitiveness could lead to relocation of some companies. Hence, even if France is not really advanced on its industrial production, neither on its level of robotization, France is an area full of possibilities for the implementation of collaborative robotics in other economic sectors which would decrease the diffidence against the collaborative robotics.

Furthermore, France presents many companies helping to the implementation and the use of collaborative robotics.

First, there are many international collaborative robotics constructors selling their collaborative robotics in France, for example it is the case of Yaskawa. Those international brands can sell their collaborative robotics by their own or they can use intermediaries to do so.

[47] webinar of INRS "*Robots collaboratifs : quels enjeux pour la prévention?"* (04.06.2018)
[48] NESTA Lionel, Désindustrialisation ou mutation industrielle ?, INSEE
[49] Expression used by Ludovic SERALTA https://www.youtube.com/watch?v=wATqoTMlqJE

For instance, the company HMI-MBS is a case in which 30 employees[50] act as a consulting group mainly distributing Universal Robots solutions.

Even if the international collaborative robotics brands are well anchored in the industrial landscape automation, there are also French collaborative robotics constructors, who could be characterised by their *"thinking out of the box"* way of working:

- Ideatech[51]: Ideatech creates solutions such as Easiflex. In their own words: "*This company provides programmatic and frugal collaborative robotics solutions*". Before implementing collaborative robotics for a client, the company Ideatech will begin by providing a proof of concept (POC), this way of working allows the company to base its solutions in function of the real issues known by the industrial client.

French collaborative robotics constructors can also be very specialised, such as:

- Meanwhile[52]: Meanwhile is a collaborative robotics constructor specialised in autonomous and intelligent mobile robotics. They offer solutions for autonomous mobile robotics. These are intended for the transport of goods in healthcare establishments, but also within manufacturing industries and establishments opened to the public. The mobile collaborative robotics offered by Meanwhile are completely autonomous in their route. To achieve their autonomy, these robots use artificial intelligence (called SLAM: Simultaneous Location And Mapping) allowing them both to locate themselves at all times and to dynamically avoid any obstacle that has not been mapped.

- Niryo: Niryo[53] is a French brand which creates collaborative robotics. Their collaborative robotics are mainly used for training contents and therefore are used in a didactic way. Their solution is based on the creation of Niryo One, their first 6-axis collaborative robot designed for education and research, based on open-source technologies (Raspberry Pi, ROS, etc.). Ned, its successor, brings many improvements to it, including an aluminum structure providing it with precision and repeatability of 0.5mm. They also offer a next-generation solution for industry, composed by collaborative robotics, vision and edge computing. Their reduced collaborative robotics, with cheap prices (entry price at 2,500 euros) allow academies to buy collaborative robotics and train their students on collaborative robotics as well as companies to test collaborative robotics solutions before implementing real ones in their production lines.

Of course, those previous detailed examples are only a sample of all the French collaborative robotics constructors' companies. We could also quote, among others, Isybot[54], which is the result of CEA works and which has just received a first order of 2 collaborative robotics for the Bénéteau group concerning various sanding operations of pleasure boats.

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[50] https://www.hmi-mbs.fr/
[51] https://www.ideatech.fr/robotique-easyflex
[52] https://meanwhile-france.com/
[53] https://niryo.com/fr/
[54] https://www.isybot.com/?gclid=CjwKCAjwkvWKBhB4EiwA-GHjFh7ZVWo-q-p3VHN_Jqj1u0AXM9vISQBvyaVMgl0uHvQlZYQ7J8NQvRoC4gMQAvD_BwE

France is also a favorable land for the implementation of collaborative robotics in industries. For this reason, several consulting companies help industrial companies to implement collaborative robotics in their production lines.

- Among others, the consulting group Valeurs et Ressources[55] providing and accompanying industrial companies on 3 axes which constitute the conditions for the success of industrial development. The core product-process business, the associated economic model and the management of skills and organisations. A large part of their interventions are, thus, related to the integration of technological building blocks 4.0, in particular robotics and collaborative robotics.

For a long time, the French national education system did not consider the trainings needed by those new technologies. Nowadays, it seems that the French educational environment is adapting its programs to those new needs of industries; among others the Institute of technology Art et Métiers[56] stands out or even the university Paris Est-Créteil. This report will present those newly created programs in a more detailed way in the following section.

1.2.2.4 National policies that encourage companies to implement collaborative robotics

Many national policies promote actions and initiatives for the dynamism of private companies, as well as the aid that will allow them to accelerate and translate into tangible industrial realities[57].

This is, for instance, the case for Spain; through the drafting of the General Guidelines of the new Spanish industrial policy 2030, the government has promoted the use of collaborative robotics in industrial companies. In France, the government has established funds dedicated to companies for them to buy cobots through subventions (either national or regional). Those two examples are not an exhaustive representation of the policies put in place in European Union countries to promote collaborative robotics in industrial companies, but they constitute a great example to show the range of policies engaged to promote collaborative robotics use in the industrial sector.

Therefore, governments may apply many different strategies to encourage the collaborative robotics implementation in industrial companies; for instance, through fund helps for companies to buy collaborative robotics or simply in the promotion of collaborative robotics use through stimuli.

1.2.2.5 *Diversity of the use of collaborative robotics in companies based in Europe*

As mentioned in the introduction section of the present report, our information has been based on 62 case studies, 36 national reports and 52 interviews conducted by the partners of this project. With the data provided by those materials we have underlined the fact that there

[55] http://valeurs-ressources.fr/
[56] https://artsetmetiers.fr/fr/ms-colrobot
[57] General Guidelines of the New Spanish Industrial Policy 2030 https://industria.gob.es/es-es/Documents/Directrices%20Generales%20de%20la%20Pol%C3%ADtica%20industrial%20espa%C3%B1ola%2025.02.19%20FINAL.pdf

are sometimes more differences between the types of companies using collaborative robotics instead of the countries where they are located. There are three main factors differentiating companies in their use of the collaborative robotics:

- Their size (1),
- The ways collaborative robots are used (2),
- The brands of the collaborative robotics used (3).

1.2.2.5.1 A difference in the size of the companies using collaborative robotics

The use of collaborative robotics does not really depend on the country of use, but more on the company which uses it and in the functionality of the collaborative robotics. Considering the size of the companies using the collaborative robotics: obviously, there are multinational firms using collaborative robotics (e.g. we have identified a company employing more than 160,000 people which uses collaborative robotics in its production lines). Conversely, we have also identified a micro company employing only 8 people which uses collaborative robotics. So, the diversity of the companies using collaborative robotics is huge. These examples reveal the fact that collaborative robotics can be adapted to every size of companies.

1.2.2.5.2 Different ways to use collaborative robotics

As seen in the introduction section of the present report, collaborative robotics can be used at different steps of the production line since they perform a wide range of tasks: assembling, palletising and depalletising, screwing, controlling the quality, placing trays on packaging line, loading and unloading components and placing in the filling line. Therefore, the companies that use collaborative robotics to assemble their products are of better renown than for example other two companies of the same country which make no use of collaborative robotics to assemble their products. Thus, there are similarities between companies of different countries (which is beyond the limits of the present report).

1.2.2.5.3 Different brands of collaborative robotics used

Here, we would like to gather and show the wide variety of collaborative robotics providers such as: *Kuka: LBR iiwa, Bosch, ABB: Yumi, Universal Robots: UR5, UR3, robots+ , Rethink Robotics: Sawyer, Kawasaki: Scara Duaro, Yaskawa: Cobot HC10, Franka Emika: Panda, Denso: Cobotta, Nachi: CZ-Reihe, Omron: TM-Roboter, Kassow: 7-Achs-Cobots, Doosan, Fanuc: CRX-10iA, Mitsubishi: Melfa Assista, AUBO, F&P Personal Robotics, Fanuc, Kinova, Kassow Robots, Automate, Igus, Mabi, Pilz, Stäubli, Siasun, Elephant robotics*… Therefore, those cobots neither work in the same way nor are constructed in the same way. So, workers may need different skills to work with each collaborative robotics depending on the brand.

As a conclusion of this sub-part in which the diversity of use of the collaborative robotics used in manufacturing sectors in the European Union has been introduced, we can say that this diversity is huge and depends on the size and the sector of the company using the collaborative robotics. This diversity also depends on the functionality and the placement of the collaborative robotics on the production line of the company. Furthermore, the diversity of use of

collaborative robotics depends on the collaborative robotics brand used. Of course, every collaborative robotics presents specificities directly linked to the constructor brand.

1.3 Presentation of the legal aspects, ISO standards and safety norms

This section will focus on the ISO legal aspects and safety norms which regulate collaborative robotics.

1.3.1 General overview

The Treaty on the Functioning of the EU (TFEU) regulates the functioning of the Union[58]. In accordance with the Treaty, various directives have been adopted so that the objectives of free movement of goods and protection of citizens can be achieved simultaneously. In accordance with Article 114 of the TFEU, the Machinery Directive 2006/42/EC was issued to approximate the laws, regulations and administrative provisions of the member states, which sets out the tasks for meeting health and safety requirements and thus defines a uniform level of protection for accident prevention within the EU[59]. However, the directives issued by the EU do not initially have any direct effect on individual citizens or on a company. The contents of these directives only become effective in the respective member states when they are transposed into national law[60].

1.3.2 Four main modes of interactions

The standards also define four modes of interactions that a collaborative robot must be able to perform in a Human Robot Collaboration (HRC) situation:

- **Safety Monitored Stop:** The robot works non-collaborating as long as no human is in the working area. As soon as a human enters the collaboration room, the robotic system stops. The robot resumes its movement only after the human has left the collaboration room.
- **Hand Guiding:** Physical contact between humans and robots takes place. The human controls the robot by touching a manually operated device with an enabling switch on the robot (e.g. on the robot tool). The forces applied by the operator are recorded and converted into control signals.
- **Speed and Separation:** Robot and human are together in the collaboration room, but the safety distance between the interaction partners is continuously maintained. If the distance is reduced below the safety distance, the robot stops. The speed and distance monitoring applies to all persons in the collaboration room.
- **Power and Force Limiting:** Here, intentional, or unintentional physical contact between robot and human can occur. This kind of operation requires specially designed robot systems, which guarantee safety by e.g. inherently safe means in the robot or by a safety-related control system. This means that the robot is weakened to such an extent

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[58] Europäische Kommission, „Vertrag über die Arbeitsweise der Europäischen Union (konsolidierte Fassung) vom 26.10.2012 Amtsblatt der Europäischen Union", 26 10 2012. [Online]. Available: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:12012E/TXT:de. [Zugriff am 06 05 2020].
[59] M. Dietrich, R. Schumacher und D. Lilienthal, „Leitfaden Sichere Maschinen - in sechs Schritten zur sicheren Maschine - Sick Sen-sor Intelligence AG," Sick GmbH, 22 08 2017. [Online]. Available: https://www.sick.com/de/de/search?q=8008007:Def_Type:Download. [Zugriff am 06 05 2020].
[60] C. Bittner, H. Bode, A. Christ, R. Gaiser, A. Hahn, J. Hasel, T. Klindt und M. Moog, Das Sicherheitskompendium für den Umgang mit Normen zur funktionalen Sicherheit, 2017.

by appropriate design or control technology that no damage can be done to the human during operation and thus contact does not necessarily have to be avoided.

All those standards are resumed in the following figure (**Figure 30**).

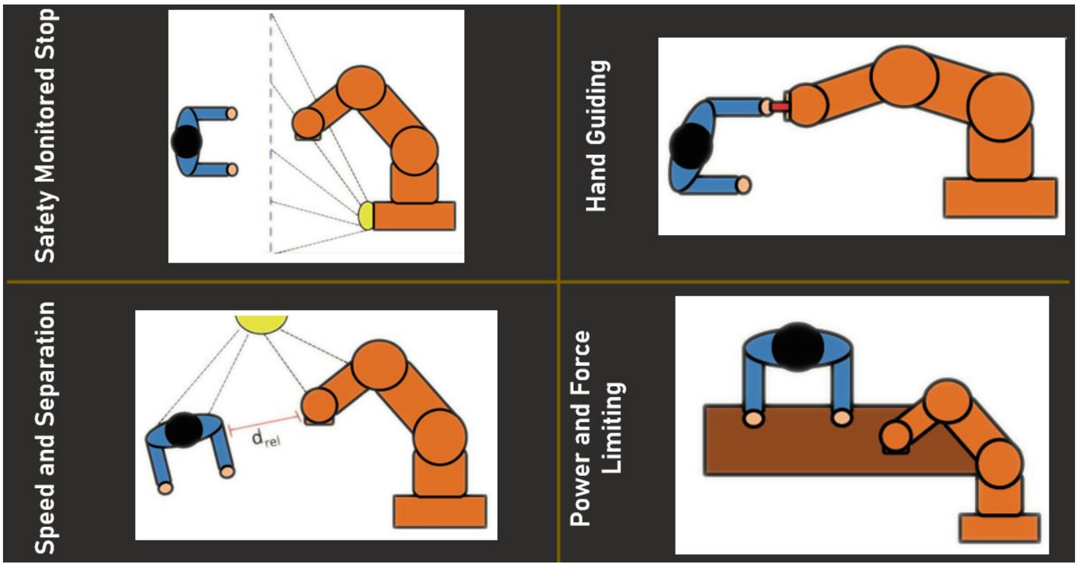

Figure 30. Representation of the forms of interaction between the human and the robot[61]

Thanks to the previous figure (**Figure 4**), we can notice that one of the main specificities of the collaborative robotics is their **safety during their use**. But this element is not the only one to be remarkable about the collaborative robotics. Cobots also present nine other remarkable aspects, they:

- are high-tech robots with integrated joint torque sensors which can detect contact,
- have a lightweight construction,
- have a powerful controller and software,
- are smaller, lighter and quieter than classic industrial robots,
- have no dangerous housing edges on the surface,
- can be flexibly adapted to varying production processes,
- are characterised by low costs for integration and start,
- can be easily reprogrammed and installed,
- can be operated safely in the vicinity of people.

1.3.2.1 *Risk reduction measures for collaborative robots*

When operating a collaborative robot, SMS, GH, SSM safety levels may not be required if the application forces / pressures are under the ISO TS/15066 biomechanical limits for the onset of pain. That eliminating the need for slowing or stopping the robot if human is entering a robot operating zone.
Force limiting defined in TS15066 based on affected body areas is shown in the following table (**Table 6**).

[61] Based on Müller et al. (2019) „Handbuch Mensch-Roboter-Kollaboration“

Body region		Specific body area	Quasi-static contact: Maximum permissible pressure [a] p_s N/cm²	Quasi-static contact: Maximum permissible force [b] N	Transient contact: Maximum permissible pressure multiplier [c] P_T	Transient contact: Maximum permissible force multiplier [c] F_T
Skull and forehead [d]	*1*	*Middle of forehead*	*130*	*130*	*not applicable*	*not applicable*
	2	*Temple*	*110*		*not applicable*	
Face [d]	*3*	*Masticatory muscle*	*110*	*65*	*not applicable*	*not applicable*
Neck	4	Neck muscle	140	150	2	2
	5	Seventh neck muscle	210		2	
Back and shoulders	6	Shoulder joint	160	210	2	2
	7	Fifth lumbar vertebra	210		2	2
Chest	8	Sternum	120	140	2	2
	9	Pectoral muscle	170		2	
Abdomen	10	Abdominal muscle	140	110	2	2
Pelvis	11	Pelvic bone	210	180	2	2
Upper arms and elbow joints	12	Deltoid muscle	190	150	2	2
	13	Humerus	220		2	
Lower arms and wrist joints	14	Radial bone	190	160	2	2
	15	Forearm muscle	180		2	
	16	Arm nerve	180		2	

Table 6. **Force limiting defined in TS15066 based on affected body area**

Forces and points of application in PFL contact are divided into two separate groups:

- Transient Contact - contact duration is short (< 50 ms). Human body part can usually recoil,
- Quasi-Static Contact –contact duration is significantly longer than 50ms. Human body part usually trapped.

However, in some cases it is extremely hard to have forces and pressure that are below the ISO TS/15066 limits (i.e., the end effector design or processed detail has sharp edges). If the forces or pressure are too high, the use of auxiliary safety measures is a must. These can be:

- administrative controls (fences, floor markings, light curtains),
- laser scanners (to reduce speed on approach),
- suitable robot design (soft materials, rounded covers).

The possible risk reduction measures:

- robot design factors (for example, round shapes, ductile materials),
- a suitable choice of applications and the design of the robot cell (for example, gripping, harvesting, trajectory, etc.).

	Transient contact	**Quasi-static contact**
collaborative robotics **construction**	Reducing collaborative robotics mass Increasing contact area Increasing contact duration	Increased contact area
collaborative robotics **control**	Decreasing collaborative robotics speed	Reducing maximum force Reducing contact duration

Table 7. **collaborative robotics construction and collaborative robotics control in front of their transient contact and quasi-static contact**

The range of collaborative applications are restricted due to the following:

- Low payload: in most cases, the payload does not exceed 15kg, which limits the type of workpieces to handle.
- Low speed: in collaboration mode, truly collaborative robots do not run at their highest speed considering the speed limitations given by the standards, which can cause difficulty to meet short cycle times.
- Level of risk: to ensure operators safety, collaborative applications will present risks which could be mitigated. However, the uncertainty of human behavior needs to be taken into account which increases the level of perceived risk.
- Limited applications: shared workspaces for the robot and operator solve very specific problems within the automotive industry, other automation solutions have been deployed in a cost-effective manner,
- Materials supply. The overall time and cost efficiency of assembly processes does also only depend on how assembly parts are fed to cooperative workplaces,
- As human–machine cooperation targets to higher flexibility and adaptability, the parts feeding process also needs to be highly flexible.

1.3.3 Directives for placing on the market and commissioning an HRC application

The most important regulation for placing machines and other products on the market in the European area is the Machinery Directive 2006/42/EC. According to Article 2 (h) of the Machinery Directive, the term "placing on the market" means "the making available for the first time [, against payment, of a machine] or partly completed machinery". According to Article 1, the scope of the Machinery Directive 2006/42/EC includes machinery as well as partly completed machinery[62]. For further investigations of the obligations of placing an HRC application on the market, it must first be examined how these terms are to be differentiated and which term is involved in the case of a collaborative robot system.

A robot as an individual part is an incomplete machine. If the HRC application is not considered as a whole (gripping technology, peripherals, further hardware, etc.), but only the robot arm, this is to be regarded as an incomplete machine[63]. The HRC application as a whole is a complete machine. Before placing machines on the market, the complete system must be provided with an EC declaration of conformity and a CE mark in accordance with the Machinery Directive 2006/42/EC and must therefore undergo a certification process[64]. An HRC application must therefore be CE certified before it is placed on the market. For partly completed machinery

[62] Europäische Kommission, „Richtlinie 2006/42/EG des Europäischen Parlaments und des Rates vom 17. Mai 2006 über Maschinen und zur Änderung der Richtlinie 95/16/EG (Neufassung) Amtsblatt der Europäischen Union," 17 05 2006. [Online]. Available: https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32006L0042&from=DE. [Zugriff am 06 05 2020].
[63] R. Müller, J. Franke, D. Henrich, B. Kuhlenkötter, A. Raatz und A. Verl, Handbuch Mensch-Roboter-Kollaboration. 1. Auflage, München: S. Hanser-Verlag, 2019.
[64] R. Müller, J. Franke, D. Henrich, B. Kuhlenkötter, A. Raatz und A. Verl, Handbuch Mensch-Roboter-Kollaboration. 1. Auflage, München: S. Hanser-Verlag, 2019.

(e.g. robot arm), only a declaration of incorporation is required instead of the EC declaration of conformity in accordance with Article 7 of the Machinery Directive 2006/42/EC[65].

Obligations of the manufacturer before placing a **complete machine** on the market[66]. The manufacturer must:

1. Ensure that the machine complies with the applicable essential health and safety requirements as set out in Annex I,
2. Ensure that the technical documentation referred to in Annex VII, Part A, and the instructions for use are available,
3. Carry out the applicable conformity assessment procedures in accordance with Article 12, and draw up the EC declaration of conformity,
4. Affix the CE marking in accordance with Article 16.

Obligations of the manufacturer before placing an **incomplete machine** on the market[67]. The manufacturer must prepare the following documents:

1. special technical documents according to Annex VII Part B,
2. assembly instructions according to Annex VI,
3. declaration of incorporation according to Annex II Part 1.

Ensuring the essential health and safety requirements according to Annex I of the HRC involves carrying out a risk assessment[68].

Normative requirements for the implementation of HRC applications

Robots are hazardous to humans due to their payload inertia, weight, structure (sharp edges), speed and applied forces. To protect human from machines, preventive actions should be made, based on the criteria outlined in the safety standards. There are different types of safety standards, starting from basic acknowledgment and ending with specific requirements for exact machines as shown on the following figure **(Figure 31**).

[65] R. Müller, J. Franke, D. Henrich, B. Kuhlenkötter, A. Raatz und A. Verl, Handbuch Mensch-Roboter-Kollaboration. 1. Auflage, München: S. Hanser-Verlag, 2019.
[66] Europäische Kommission, „Richtlinie 2006/42/EG des Europäischen Parlaments und des Rates vom 17. Mai 2006 über Maschinen und zur Änderung der Richtlinie 95/16/EG (Neufassung) Amtsblatt der Europäischen Union," 17 05 2006. [Online]. Available: https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32006L0042&from=DE. [Zugriff am 06 05 2020].
[67] Europäische Kommission, „Richtlinie 2006/42/EG des Europäischen Parlaments und des Rates vom 17. Mai 2006 über Maschinen und zur Änderung der Richtlinie 95/16/EG (Neufassung) Amtsblatt der Europäischen Union," 17 05 2006. [Online]. Available: https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32006L0042&from=DE. [Zugriff am 06 05 2020].
[68] R. Müller, J. Franke, D. Henrich, B. Kuhlenkötter, A. Raatz und A. Verl, Handbuch Mensch-Roboter-Kollaboration. 1. Auflage, München: S. Hanser-Verlag, 2019.

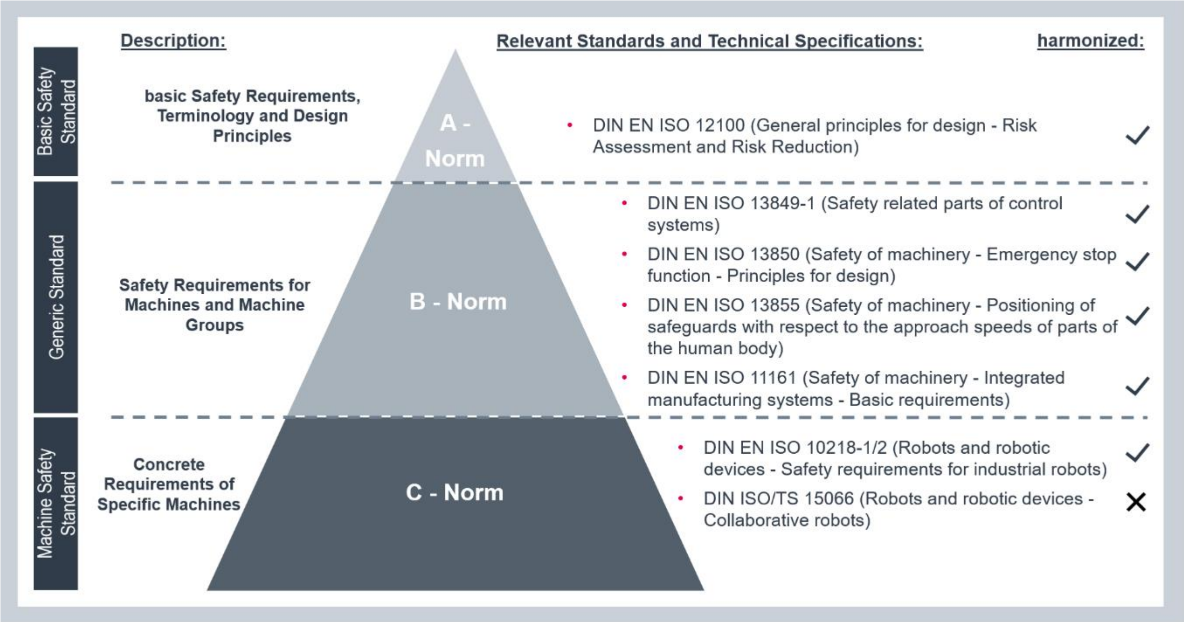

Figure 31. Overview of the Standards[69]

"A-type standards" (ISO 12100, IEC 61508) define basic terminology, general requirements and methodology used in achieving safety of machinery (i.e., risk assessment and risk reduction, functional safety of electrical, electronic and programmable electronic equipment).

"B-type standards" (ISO 13849-1, IEC 62061) are generic safety standards for specific safety aspects and safeguards which describe the specific functional aspects of emergency-stop devices and two-hand control devices.

"**C-type standards**" have priority over the other two standards categories. There are two standards for industrial robots. First, ISO 10218-1:2011 collects the safety requirements for robot manufacturers and addresses the design of robot and its controller. Second, ISO 10218-2: 2011 is intended for system integrators and describes the safety requirements for an

[69] Overview of relevant standards for the introduction of HRC applications (excerpt) in accordance with the experts [69]D. A. Markis, D. H. Montenegro, M. Neuhold, A. Oberweger, C. Schlosse und C. Schwald, „Fraunhofer Austria Research GmbH Sicher-heit in der Mensch-Roboter-Kollaboration Teil 1 Grundlagen, Herausforderungen, Ausblick," 2017. [Online]. Available: https://www.tuv.at/loesungen/industry-energy/industrie-40/. [Zugriff am 28 10 2020].

S. Hilmar, „Wegweiser für die effektive Nutzung von Normen zur Maschinensi-cherheit - ISO/TR 22100-1 des VDMA - Verband Deutscher Maschinen- und Anlagenbau," 2015. [Online]. Available: https://www.beuth.de/blob/97162/83d3ad8607eed04466cb341c862b0cb8/iso-tr-22100-1-wegweiser-data.pdf. [Zugriff am 11 05 2020].

DIN EN ISO 10218-2, „Industrial robots - Safety requirements - Part 2: Robot systems and integration (ISO10218-2:2011)," Berlin, S. Beuth Verlag, 2012.

Europäische Kommission, Summary of references of harmonised standards published in the Official Journal – Directive 2006/42/EC 1 of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC, Brussels 16.4.2020, 2020.

industrial robot system, consisting of an industrial robot and any auxiliary devices. (ISO 10218 -1/2 new, 3rd edition is currently under development). For collaborative robot currently exists only technical specification (ISO/TS 15066:2016), which provides additional information and guidance on collaborative robot operations for those who conduct risk assessments when humans and robots work together. It is first in the word safety requirement for collaborative robots. ISO/TS means technical specification, showing what safety requirements that exists nowadays, are still under development and the final version of safety standard will be released in the future. (Collaborative robots are a relatively new technology).

1.3.4 DIN EN ISO 12100: General design approaches - Risk assessment and risk reduction

This harmonised standard specifies the basic terminology and a methodology for the safe design and construction of machinery. In doing so, the standard establishes guiding principles for risk assessment and risk reduction. It also describes procedures for identifying hazards and for risk assessment and risk evaluation in the relevant phases of a machine's service life. In addition, this standard provides approaches for the elimination of hazards or the provision of sufficient risk reduction, as well as a guideline for the documentation and proof of the risk assessment and the risk reduction process[70].

1.3.5 DIN EN ISO 13849-1: Safety of machinery - Safety-related parts of control systems

DIN EN ISO 13849-1 is a basic standard for functional safety. The application of the standard can be assigned to the area of risk assessment (cf. DIN EN ISO 12100). The standard generally deals with the assignment of suitable reliability classes of risks based on a risk graph and with the assessment of safety functions using structural and statistical methods[71]. DIN EN ISO 13849-1 pursues the goal of checking and ensuring the suitability of safety measures for the respective application.

For each selected safety function that is to be used in the planned application, a required performance level (PLr) must first be defined and documented. The determination of the PLr thereby represents the result of the risk assessment, related to the share of risk reduction by the planned safety functions. The greater the proportion of risk reduction to be provided by the safety function, the greater the PLr must be[72]. If the PLr has been determined for the respective application, all safety-relevant control systems as well as sensors and actuators of the application must comply with the determined PLr and fulfill its requirements[73].

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[70] DIN EN ISO 12100, *Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO12100:2010) DIN Deutsches Institut für Normung e.V.,* Berlin: S. Beuth Verlag, 2011.

[71] C. Bittner, H. Bode, A. Christ, R. Gaiser, A. Hahn, J. Hasel, T. Klindt und M. Moog, Das Sicherheitskompendium für den Umgang mit Normen zur funktionalen Sicherheit, 2017.

[72] DIN EN ISO 13849-1, *icherheit von Maschinen - Sicherheitsbezogene Teile von Steuerungen - Teil 1: Allgemeine Gestaltungsansätze (ISO13849-1:2015) DIN Deutsches Institut für Normung e.V. Berlin,* Berlin: S. Beuth Verlag, 2015.

[73] R. Müller, J. Franke, D. Henrich, B. Kuhlenkötter, A. Raatz und A. Verl, Handbuch Mensch-Roboter-Kollaboration. 1. Auflage, München: S. Hanser-Verlag, 2019.

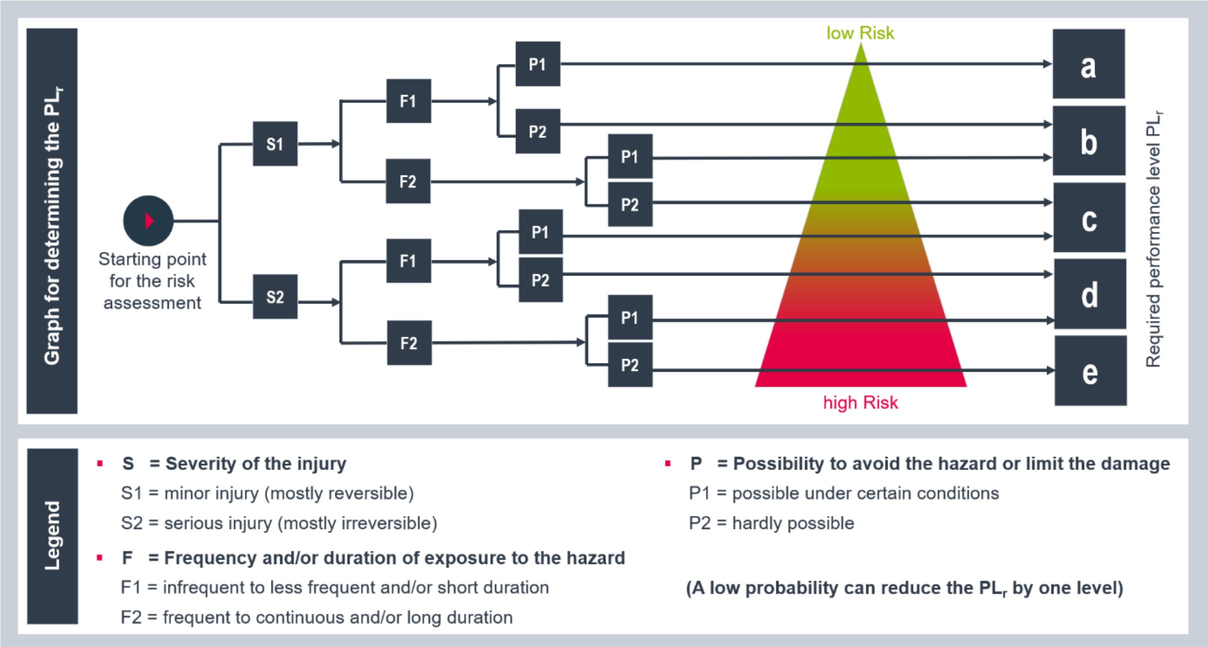

Figure 32. Graph for determining the PL_r for safety functions in accordance with DIN EN ISO 13849-1[74]

In addition to PLr, DIN EN ISO 13849-1 requires a further classification of the requirements for the safety functions with regard to resistance to faults and behavior when faults occur. This classification is made in the following five categories: B, Cat.1, Cat.2, Cat.3, Cat.4. The achievement of a performance level is significantly influenced by the category. If the category has been determined for the respective application, all safety-related control systems as well as sensors and actuators of the entire application must at least meet the requirements of the determined category. Safety-related parts of control systems and safety functions of robot systems in general must be designed in accordance with DIN EN ISO 10218-1 so that they fulfill at least PLr "d" with structure category "Cat.3"[75].

1.3.6 DIN EN ISO 13850 Safety of machinery - Emergency stop function - Principles for design

DIN EN ISO 13850 specifies the functional requirements and design principles for the emergency stop function of machines. The purpose of the emergency stop function is to avert or prevent existing or imminent emergency situations that arise due to the behavior of the machine operator or from another unexpected hazardous event[76].

[74] Sicherheit von Maschinen - Sicherheitsbezogene Teile von Steuerungen - Teil 1: Allgemeine Gestaltungsansätze (ISO13849-1:2015) DIN Deutsches Institut für Normung e.V. Berlin, Berlin: S. Beuth Verlag, 2015

[75] DIN EN ISO 10218-1, *Industrieroboter - Sicherheitsanforderungen - Teil 1: Roboter (ISO10218-1:2011) DIN Deutsches Institut für Normung e.V. Berlin,* Berlin: S. Beuth Verlag, 2021.

[76] DIN EN ISO 13850, *Safety of machinery - Emergency stop function - Design principles (ISO13850:2015) DIN Deutsches Institut für Normung e.V. Berlin,* Berlin: S. Beuth Verlag, 2015.

1.3.7 DIN EN ISO 11161 Safety of machinery - Integrated manufacturing systems - Basic requirements

DIN EN ISO 11161 specifies the safety requirements for Integrated Manufacturing Systems (IMS). An IMS is a system that contains two or more interconnected machines that work together in a coordinated manner and are designed for special applications, such as the production of individual parts or assemblies. DIN EN ISO 11161 provides requirements and recommendations on how to design a safe construction, technical protective measures, and user information for IMS of this type[77]. In the area of HRC, IMS are created, for example, by the implementation of the application by two or more collaborative robotics or by the combination of collaborative robotics with other machines, such as the loading of lathes or milling machines by a collaborative robotics. If an HRC application to be planned corresponds to an IMS, the following additional aspects must be taken into account as part of the risk assessment and risk reduction process[78].

1.3.8 DIN EN ISO 10218-1/2 Robots and robotic devices - Safety requirements for industrial robots

DIN EN ISO10218-1/2 is the applicable standard for industrial robot systems and defines the basic safety requirements for the operation of robot systems. This standard consists of two parts. While the first part deals with the requirements for the robot itself, the second part, which is mainly relevant for this work, defines the safety requirements for the integration of robots and robot systems into an operational environment[79].

DIN EN ISO 10218-2 describes the relevant hazardous situations that can arise during the operation of robots in the industrial sector and also contains requirements and guiding principles to eliminate or sufficiently reduce the risks associated with these hazards.

1.3.9 DIN ISO/TS 15066 Robots and robotic devices - Collaborative robots

In the current version of ISO/TS 15066, in addition to the specifications for carrying out the risk assessment and hazard identification process, there are also further specifications for the general design of the collaboration space, for minimum distances between humans and robots, for maximum robot speeds, and for the applicable requirements for safety principles such as power and force limitation[80]. The technical specification is only valid in conjunction with the safety requirements described in DIN EN ISO 10218[81].

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[77] DIN EN ISO 11161, *Safety of machinery - Integrated manufacturing systems - Basic requirements (ISO 11161:2008 + Amd 1:2010) DIN Deutsches Institut für Normung e.V. Berlin,* Berlin: S. Beuth Verlag, 2010.
[78] DIN EN ISO 11161, *Safety of machinery - Integrated manufacturing systems - Basic requirements (ISO 11161:2008 + Amd 1:2010) DIN Deutsches Institut für Normung e.V. Berlin,* Berlin: S. Beuth Verlag, 2010.
[79] B. Ostermann, „Entwicklung eines Konzepts zur sicheren Personenerfassung als Schutzeinrichtung an kollaborierenden Robotern," Bergische Universität Wuppertal, Wuppertal, 2014.
[80] M. Schenk und N. Elkmann, „Sichere Mensch-Roboter-Interaktion: Anforderungen, Voraussetzungen, Szenarien und Lösungsansätze," in *Demographischer Wandel - Herausforderung für die Arbeits- und Betriebsorganisation der Zukunft*, Berlin, S. GITO mbH Verlag, 2012.
[81] DIN ISO/TS 15066, *Roboter und Robotikgeräte - Kollaborierende Roboter (ISO/TS 15066:2016) DIN Deutsches Institut für Normung e.V.,* S. Beuth Verlag, 2017.

DIN ISO/TS 15066 contains generally applicable safety requirements to be placed on a collaborative robot system. In addition to the general safety requirements, DIN ISO/TS15066 also provides explicit information and requirements for the respective modes of collaborative operation.

1.3.10 Requirements profile from the legal and normative regulations for the safe design of HRC applications

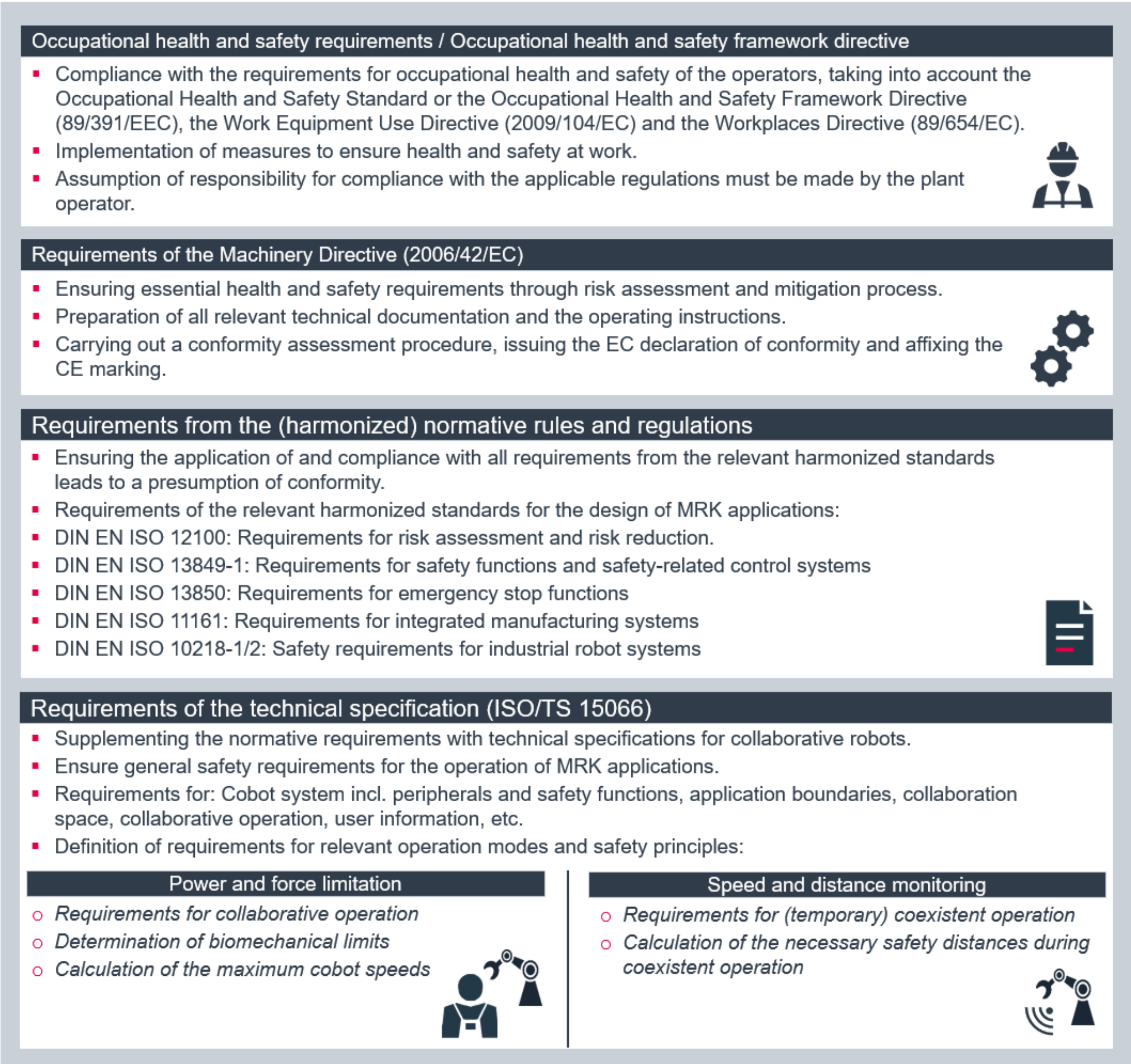

Figure 33. Requirements profile from the legal and normative regulations for the safe design of HRC applications[82]

[82] *I. Gröner, „Sichere Anlagenplanung einer Mensch-Roboter-Kollaboration," Masterthesis, Karlsruhe, 2020.*

1.3.11 Specificities per country

In different European Union countries, the regulations of the Machinery Directive 2006/42/EC (called Machine directive 2006/42/CE for France and Spain) were implemented by the Ordinance of the Act on the Provision of Products on the Market (*Produktsicherheitsgesetz* (*ProdSG*)) and the ninth Ordinance to the *Produktsicherheitsgesetz* (*9. ProdSV*) based on it for Germany. HRC applications fall under the scope of the Machinery Directive 2006/42/EC[83]. In order to implement and fulfill all applicable regulations of the Machinery Directive 2006/42/EC, the manufacturer of a system can refer to the presumption of conformity through the application of harmonised standards in accordance with Article 7 of the Machinery Directive 2006/42/EC. This means that if a machine complies with the specifications of the harmonised standards, it can generally be assumed that it also complies with the essential health and safety requirements of the Machinery Directive 2006/42/EC. Standards are not legally binding but serve as an aid to decision-making in the event of a dispute[84].

Harmonised standards include all standards or technical specifications which have been ordered by the European Commission through the award of mandates or standardization contracts and published in the Official Journal of the EU[85].

As a conclusion on the regulation and safety norm concerning the use of collaborative robotics: we can say that the use of collaborative robotics is regulated by several norms, but it highlights the fact that sometimes it is a challenge to face for the companies to apply to those regulations.

[83] B. Ostermann, Entwicklung eines Konzepts zur sicheren Personenerfassung als Schutzeinrichtung an kollaborierenden Robotern, Wuppertal: Bergische Universität Wuppertal, 2014.
[84] DIN Deutsches Institut für Normung e.V., „DIN," [Online]. Available: https://www.din.de/de/ueber-normen-und-standards/normen-und-recht/rechtsverbindlichkeit-durch-normen.
[85] Europäische Kommission, „Richtlinie 2006/42/EG des Europäischen Parlaments und des Rates vom 17. Mai 2006 über Maschinen und zur Änderung der Richtlinie 95/16/EG (Neufassung) Amtsblatt der Europäischen Union," 17 05 2006. [Online]. Available: https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32006L0042&from=DE. [Zugriff am 06 05 2020].

1.4 Analysis report of the current use of collaborative robotics in the manufacturing sectors in the European Union thanks to the TOURINGS' project results.

As mentioned in the introduction of this report, the document has been written based on the information taken from 62 case studies identified in five different countries of the European Union, 52 interviews (mainly conducted in Germany) and 36 national reports identified by the six partners in the five different countries partners of the TOURINGS' project. The TOURINGS' project also led to the delivery of a questionnaire (see **Appendix 1**) through different distribution channels (publications on LinkedIn, direct email sent, etc.). This questionnaire, composed by 32 questions, was destined to people working directly or indirectly with collaborative robotics in the manufacturing sector across the European Union. Unfortunately, the questionnaire only received 29 answers. The respondents of our questionnaire are divided as shown in the following figures (**Figure 34, Figure 35, Figure 36)**.

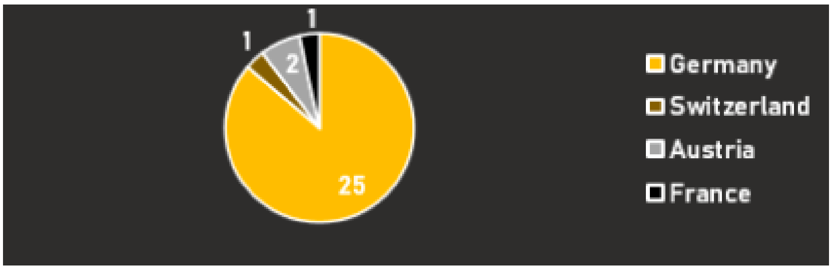

Figure 34. Countries of origin of the respondents of the questionnaire

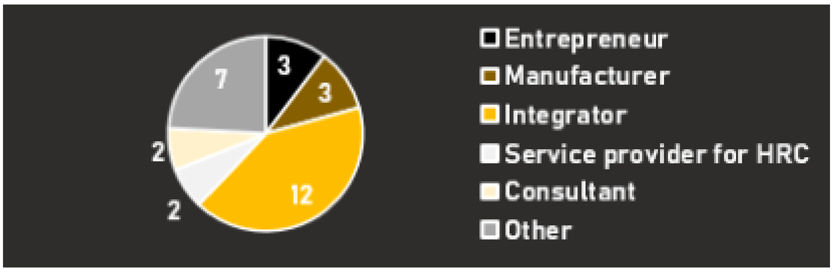

Figure 35. Profession of the respondents of to the questionnaire

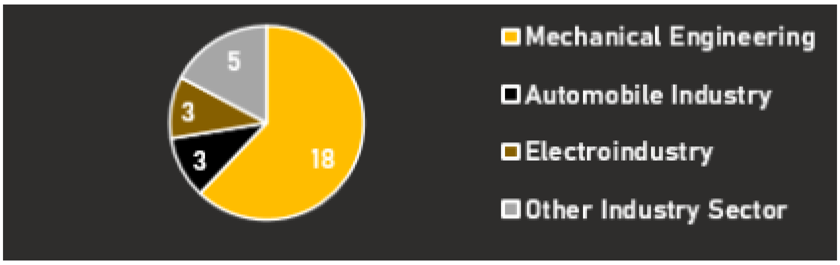

Figure 36. Industry in which the respondents the questionnaire work

Bearing in mind the data of section 1.2.2 of this Report, the population sample answering the TOURINGS questionnaire does not reflect well the current use of collaborative robotics in the European Union, neither the origin of the people answering to the questionnaire nor the sector in which they work for. Therefore, we must draw the reader's attention to the fact that the statements aroused by the analysis of the results taken from the questionnaire will only constitute hypotheses and cannot be considered as general statements.

Concerning the experience of the respondents, the following figure (**Figure 37**) shows that the respondents sample is mainly composed by people with a certain experience based on the number of years they have spent working with collaborative robotics, while less than one fourth is widely experienced with more than 5 years of expertise in the human robot collaboration area.

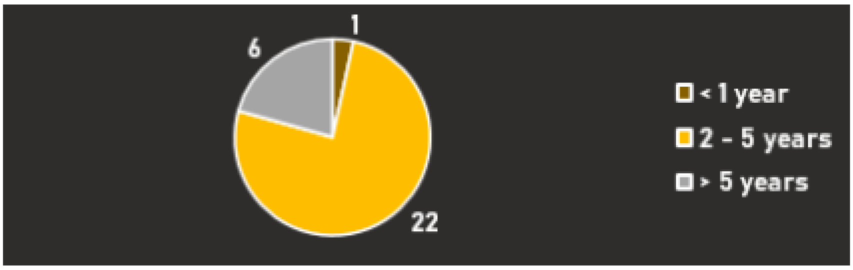

Figure 37. Years of expertise of the respondents of the TOURINGS questionnaire

Considering the fact that collaborative robotics only exists since 2008, we can ponder that the training time necessary to train workers in this newly created sector of robotics has taken much time, and therefore we could pose the hypothesis that the previous figure (**Figure 37**) reflects to a great extent the current division of the number of years of expertise of the people working directly or indirectly with collaborative robotics.

In the sample studied during the TOURINGS' project, we notice with surprise that despite most of the respondents working in companies where no human robot collaboration process exist (**Figure 38**), they are highly experienced in the planning and implementation of human robot collaboration processes as shown in **Figure 39** and **Figure 40**.

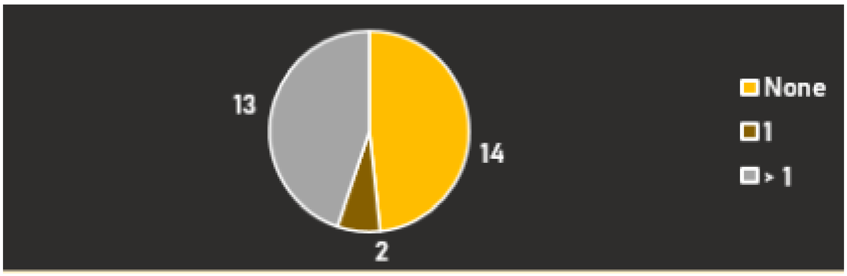

Figure 38. Number of collaborative robotics processes implemented in the current company of the respondent of the questionnaire

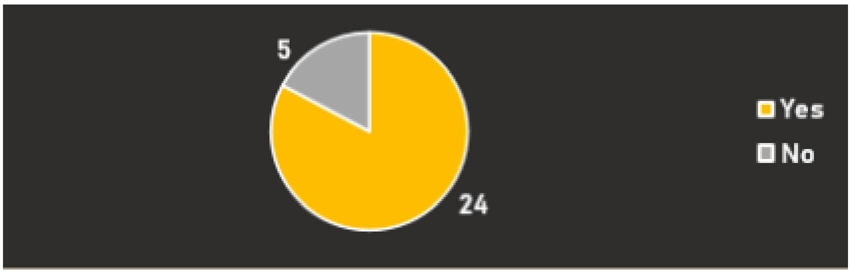

Figure 39. Experience of the respondent of the questionnaire in the planning and implementation of human robot collaboration process in industrial companies

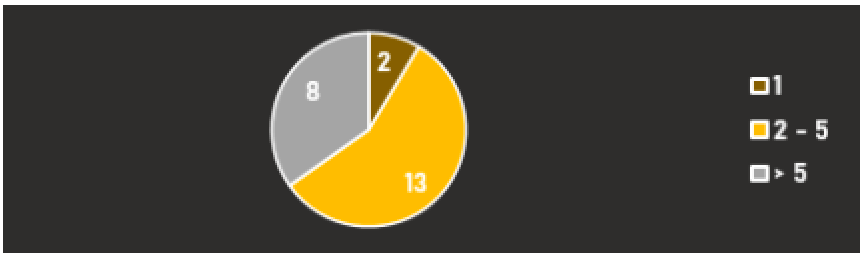

Figure 40. Number of planned and implemented human robot collaboration processes per respondent

Therefore, even if the TOURINGS’ questionnaire results do not perfectly reflect the current use of collaborative robotics in the manufacturing sector of the European Union countries concerning the distribution of the population sample, we can notice that the respondents’ sample is a highly qualified population sample. Consequently, the questionnaire results from the TOURINGS’ project might provide more valuable observations and highlight difficulties encountered by experienced people working with collaborative robotics, and who will not give a first impression about their use of collaborative robotics. Thus, we can conclude that our results will provide long-term analysis about the implementation and use of collaborative robotics in manufacturing sectors.

Concerning the operating modes of the use of collaborative robotics, the following figures (**Figure 41** and **Figure 42**) present the fact that most of the respondents think that collaboration (power and force limiting) and coexistence (safety-rated monitored stop) are the sequence in which operating modes are most often implemented.

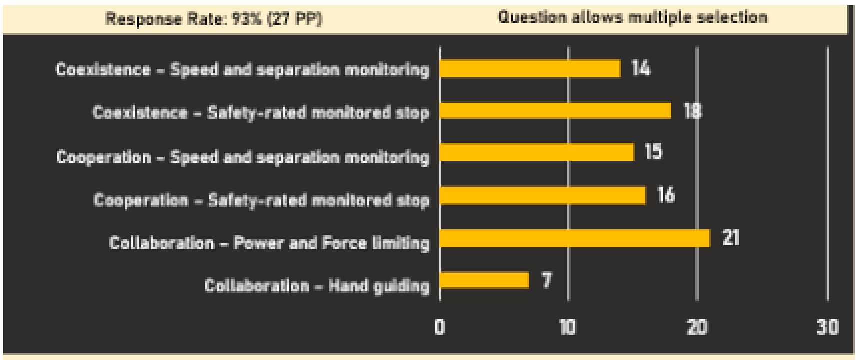

Figure 41. Operating modes for the HRC applications used by the respondents

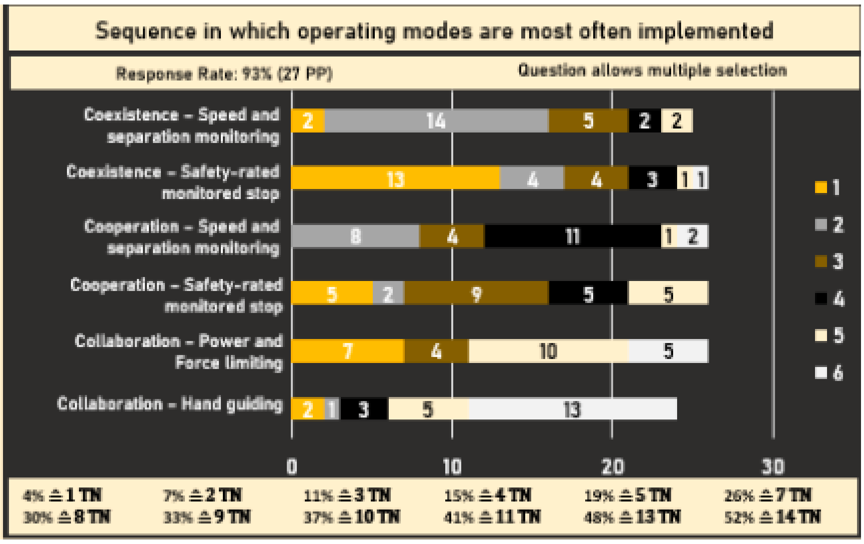

Figure 42. Sequence in which operating modes are most often implemented following the respondents' sample

As seen in **Figure 34**, more than 90% of the respondents are German. Therefore, we can imagine that the three following figures (**Figure 43**, **Figure 44,** and **Figure 45**) corresponding to the brands of collaborative robotics used, manufacturing and gripping systems used and preferred might be influenced by the country of the population sample.

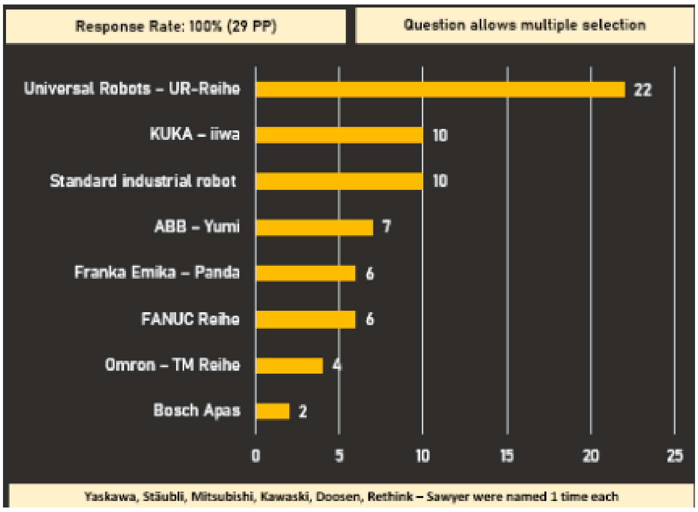

Figure 43. Brand and model of cobots used by the repsondents

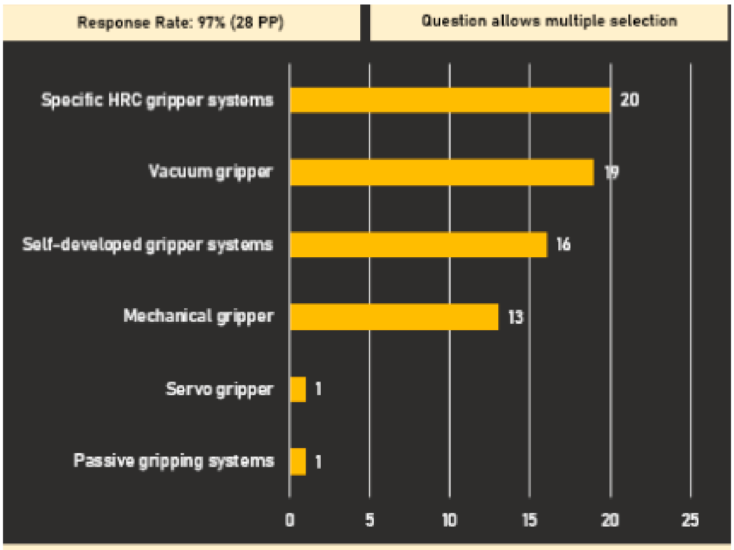

Figure 44. Gripping technology used by the respondents

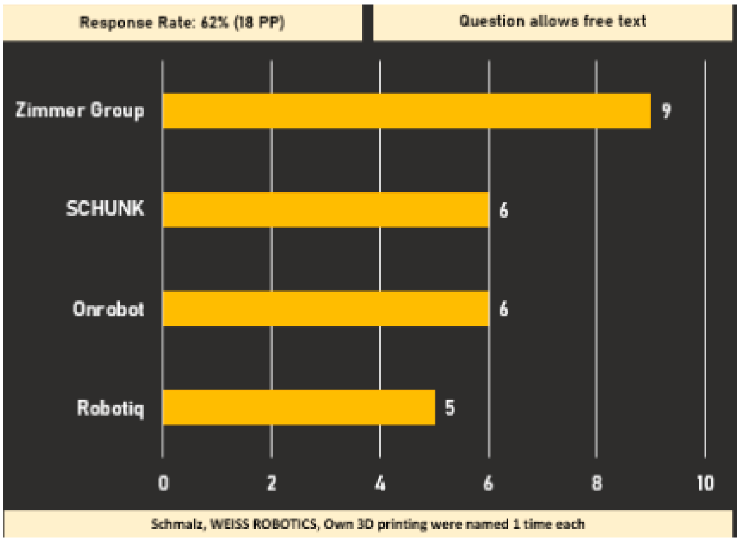

Figure 45. Preferred manufacturer of gripping systems for the respondents

As stated above, the three last figures (**Figure 43, Figure 44,** and **Figure 45**) may not reflect the complete market of collaborative robotics and might be influenced by the fact that most of the respondents are German. Therefore, we can pose the hypothesis that they prefer using German tools (Kuka cobots, for example, and Zimmer's gripping systems). Those preferences can be linked to the geographical fact: if the providing company is German, the delivery will be fast, such as the implementation of the collaborative robotics. Furthermore, this element can be explained by the fact that if the provider's company is in Germany, the training courses can be delivered in German. And this explanation could be valid for any other country belonging to the European Union considering that there is no European Union country having English as their official language. Thus, if there is a national provider for any collaborative robotics or gripping system, the company implementing collaborative robotics will choose national provider's company (if the price is not deterrent).

Concerning the processes suitable for the human robot collaboration applications, most of the respondents has considered that handling and pick and place processes were the most suitable for the human robot collaboration applications, as shown in the following figure (**Figure 46)**.

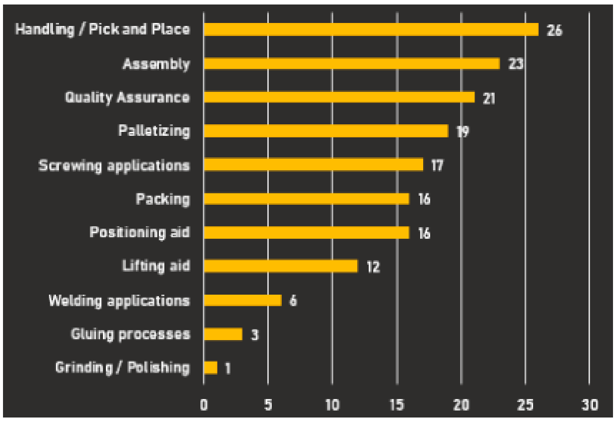

Figure 46. Most suitable processes for human robot collaboration applications according to the respondents

The previous figure (**Figure 46**) shows an interesting fact, the level of difficulty is not the same at all between the different processes. The most suitable process according to the respondents is the handling, pick and place process, while it is not the most difficult process. Conversely, the second and third most suitable processes for human robot applications according to the respondents seem more difficult than the pick and place process which can be fully automised. Therefore, the respondents consider that collaborative robotics can perform both difficult and easy tasks in the same proportions.

The following figure (**Figure 47**) shows the main characteristics that a process must have in order to be useful for a human robot collaboration application according to the respondents' answers.

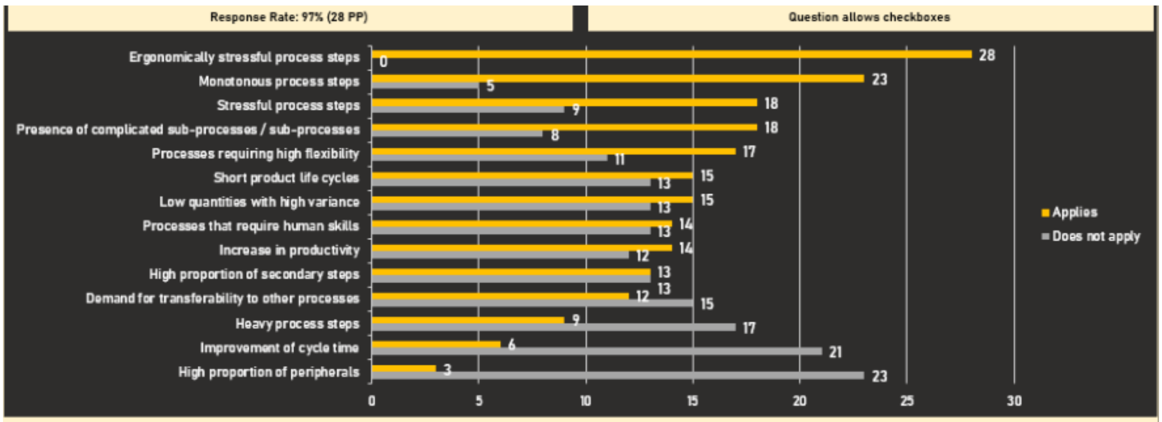

Figure 47. Characteristics needed by a process to be useful for a human robot collaboration application according to the respondents

The previous figure (**Figure 47**) shows a division of opinion in the matter of the characteristics needed by a process to be useful for a human robot collaboration application.

This may be explained with the answers gathered in the **Figure 46** and the **Figure 47**. If the processes suitable for human robot collaboration application are not the same for each respondent, it stands to reason that the characteristics needed by a process to be useful for a human robot collaboration application are not the same either.

One of the most surprising elements analysed through the TOURINGS' survey results, is that no two people agreed on the process to plan and implement a human robot collaboration application. The following figure (**Figure 48**) shows the data.

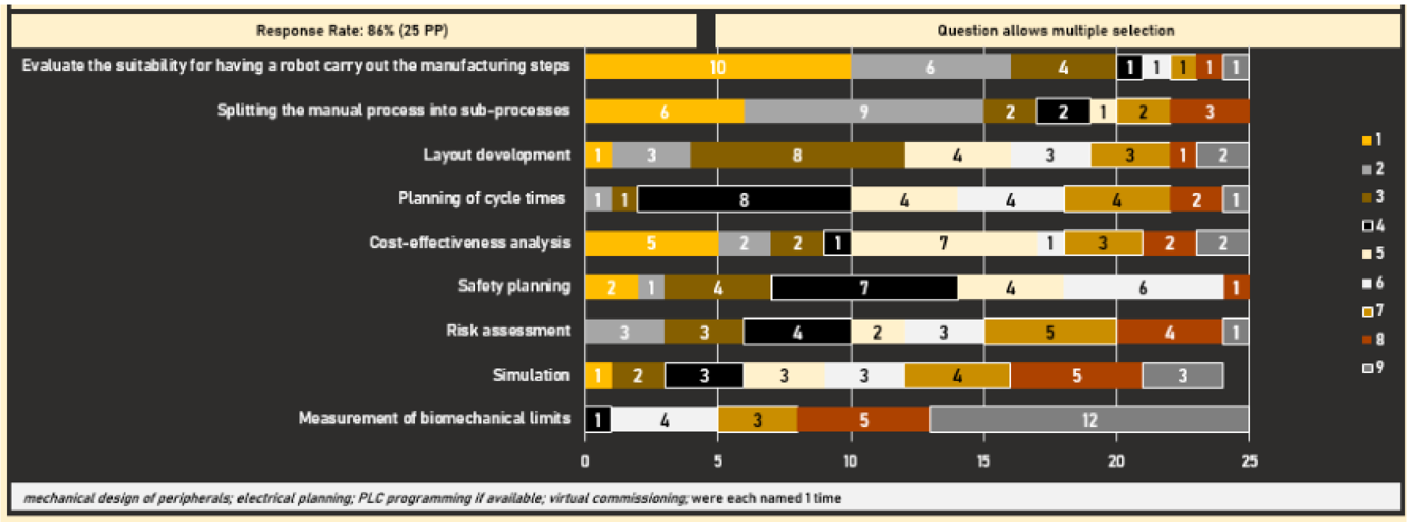

Figure 48. Sequence of processing in the planning and implementation of human robot collaboration application according to the respondents

More than an anecdotal fact, the previous figure (**Figure 48**) brings forward that the use of collaborative robotics is so recent that there are no standardized processes enabling its implementation and use. Therefore, the TOURINGS' project will deliver a kind of "good practices guide" through its training modules, and therefore will contribute to the improvement of the real effective use of collaborative robotics in manufacturing companies of the European Union.

As a conclusion of the results of the TOURINGS' questionnaire, we can state that the population's sample does not reflect the entire European Union current use of collaborative robotics. However, those results allow the assessment of some hypothesis about as the preference for national brands, referred to the brand of the collaborative robotics and the gripping system manufacturer, but also that the process employed for a human robot collaboration application will include specific expectations from the workers in terms of essential characteristics.

2. Main benefits and main challenges faced by companies to install Collaborative Robotics in the European Manufacturing sector

As seen in the previous sections of this report, companies tend to use more and more collaborative robotics in their production lines. This trend is, of course, linked to the benefits gained thanks to the implementation of collaborative robotics; nevertheless, it is also, unfortunately, linked to new challenges. The second part of this report will focus on the main benefits and challenges analysed by some European companies.

2.1 Main benefits analysed by European companies

2.1.1 Main expected benefits

This subsection will present the theoretical advantages gained by a company after implementing collaborative robotics on its production line. The reasons why companies want to collaborate could be resumed in the following list of advantages provided by collaborative robotics. A company would collaborate thanks to the cobots':

- Ergonomic aspects,
- Demographic change,
- Flexibility,
- Product quality / Precision,
- Economic efficiency.

The collaborative robotics makes it possible:

- To automate sensitive or complex tasks,
- To enable completely new assembly concepts,
- To enable teamwork between humans and robots,
- To help relieve workers at unergonomic workplaces,
- To reduce production costs in high-wage countries,
- To eliminate classic causes of accidents,
- To reduce cost intensive manual tasks.

The collaborative robotics present several advantages compared to classical industrial robots:

- First, collaborative robotics help people with repetitive, monotonous, arduous and dangerous tasks. The human operator can concentrate on the most qualified tasks with the highest value added, which improves the final quality of the products. Unlike industrial, heavy and rigid robots which cannot be moved, collaborative robotics can be moved from one task to another by the operator without reprogramming.
- collaborative robotics work without safety fences. Cells are often very expensive, so eliminating them reduces costs.
- collaborative robotics are less expensive than traditional industrial robots (the entry price is 10,000€) and may be suitable for companies with potential to invest under 50k euros that want to automate certain tasks.

- The implementation of collaborative robotics allows to preserve the ergonomics of an already existing workstation.
- And last, but not least: collaborative robotics are more versatile and thus adapt to changes in production.

As a conclusion on this section concerning the expected advantages of the collaborative robotics, we can say that theoretically: collaborative robotics present an infinity of advantages compared to traditional industrial robots. Now, we are able to draw a parallel between those theoretical advantages with the advantages underlined through the analysis of the interviews and case studies conducted in the TOURINGS project.

2.1.2 Main benefits identified by companies located in Europe and according to the typology presented in part 1.

Even if the benefits of the collaborative robotics use in European Union companies are similar disregarding the countries, we have chosen to separate the benefits following our typology in order to underline the fact that sometimes there are discrepancies between the benefits found in the countries belonging to our typology[86]. This typology is presented in the following table (**Table 8**).

2.1.2.1 *As a reminder, the definition of the four categories of our typology:*

Type 1	The first category is characterised by countries, which are advanced both in the industrial sector and in their level of robotization (and therefore on their use of collaborative robotics). **Germany** is a perfect example of this category.
Type 2	The second category is represented by countries, which are less advanced both in the industrial sector and in their level of robotization (and use of collaborative robotics) compared with type 1. **Italy** is advanced on the industrial sector and in its use of collaborative robotics but is one third less advanced than Germany.
Type 3	The third type includes countries, which are advanced on their industrial sector but not much on their use of collaborative robotics. **Estonia** is an example of this category.
Type 4	The fourth category is composed by countries which are a bit late in the development of their industrial sector (it can be due either to a lack of development or to a retreat from their industrialisation) and which are a bit late in their use of collaborative robotics compared with the other European Union countries. **France or Spain**

[86] We need to remind the reader that the expected benefits remain to specific situations analysed through case studies (presented in **Appendix 4**) and therefore belong to specific situations and cannot be elevated to the general law rank for all companies, even if some similarities arise.

	will be used as examples for the presentation of this category.

Table 8. **Four types of European countries based on the number of collaborative robotics used in industry and the weight of industry in the GDP**

2.1.2.2 *Main benefits identified by some German companies*

The following table (**Table 9**) presents the benefits of the use of collaborative robotics in German case studies.

Reasons of the collaborative robotics use detected by the cases studies	▪ Cobot can pick up/remove a part and place it in a second holder ▪ Cobot can assemble, place, fix and adjust components ▪ Cobot can check the correctness and verification ▪ Cobot can hold and move heavy parts ▪ Cobot can remove parts from the assembly line ▪ Cobot can weld the parts ▪ Cobot allows collaborative joining process ▪ Cobot allows collaborative function tests
Advantages provided by collaborative robotics identified thanks to case studies	▪ Improves ergonomics and quality (physical and cognitive stress reduction) ▪ Increases safety for worker ▪ No rigid separation of full automatisation and manual work: better hand in hand work ▪ Easy to integrate into work process: easy operation and programming ▪ Increases flexibility and efficiency ▪ Manual use cases that were ergonomically or safety critical should be implemented, robots are most used in physically demanding activities ▪ Less stress for workers, better quality and productivity ▪ Save time and money ▪ Repeatability
Implementation of collaborative robotics in a production line	**It takes three departments to implement human robot collaboration:** 1. Knowledge in information structure, program structure, solution (classical case a computer scientist) 2. Knowledge in risk assessment, uncovering what manufacturers promise in marketing talks and where the traps are 3. Knowledge in construction, mechanics, electrics **Design interactions between workers and** collaborative robotics: ▪ Ergonomic workplace design ▪ Involve employees in the process (have extensive know-how and work with the workplace every day) ▪ Human starts cobot ▪ Human presents the parts to the robot ▪ Workers work laterally and the robot is placed centrally

	▪ Workers hand the parts to the robot and vice versa ▪ Workers work laterally and the robot is placed centrally ▪ The employee interacts with the robot using explicit and implicit gestures and thus controls which positions the robot should move to ▪ Human guides the cobot ▪ Error handling by humans **Put in place plan as illustrated in the case studies:** 1. **Step 1. Detection of the need:** ▪ Detect what kind of workers the companies need to put in place cobots 2. **Step 2. Training:** ▪ Training for workers ▪ Seminars, advisory services 3. **Step 3. Create useful materials:** ▪ User interface: (e.g., Sofia: specially for the new KUKA robot generation of lightweight robots (LBR)), which enables simple and easy-to-learn operation and programming) ▪ Brochures for technical data and manual guidance ▪ Provide workers with innovative welding technology, intuitive software and exclusive services ▪ Digital twin 4. **Step 4. Human Resources needs:** ▪ Use workers who are familiar with the process as integrators ▪ Workers that operate the cobot 5. **Step 5. Make the cobot working:** ▪ Workers learn how to use the software then they teach cobot ▪ Use teach packet ▪ Research projects

Table 9. **Benefits of the use of collaborative robotics found in Germany thanks to the case studies and the interviews conducted**

2.1.2.3 *Main benefits as identified by some Italian companies (As a reminder Italy belongs to the type 2)*

According to the Italian cases studies[87], human robot collaboration presents advantages when its use is compared to industrial robotics[88]. These advantages would be:

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[87] https://www.universal-robots.com/case-stories/lem-optical/
https://www.universal-robots.com/case-stories/marka/
https://www.fanuc.eu/it/it/casi-di-successo/vigap?returnurl=https%3A%2F%2Fwww.fanuc.eu%2Fit%2Fit%2Fcasi-di-successo
[88] https://www.todrobot.com/blog/principali-vantaggi-della-robotica-collaborativa/

- The interaction between the robot and the operator,
- Collaborative robotics can assist operators in performing difficult tasks that cannot be completely automated,
- Collaborative robotics use does not require safety fence or cage,
- Collaborative robotics are easy to program and use,
- Collaborative robotics permit accurate execution of a task,
- The robot moves effortlessly from one place to another in the production line.

Moreover, the accurate execution of tasks allows companies in the achievement of constant productivity and greater rationality in workforce management and in providing a number of customisations requested by clients, which would have been impossible to achieve manually. The collaborative robotics have also allowed the company to optimise some strategic processes thereby increasing productivity and end quality. Despite a few disadvantages, the analysis of the Italian data has demonstrated that human robot collaboration is the best choice for small and medium companies thanks to the limitation of the space required for the collaborative robotics implementation. Furthermore, the collaborative robotics implementation in Italian companies has revealed that the employees were relieved from repetitive and arduous tasks which has led in the majority of cases, to a general improvement of the companies' production line operational efficiency.

2.1.2.4 *Main benefits as identified by some Estonian companies (As a reminder Estonia belongs to the type 3)*

According to the Estonian case studies, the main reason why companies adopt the use of collaborative robotics is because of its simplicity concerning its implementation process, its ease of use and of programming. Furthermore, the use of collaborative robotics in Estonia is certainly facilitated by their relatively low cost, which expands their use even in companies with a relatively small number of employees (less than 50 people).

One of the additional benefits of using collaborative robotics, which is proper to the specific Estonian case, is related to labor shortages and to its aging population and the specific characteristics of the Z and alpha generations. Generation Z is composed by people born from 1995 to 2010. From earliest youth, they have been exposed to the internet and therefore are true digital natives, to social networks, and to mobile systems. That context has produced an hypercognitive generation very comfortable with collecting and cross-referencing many sources of information and with integrating virtual and offline experiences. Businesses must rethink how they deliver value to the consumer, rebalance the production and how to consider the work ethics of Z and alpha generations.

The rationality of collaborative robotics application in factories can also be evaluated by a comparison between the use of collaborative robotics and the conventional industrial robots. According to *Fasth*, collaborative robotics have advantages over conventional industrial robots, like:

- They are able to work safely with a person (thanks to high-speed sensors and different types of cameras),

- They are easy to install and configure (in some cases it is possible to go without programming),
- They have a lower cost, many of them are cheaper than the usual industrial robot: 20,000 € instead of 50,000 €,
- They are easier to install and configure than traditional automated robots, biggest part of collaborative robotics only weigh about 30 kg, and only need a 220v outlet,
- They are flexible and easy to adjust, they provide a graphical user interface (GUI), which permits an intuitive programming interface.

Therefore, the following chart (**Table 10)** is a summary of the advantages brought forward by using collaborative robotics instead of using traditional automated industrial robots.

Traditional industrial robots' characteristics	Collaborative robotics' characteristics
• Fixed installation • Repeatable tasks rarely changed • Lead-through and off-line programming, high programming skills are required • Hard to integrate • Rarely interaction with the worker, only during programming • Worker and robot are separated through fence • Cannot interact with people safely • Profitable only with medium to large volumes of production • Big, very fast, hard to move, hard to start using • High payload • Return on investment (ROI) achieved between 3 and 5 years	• Flexibly relocated • Frequent task changes • On-line programming (lead-through walk-through), no programming skills are required • Relatively simple to integrate • Frequent interaction with the worker, force/precision assistance • Shared workspace • Safe interaction with people • Profitable even at low volume production • Small, slow, easy to use and easy to move • Limited reach and payload • Return on investment achieved typically between 1 and 2 years

Table 10. **Conventional and collaborative robot's comparison**

Furthermore, traditional industrial robots require incredible amounts of programming and sensors to account for the many possible variables. For example, it is far more cost effective for a person to bring and present parts to a robot for subassembly or welding than to train the robot to go elsewhere in a facility. All of the safety and environmental factors involved turn the tasks of gathering materials and performing the job more sophisticated with the use of industrial robots. collaborative robotics, conversely, work with software for many machines and applications, which means they can quickly be redeployed to add flexibility to operations. Besides, they are lightweight but reliable. Many cobots have warranties that account for enough operational hours to run continuously for several years.

2.1.2.5 *Main benefits as identified by some Spanish and French companies (As a reminder Spain and France belong to the type 4)*

❖ **Spain**

Automation has a clear effect on competitiveness, as it increases production capacity and optimises the efficiency of floor space. As a result, it protects us from competition. On the employment side, it generates new opportunities compared to manual processes and creates more specialised and highly skilled profiles. COVID-19 made a new paradigm, Spain is moving more and more towards a contactless society to avoid contracting the virus. One great benefit is to create a dialogue about industrial policies in a country that has been committed for years to minimising it. The main benefits of the implementation of collaborative robotics units into manufacturing companies in Spain have had the following impacts:

- The standardization of processes and an ease of programming the robot helping companies to adapt their productivity needs to its growth process,
- Easy programming enables companies to maintain control over the decisions made by the robot,
- Reduction of changeover time compared to the task performed manually,
- The robot offers flexibility, adaptability and customisability on the assembly line,
- 35% of higher productivity,[89]
- Employees freed from repetitive and low-value-added tasks which could cause injuries,
- Optimising the use of resources,
- Cost reduction due to truly collaborative applications,
- High versatility, the robots could be adapted to different production needs,
- High scalability, behavior could be easily changed by re-programming,
- Occupies 50% less space than an industrial robot,
- Eliminates musculoskeletal disorders due to crate lifting,
- Better monitoring of all processes,
- Increased control over production,
- Higher level of employee motivation.

Apart from the price of collaborative robotics units, one of the main benefits have been the zero click interfaces. In other words, the natural human-robot connection. This includes the ability to analyse and understand the environment, interpretation and emotional communication. The current trend is addressed to robotics that does less, but does it better: direct-use and direct-utility robotics. These are integrating, in a progressive way, technologies from service robotics, which make industrial robots more multi-purposes.

❖ **France**

Through the case studies analysed in France, the benefits of the use of collaborative robotics are numerous and are presented in the following list.

- First, many companies declare that they have implemented collaborative robotics in their production line in order to decrease the number of issues linked to WMSDs (Work-related Musculoskeletal Disorders). For example, Mademoiselle Dessert got a prize [90] to reward their employer responsibility thanks to the adoption of collaborative robotics in

[89] Average identified thanks through case studies. Of course this rate can be different following the type of application used and work conditions proper to each company.

[90]https://www.usinenouvelle.com/article/prix-marque-employeur-responsabilite-sociale-2020-mademoiselle-desserts-des-cobots-aux-fourneaux.N1004134

its production line. This advantage is also presented by the SNCF (General company of French railways), in their use of collaborative robotics, the operator continues to practice his technical gesture and thus his personal added value, but does not anymore undergo the inconveniences linked to his task (vibrations, weight,e tc.)[91]. This benefit is also extoled by numerous other companies such as Normaero[92], Thyssenkrupp Presta France[93], etc.

- The second "social" advantage advanced by companies is the higher safety for the operators by using collaborative robotics instead of traditional automated industrial robots especially thanks to the safety-rated monitor stop. This argument has been decisive in the adoption of collaborative robotics for SNCF[94] among others.
- Another "social" advantage is raised by the Jacquemet[95] company. They declare that instead of cancelling employment, they operate an upskilling activity for the employees who will work with collaborative robotics. The result seems to be an improvement for all the industrial job market and the whole entire industry thanks to an outreach of skills.
- Another fact advanced by companies is that their productivity rate has increased thanks to the use of collaborative robotics especially thanks to the ease of reprogramming to modify the dedicated task the collaborative robotics are working on. This explanation is developed by the brand L'Oréal which uses Onrobots cobots model to automate their research and development tests[96]. The productivity rate is also improved by indirect consequences, for Thyssenkrupp Presta France, the reduction of work-related musculoskeletal disorders linked to operators' repetitive tasks has driven to a reduction of the number of sick days for the employees leading to a better production rate.[97] It also appears that in reality, many robotic cells did not work as efficiently as expected[98] due to many machines' shutdowns, leading to a lack of competitiveness and a waste of time.
- Other companies declare that they have gained space while the land pressure was increasing almost in the capital Paris and its outskirt. So, the use of collaborative robotics has been an advantage about the direct costs for some companies. Furthermore, the reduction of total costs for companies has also been due to the possibility of reducing the workforce as presented by the Sanofi case study[99].
- Another case study has highlighted the other financial advantages led by collaborative robotics implementation in their production lines. It is the case for the group Jacquemet[100] which has implemented 5 cobots Universal Robots in which 3 were implemented in an internal way thanks to the upskilling of the technicians. They also implemented 3 conventional Fanuc robots characterised by their high cadence. All their collaborative robotics are flexible and used each day. Thanks to those implementations the Jacquemet company has a higher level of robotization than South Korea, the most

[91] https://www.digital.sncf.com/actualites/fiche-tendance-cobot
[92] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/normaero/
[93] https://www.youtube.com/watch?v=JUMpaIxSLRM
[94] https://www.digital.sncf.com/actualites/fiche-tendance-cobot
[95] https://www.youtube.com/watch?v=Ek5ZvnhGDgU
[96] https://www.bfmtv.com/economie/comment-l-oreal-fait-appel-aux-robots-pour-sa-r-d-capillaire_AN-202011190108.html
[97] https://www.youtube.com/watch?v=JUMpaIxSLRM
[98] https://www.youtube.com/watch?v=Ek5ZvnhGDgU
[99] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/
[100] https://www.youtube.com/watch?v=Ek5ZvnhGDgU

advanced country in the number of robots for 10,000 employees, as shown by the following figure (**Figure 49**):

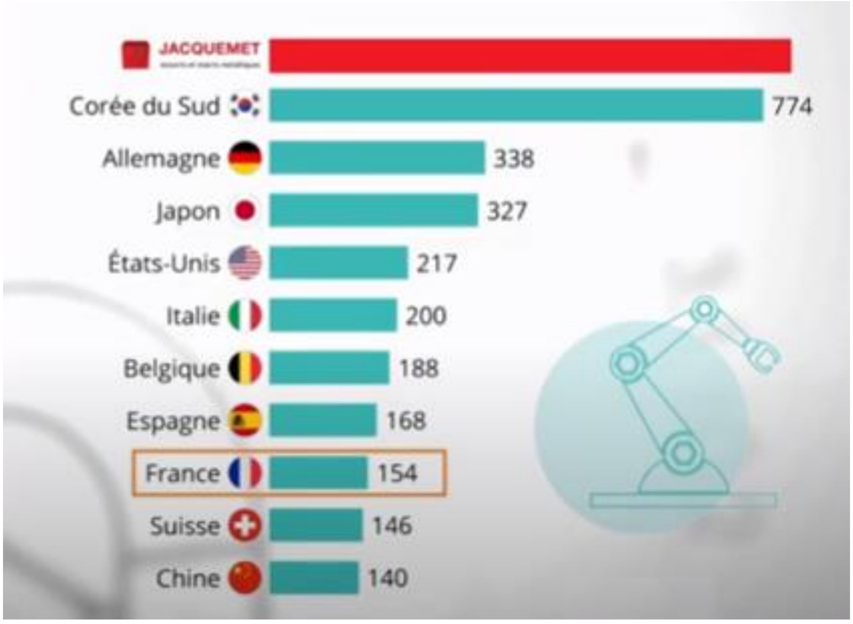

Figure 49. Number of industrial robots for 10,000 employees in industrial sector in 2018[101]

For them, the most relevant financial advantage led by the collaborative robotics implementation in their production lines is of course linked to the high ROI led by collaborative robotics use (which is 2 to 3 times faster than conventional robotics), but also by the indirect advantages led by collaborative robotics. For them, the automation of production lines is vital for PMEs, as they declare "*Jacquemet would probably not exist anymore if there would not have been this automation implementation*"[102], it is the only way for re-locations of companies because they became again competitive in comparison with other countries from Asia or East Europe, thanks to their newly acquired flexibility and their proximity to their clients provided by the collaborative robotics use.

- It also seems that the productivity rate increases thanks to the use of collaborative robotics in production lines during out of work hours, leading to a reconciliation with the TRS (indicator helping to follow the rate of use of the machines). This is a result of collaborative robotics being used during the night, when the fabric is closed, during vacations, etc. Thus, the TRS increases thanks to the collaborative robotics use.
- Furthermore, the case of France is a bit specific about the financial advantage in using collaborative robotics instead of traditional automated industrial robots. Administrative regions give subventions for the companies to get cobots. Therefore (depending on the revenue of the considered company and depending on the region), the total cost of a collaborative robotics bough can decrease by 75% in comparison with its original price. This advantage helps small and medium companies to buy collaborative robotics and to implement them on their production line. For example, this financial benefit was the decisive argument for the 8 employees' company Normaero to implement collaborative

[101] https://www.youtube.com/watch?v=Ek5ZvnhGDgU
[102] https://www.youtube.com/watch?v=Ek5ZvnhGDgU

robotics in their production line.[103] The financial aspect is also linked to the return on investment and not only to the price of the cobot. In the vast majority of cases a collaborative robotics is profitable after 2 years following the Sanofi's declarations.[104]

- As in the other countries, the other advantages declared by companies are linked to the collaborative robotics flexibility, high security systems, their precision in tasks and their better ergonomics. For example, for the company Airbus Aero, collaborative robotics have been implemented through the prism of the Asimov project. This project has permitted to solve issues linked to the precision, even errors, in the printing of holes for the mounting of certain aerostructure elements of the A380. Automating their marking also allowed them to improve their production rate.[105]
- The use of collaborative robotics allows to change easily the operator working on this tool, which is another advantage, sometimes forgotten because it does not highlight the versatility of collaborative robotics in the two main senses: to be adapted to the production needs and to be used by different operators at different times. As mentioned above, the operator job can be hard and may cause muscular troubles, so it is important that the turnover rate on those positions is high. Thus, the use of collaborative robotics allows to easily replace the operators working on it.
- Collaborative robotics implementation also answers to a chronic issue linked to the lack of workforce for repetitive and arduous jobs.
- The maintenance of the collaborative robotics can be performed by companies that do not identify with the constructor of the collaborative robotics'. This fact generates new jobs.

2.1.2.6 *Comparison with TOURINGS' survey results*

According to the respondents of the TOURINGS' survey, the main advantage provided by using collaborative robotics would be the improvement of ergonomics in comparison with traditional automated industrial robots, as shown in the following figure (**Figure 50**). The improvement of ergonomics is key for some companies. For example, Sanofi has chosen its model on the base that the tool of arms they use would be easily changed.[106]

[103] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/normaero/
[104] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/
[105] https://www.basystemes.com/fr/projets-rd/asimov/
[106] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/

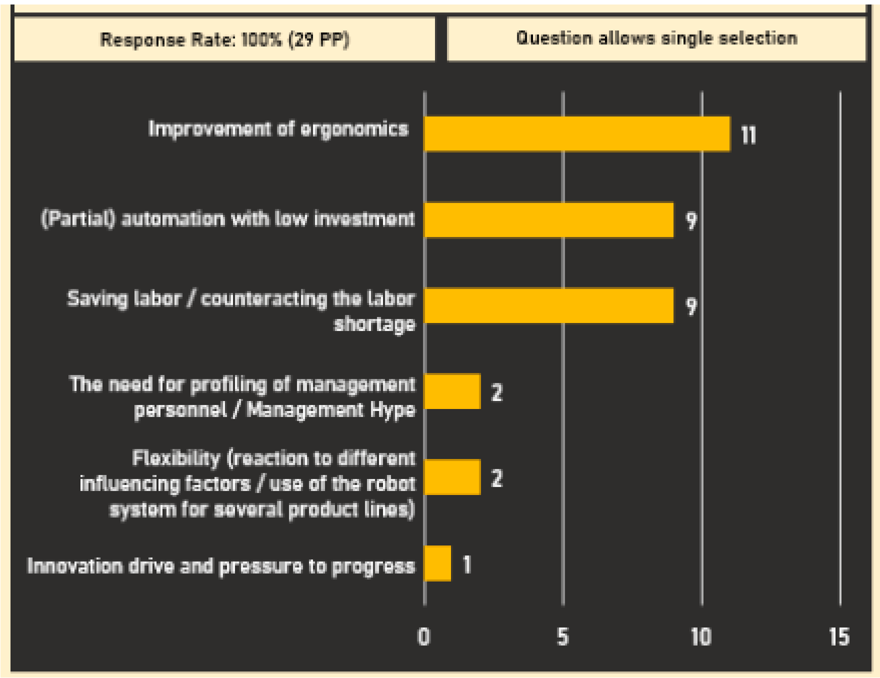

Figure 50. Main reasons to implement human robot collaboration application in their production line according to the respondents of the TOURINGS' questionnaire classified by order of priority

In the previous figure (**Figure 50**) we can notice that the financial aspect is also important for the respondents. As we can see, the financial aspect is linked to the second and the third main important reasons helping to the decision of implementing collaborative robotics in production lines of manufactories.

This prominent importance of the financial aspect that balances the decision to implement collaborative robotics in production lines is further revealed by the analysis of the TOURINGS' questionnaire answers than by the case studies analysed per country. This noticeable element can find an explanation on the fact that the questionnaire is anonymous following the RGPD rules, while the case studies are public and contribute to the general companies' communication. Therefore, it seems that the official communicational most important advantages of the implementation of collaborative robotics are linked to the operators' health and security while the unofficial real advantage of this implementation is much more linked to financial benefits.

More than expected benefits, some elements are necessary characteristics that a process must have in order to be useful in a human robot collaboration application as shown in the two following figures (**Figure 51 and 52**).

Response Rate: 90% (26 PP)		Question allows multiple selection		
Selected cell: MAX(Advantage; Disadvantage) AND value > 50%				
Property	Advantage of HRC compared to manual process	Disadvantage of HRC compared to manual process	Advantage HRC compared to full automation	Disadvantage HRC compared to full automation
Improvement of cycle time	11	11	2	23
Increase in productivity	17	4	4	19
Low error rate / High quality	20	5	1	18
Compliance with low tolerances	14	6	2	15
Small Quantities / single-piece production	4	16	17	1
High variance	7	13	19	2
Fast reprogramming	8	10	19	1
Fast adaptability to changing conditions	7	1	20	13
Low space requirements	2	14	16	6
Counteracting the shortage of manpower	21	2	10	6
Easy to learn / operate / use	1	9	18	3

Figure 51. Characteristics that a process must have in order to be useful for a human robot collaboration application according to the respondents

Response Rate: 90% (26 PP)	Question allows multiple selection			
Selected cell: MAX(Advantage; Disadvantage) AND value > 50%				
Property	Advantage of HRC compared to manual process	Disadvantage of HRC compared to manual process	Advantage HRC compared to full automation	Disadvantage HRC compared to full automation
Elimination of time consuming training	8	10	17	3
Economic efficiency	14	8	9	3
Low investment	8	15	14	9
Fast amortization	9	10	12	7
Precision	18	6	3	14
Speed	7	13	1	21
Repeatability	21	1	5	14
Response to uncertainties	8	13	12	5
Fast installation	6	15	17	4
Collision detection	11	6	18	2
Sensitivity	12	7	18	3

Figure 52. Characteristics that a process must have in order to be useful for a human robot collaboration application according to the respondents part 2

Even if collaborative robotics use presents several advantages in comparison with traditional automated industrial robots, its use has been such democratised that nowadays there are necessary characteristics expected by the people working directly or indirectly with the collaborative robots, as shown in the two previous figures (**Figure 51 and 52**).

As a conclusion, on the matter of the advantages of the use of collaborative robotics in the industrial companies of the European Union countries, we can say that the use of collaborative robotics entails several advantages, which are mainly similar to the expected ones. Nevertheless, we can notice a huge discrepancy on the order of importance of advantages in decisional weight to implement collaborative robotics in production lines following the communicational aspect of a such public announce. The following table (**Table 11**) gathers all the advantages in an attempt to summarise them :

Advantages of using collaborative robotics	Reasons why it is an advantage?
From a technical point of view	
Cobots are modular:	• They are smaller, lighter and quieter than classic industrial robots. • They have a lightweight construction. ▪ They allow the standardization of processes and an ease of programming, helping companies to adapt their productivity needs to its growth process. ▪ They can be used by different operators.
Cobots are flexible:	• They can be flexibly adapted to varying production processes. • They can be easily reprogrammed and installed. • They offer many possibilities of use (palletising, etc.).
Cobots are easy to use:	• Thanks to their graphical user interface, also called “zero click interface”.
Cobots are precise:	▪ Thanks to them, there is no rigid separation of full automatisation and manual work: it leads to a better hand in hand work.
Cobots can work during long periods:	▪ It also appears that in reality, many robotic cells did not work as efficiently as expected[107] due to many machines’ shutdowns, which can lead to a loss of 30,000 to 50,000 euros per hour of shutdown for the

[107] https://www.youtube.com/watch?v=Ek5ZvnhGDgU

	company[108], leading to a lack of competitiveness and a waste of time, while cobots can work during long periods without knowing shutdowns.
From a financial point of view	
Cobots are not expensive:	• Cobots are less expensive than traditional industrial robots (the entry price is 10,000€). Furthermore, while a company buys a cobot it can benefit from regional or national subventions. • They are characterised by low costs for integration and start.
Cobots allow to decrease the indirect costs:	• Contrary to traditional industrial robots they do not need safety fences or cage. Therefore, cobots occupy 50% less space than an industrial robot, which diminishes the total cost of cobots' use.
Cobots allow a better ROI than traditional industrial robots:	• In the majority of cases a cobot is profitable after 2 years, which constitutes a "great" return on investment.
Cobots implementation allows a better TRS:	• The cobots can work during hours where the fabric is closed. Therefore, it leads to a gain in competitiveness for the companies implementing cobots in their production lines.
From a human resources point of view	
Cobots are secure in their use:	• Cobots are high-tech robots with integrated joint torque sensors which can detect contact and avoid humans. • Cobots do not have dangerous housing edges on their surface.
Cobots' use allows to improve operators' health:	• Using cobots allows to reduce WMSDs. They also allow a physical and cognitive stress reduction of the operators.
Cobots' use allows to free employees from arduous tasks:	• Cobots helps to relieve operators from repetitive and arduous tasks thanks to their ergonomics, and also because they can be used by different users so, it generates a great turnover on those tasks.
Cobots implementation is a solution for a lack of workforce:	• Cobots are mainly used to perform the tasks that no employee wanted

[108] Strategy Group company (ESG) research

	to perform. So, they are a solution for the companies which know a lack of workforce, or a high turnover on jobs implying arduous and repetitive tasks.
Cobots use develops the upskilling of the workers:	• The use of cobots implies an upskill of the workers directly or indirectly in contact with the cobots. Therefore, the use of collaborative robotics helps to a general upskilling phenomenon in industries thanks to an outreach of skills in industrial sector.
From a managerial point of view	
Cobots allow an easy analysis of their productivity by the companies' managers:	• Compared to traditional industrial robots, cobots permit a better monitoring of all processes.
Both from a human resources and a financial point of view	
Cobots allow to diminish the number of employees:	• Cobots' use entail a decrease in the costs of the company and an increase in its productivity rate.
Cobots lead to a gain of added value	• Thanks to the cobots' use, the human operator can be focused on the most qualified tasks with the highest value added, which leads to a recruitment of higher skills profiles.
Both from a human resources and a technical point of view	
Cobots turn the jobs linked to their use appealing:	• Nowadays, people who come into the active life are digital natives. Therefore, when a company uses collaborative robotics in its production line, the jobs proposed by this company become more appealing.
General consequence	
All those advantages gathered are a catalyst to lead to the conclusion that collaborative robotics use results in an increase of productivity for the industrial companies (more 35% on average).	

Table 11. **Chart resuming the advantages to use collaborative robotics**

As a conclusion of this section presenting in a non-exhaustive way all the advantages permitted by collaborative robotics implementation in production lines of manufacturing companies, we have to underline the fact that the companies have to keep in mind the following KPIs to identify if cobots are profitable or not in their production lines:

- TRS calculation: which have to be increased thanks to collaborative robotics implementation.
- The real ROI of the use of collaborative robotics.
- The effective ROI: calculated by the addition of the productivity rate, the benefits generated by the MSDs diminution, the higher quality of the final products of the company, the higher quality of work for the employees, the attractivity of the company for its clients and the versatility gained.
- The savings gained on security systems compared with the analysis risks cost.

Of course, collaborative robotics implementation and use leads to numerous advantages, but it also creates new disadvantages and new challenges that the companies have to face.

2.2 Main challenges for European Union companies with (already) implemented collaborative robotics in their production line

Even if the use of collaborative robotics represents numerous advantages for companies, it also reveals disadvantages and new challenges that they need to face. In this section, we will first present the predictable and logic challenges that a company may need to face by implementing cobots on its production line; then the financial challenges that companies have to face when they implement and use collaborative robotics, as well as the human challenges and, finally, the technical challenges based on the case studies information[109]. This study is based on the partners work, and therefore some elements are similar between countries; so, in order to avoid redundancies, we will present the disadvantages and challenges considering that the previous elements are included in each country.

2.2.1 Predictable challenges that the companies might have to face while they implement collaborative robotics in their production line

Bearing in mind that the use of collaborative robotics is recent (2008), we can imply that its implementation and use is linked to high technology. Therefore, companies must face some predictable challenges like:

- **The HR needs:** the skills required to perform jobs directly or indirectly linked to the use of collaborative robotics might be evaluated by companies which want to implement collaborative robotics in their production line. They have to address the potential need to recruit new profiles, and consequently will have to budget it. By extension, it seems logical that the implementation of collaborative robotics will be more difficult for small and medium companies because the new human resource's needs can be consistent on the total turnover of the company.
- **The financial weight:** as we have mentioned above, cobots were profitable after 1 or 2 years of use; this estimate will be different from one company to another depending on its total turnover, benefits and products produced. Therefore, before its implementation, the company will have to weight the return on investment of such new equipment. During its use, the company will have to assess the real return on investment of such implementation in comparison with its traditional tools.
- **The technical challenges:** the company will have to ensure to choose the right cobot for its production line, corresponding to its needs, with a high aftersales service. Regarding the fact that collaborative robotics are recent, some companies with a high resistance to change can be reassured by a national cobots' constructor able to help them in their mother tongue in case the company would face a technical issue.
- **The communicational aspect:** for companies placed in "social oriented" countries such as France or post URSS countries, implementing collaborative robotics can

[109] We need to remind the reader that the expected benefits remain to specific situations analysed through case studies (presented in **Appendix 4**) and therefore belong to specific situations and cannot be elevated to the general law rank for all companies, even if some similarities arise.

be seen as a threat by the employees of the company. This fear is linked to the anxiety of losing one's work in favour of a robotics workforce, easier to manage for the companies. As an example, a study published on April 25th, 2021, has explained that within 15 to 20 years, one third of jobs in France will be exposed to radical change and just over 16% of jobs will disappear, according to the Organization for Economic Cooperation and Development (OECD). This study highlights, however, that this destruction should be offset by the creation of new jobs and new ways of working.[110] Thus, the low-qualification jobs tend to be replaced by high-qualification ones, which generates the anxiety feeling in current low-qualified employees.

As a conclusion on the issue of predictable challenges that companies might face while they implement or use collaborative robotics in their production line, we can pose the hypothesis that companies will face human resources, financial, technical and multiscale communicational challenges (for the employees of the company and for the consumers).

2.2.2 The financial challenge as studied through the case studies

Even if the use of collaborative robotics is seen as a productive advantage, it appears that the use of cobots can be considered as a financial challenge.

First of all, depending on the European Union country concerned by the implementation of cobots in industries, some areas are more financially favourable to the installation of cobots in their production lines than others. Some national or regional entities facilitate the implementation of collaborative robotics by tendering grants to companies for the purchase of collaborative robotics. While the price of a cobots is around 10,000 euros and sometimes reaches more than 75,000 euros, the national and regional aid in the form of subventions can become a limit or a real advantage for the implementation of collaborative robotics in industrial companies. Furthermore, we need to keep in mind that those prices do not include the entirety of the budget needed for a collaborative robotics use: the cost of the additional hardware is missing. The price of a collaborative robotics only makes one quarter of the whole costs of the system. Sensor, cameras, safety technique, etc. have to be bought and installed separately. Moreover, countries are not equalitarian when they want to implement cobots, cobots' prices are more or less the same wherever the company's country is, while the total benefits of a company will depend on the quality of life and the purchasing power of the concerned country, both linked to the GDP of the concerned country. Therefore, European Union companies located in higher GDP countries will find it easier to implement and use collaborative robotics.

Regarding the training, there are some free trainings offered to companies for the purchase of a collaborative robotics, but this will entail indirect costs. If we ponder that a basic training can take between 2 and 5 days [111] for an operator, added to the advanced trainings, the total training duration takes 3 weeks. Therefore, for 3 weeks the operator will be trained at the use of the collaborative robotics. During this time, they will not work as efficiently as usual so it can become a challenge mostly for little industrial companies which cannot reduce their

[110] https://www.infoprotection.fr/des-cobots-pour-limiter-la-penibilite-dans-les-ateliers/
[111] https://academy.universal-robots.com/fr/nos-formations/

productivity. Conversely, when the training contents made by constructors are not free, the price of the training must be added to the previous costs. Considering that there are 3 level of difficulties in their trainings (basics, medium and advanced), the total direct cost of training for an operator is around 2,500 euros[112]. Thus, the collaborative robotics use training can become a challenge for industrial companies in the matter of their direct and indirect costs.

As a conclusion regarding the financial challenges derived from the implementation of collaborative robotics, we can state that there is a particular case of each company and this may allow them, or not, to implement collaborative robotics in their production line[113]. Of course, we may imply that the greater the benefits for the company, the easier the implementation, lowering the financial risks taken.

2.2.3 Human Resources challenges

Collaborative robotics implementation and use entail many human resources challenges: from the jobs required to the direct common work with collaborative robotics or even the perception of collaborative robotics in industries.

2.2.3.1 *Type 1: Germany*

Two main human resources challenges have been identified in German case studies:

- Employees' acceptance. Employees can be skeptical towards collaborative robotics implementation and use,
- Knowledge gap between what is shown in the media about human robot collaboration and what it looks like in reality / how it is implemented in industry.

2.2.3.2 *Type 2: Italy*

Italian case studies do not mention per se the human resources challenges faced by Italian companies while they implement or use collaborative robotics in their production line. This fact result from the communicational and promotional aspect of the documentation provided.

2.2.3.3 *Type 3: Estonia*

Estonia is internationally known for its information technology applications in the public sector. In Estonia, a large part of public service activities has been digitised, which makes administration simple, fast and flexible. The digitalisation of the industry is faster in the electronics and wood industries compared to the mechanical engineering sector. In that context, the use of collaborative robotics is mainly limited by a lack of sufficient knowledge about their capabilities and suitability.

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[112]https://academy.universal-robots.com/allied-automation/fr/formation-en-classe/advanced-training_template-1-1-1-1-1-1/

[113] We need to remind the reader that the expected benefits remain to specific situations analysed through case studies (presented in **Appendix 4**) and therefore belong to specific situations and cannot be elevated to the general law rank for all companies, even if some similarities arise.

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2.2.3.4 *Type 4: France and Spain*

❖ **Spain**

The Spanish case gathers great professionals who are recognised all over the world, but it is important that the public administration makes a firm commitment to support innovation and thus achieve a good *made in Spain* positioning. There is no doubt that automation offers innumerable advantages in terms of improved productivity, ergonomics, repeatability and process accuracy, but there is no common model that is applicable to any company. Automation allows Spanish companies to improve productivity and efficiency, and therefore they are more competitive. In the long run, this improved competitiveness must be the basis for ensuring the sustainability and growth of Spanish business, and thus to secure employment at a national scale. This process must be accompanied with a transformation of jobs, which are becoming more and more highly skilled. Therefore, establishing continuous training plans in companies for all their employees is fundamental. For example, SEAT Spain has created its own training centre for electromobility (electromobility Learning Centre, eLC[114]) where all the 15,000 employees of SEAT have been, or will be trained, in all the relevant aspects related to electric and hybrid technology.

According to the collected feedbacks, the Spanish national education system is not responding to all the needs of companies in terms of human resources. Automation and robotics are key sectors for manufacturing companies and also, these are keys to generate stable and qualified jobs. It is very difficult for industrial companies to find people trained at VET or intermediate level, being easier to find university graduates rather than intermediate level professionals in the areas of robotics and automation. It shows a gap in the Spanish education system which should promote the middle-level degree concerning industrial automation and robotics. Youngsters with university degrees have very good theoretical training which allows them to quickly adapt to the industrial environment. VET graduates are also generally well trained and can quickly be placed in companies. The quality of theoretical training is generally good in Spain but there is a lack of means for practical training. Manufacturing companies consider that there is not enough supply in VET or intermediate degrees for this training and TOURINGS is a good initiative to fulfil this gap.

❖ **France**

Concerning France, the human resources challenges are linked to two main points:

- On the one hand: the training of the people working directly or indirectly with collaborative robotics
- On the other hand: the perception of collaborative robotics by the employees and by final consumers of the companies' products.

In France, the huge disadvantage linked to collaborative robots comes from the fact that there is a defiance to collaborative robotics because of the risk of lacking training on the subject. In France, the educational system only provides one master's degree in collaborative robotics for the workers (as we will see in the following section). collaborative robotics constructors

[114] https://www.seat.com/company/news/company/seat-new-electromobility-training-centre.html

provide training methods to users. Thus, this means that a company implementing a collaborative robotics on its production line will need to train its employees at the use of collaborative robotics reducing their working hours. On balance, this may seem like a loss of time and, thus, a loss of productivity. For this reason, the implementation of collaborative robotics can scare away some French companies.

Conversely, the perception of the collaborative robotics in companies has been mitigated. Following French case studies, it appears that the vast majority of managers is favourable to the implementation of collaborative robotics in their production lines because of the numerous advantages provided by collaborative robotics on productivity while the vast majority of operators is afraid or unfavourable to the implementation of collaborative robotics in their production lines. They are scared away mainly because they think a cobot could "replace" them.

As a conclusion on the subsection concerning the human resources challenges linked to the implementation and use of collaborative robotics in European Union countries, we can state that even if they seem to be important, these challenges will disappear in time thanks to training of the populations working direct or indirectly with collaborative robotics.

2.2.4 Main technical challenges faced by industrial companies by implementing or using collaborative robotics in their production line

Based on the division created by our typology, we will present the most obvious technical challenges that the companies which use collaborative robotics have to face following the case studies analysed in the TOURINGS project.

2.2.4.1 *Type 1: Germany*

The following table (**Table 12**) summarises the main technical challenges faced by companies while they implement or use collaborative robotics in their production line.

Weaknesses	The need of simple, fast and intuitive robot training ▪ Knowledge gap between what is shown in the media about human robot collaboration and what it looks like in reality / how it is implemented in industry ▪ More complex applications require to be skilled at-risk assessment and to have a better experience. ▪ Safety rules. ▪ Integration of safety standards: ISO TS 15066 standard
Threats	▪ The probability of occurrence of harm: identifying all risks or hazards that may occur during all kind of operations or activities. Here probabilities and extents of damages or injuries and avoid or eliminate any risk of injury to human beings. ▪ Cybersecurity risks. ▪ Power and speed limitations: make it always possible to limit power and speed of robot to ensure safety for human beings.

Table 12. **Main technical challenges faced by companies, analysed in German case studies**

2.2.4.2 *Type 2: Italy*

Thanks to the study of the Italian case studies, the technical disadvantages revealed by industrial companies implementing or using collaborative robotics are:

- limited speed of execution,
- the use is limited to low-dynamic tasks.

2.2.4.3 *Type 3: Estonia*

Collaborative robotics use is increasingly attractive to manufacturers who require flexible solutions for their growing product mix and difficult working conditions, but may not have the scale of work or capital resources needed to justify larger investments in automation systems. Collaborative robotics are intended for direct interaction with a human worker, handling a shared payload and the benefits may be expected in ergonomics, in productivity and in the interface of computers and information systems to those many activities which continue to make good use of uniquely human skills.

The following figure (**Figure 53**) describes one use case in the assembly area of electronic devices manufacturing workshop. The product is a rectifier produced in the electronics industry and 7 similar rectifiers belong to the same product family. Depending on the type of rectifier, the circuit board assembly must be attached to the base plate with either 15 or 18 screws (M3x6 TORX). Attaching the circuit board assembly to the base plate is only one step in the final assembly of the product, which has both previous and subsequent activities. The workplace divided per the production line is an area of 9 m2, which includes a shelf for incoming material and the material going to work is located on the workbenches in electrostatic discharge boxes (ESD). There are a total of 4 desks in the line (dimensions 75x150cm), of which the second desk is for the screwing stage and a robot is installed there. The product moves on rails with rollers. The screwing phase for connecting the two plates on the production line is shown by the following figure (**Figure 53**).

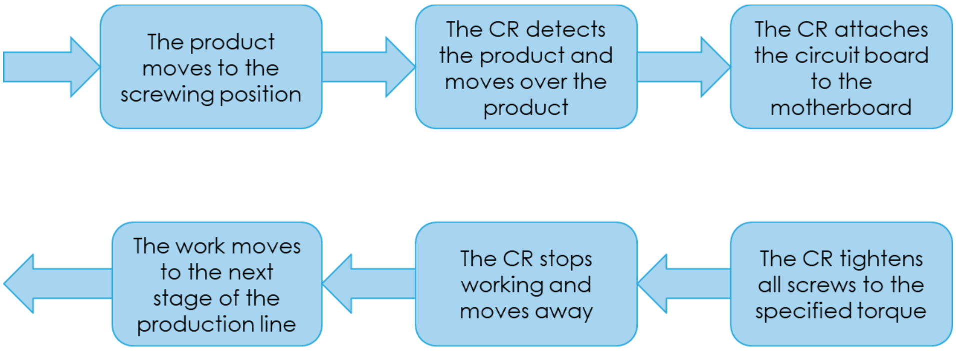

Figure 53. Diagram presenting collaborative robotics use on a production line for final assembly

A production line is a set of sequential operations established in a factory where components are assembled to make a finished product or where materials are put through a refining process to produce an end-product that is suitable for onward consumption. Collaborative robotics constitute a great challenge in the company, because they can work alongside humans without barriers. This allows them to directly assist humans with assembly jobs. They can perform the assembly themselves, assist when parts are too intricate for human handling, or help retrieve parts for workers to speed up the assembly process. This allows also to bring together production engineers, planners and production line technicians to introduce new products, to increase the productivity or to prevent or help to solve the problems in a production line, allowing to reach the target throughput and flexibility of production. With the use of computerised maintenance management systems (CMMS), it becomes possible to plan and avoid machine breakdowns and with the manufacturing execution system (MES) it becomes possible to ensure the planned results and improve the output results.

Human robot collaboration is an interdisciplinary research and application area comprising robot-human interaction, artificial intelligence, design, cognitive sciences and psychology.[115] In many applications, like assembly, executing different manufacturing processes (polishing, painting, etc.), quality control, testing, etc. robots require to work alongside people

[115] Bauer, Andrea; Wollherr, Dirk; Buss, Martin (2008). "Human–Robot Collaboration: A Survey". International Journal of Humanoid Robotics. 05: 47–66. doi:10.1142/S0219843608001303.

as capable members of human-robot teams. This makes these processes more flexible, adaptive, easy to realise often without special fixtures or equipment. The problem is characterised by the possibility that human, and robots can simultaneously execute tasks at the same workpiece either in parallel or in collaboration.

Collaborative robots are suitable for a wide range of applications, for instance, pick and place, screw driving, injection molding, measuring, inspection, testing and assembly. Besides this variety of applications, collaborative robots are additionally assumed to be fast set up and easily programmed. Thanks to flexibility and agility they could be used for manufacturing small batches with fast changeovers. While collaborative robots may be utilised to replace human workers, they are originally intended to support human workers in a common station[116]. As defined by the International Organization for Standardization[117], human–robot collaboration is an operation between a person and a robot while both share a common workspace. Different authors have described the human–robot collaboration from different aspects. The main aspect is that human and robot are sharing the same working place and time without barriers or physical separation and the systems are safe, which is regulated by different standards. The execution the separate workplace or it in a production line is a decision-making task and depends on the manufacturing task and possible resources in a company. In a manufacturing company productivity and cycle time are important criteria so, for the separate workplace or production line. For production line working efficiency additionally, it is necessary to consider the rate of use the connected workplaces and tact of the production line. Therefore, production line - balancing and scheduling of assembly lines with collaborative robots are important tasks. Consequently, the assembly line balancing problem with equipment selection is enriched by a collection of scheduling problems. In scheduling these stations, logical relations between the resources have to be considered. For instance, a task can only be performed collaboratively if neither the worker nor the robot is occupied by a different task (scheduling with logical relations). Additionally, these modes have different efficiency. Collaborative execution by a worker and a robot, for instance, is faster than execution only by the human worker (allocation-dependent task times), leading to a tradeoff between time and resource consumption[118].

The study of production line configurations along the length of the line is called *“assembly-line*‟ balancing. The set of workstations along the line that results from this balancing is the generated line configuration. Splitting the assembly line width wise rather than length wise i.e., one workstation is replaced by two identical parallel stations, and they named it as dual production line. Production tact and needed productivity of a production line are important figures in line balancing task.

Further advantages arise from the possibility of parallel work from either side of the station. The length of the assembly line may decrease which results in higher space utilisation.

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[116] Bernhardt, R., D. Surdilovic, V. Katschinski, and K. Schro¨er. 2007. Flexible assembly systems through workplace-sharing and time-sharing human–machine cooperation—PISA. IFAC Proceedings Volumes 40: 247–251. https://doi.org/10.3182/20070523-3-ES-4908.00041.
[117] International Organization for Standardization. 2011. ISO 10218-1:2011: Robots and robotic devices— safety requirements for industrial robots—Part 1: Robots. Geneva: International Standards Organization
[118] Christian Weckenborg, Karsten Kieckha, Christoph Muller1,Martin Grunewald, Thomas S. Spengler. Balancing of assembly lines with collaborative robots. Busines research (2020). 13: 93-13

Also, the robot as an additional resource reduces the production lead time. In addition, material handling, workers' movement and set-up times may also be reduced[119].[120]

Human–robot collaboration is an emerging technology in the field of novel production systems. It is important to define the roles for humans and robots to perform the task efficiently and in high quality. There is a need to consider that the execution of production task was fulfilled ergonomically, and it could eliminate stressful and repetitive tasks. The best choice is to combine the strength, precision and speed of robots with the ingenuity, judgment and dexterity of human workers. This way, human workers can take on tasks that require flexibility, while the robots handle tasks that make the best use of their strength and speed. A solution for human-robot collaboration in a production line is given in the following figure (**Figure 54).**

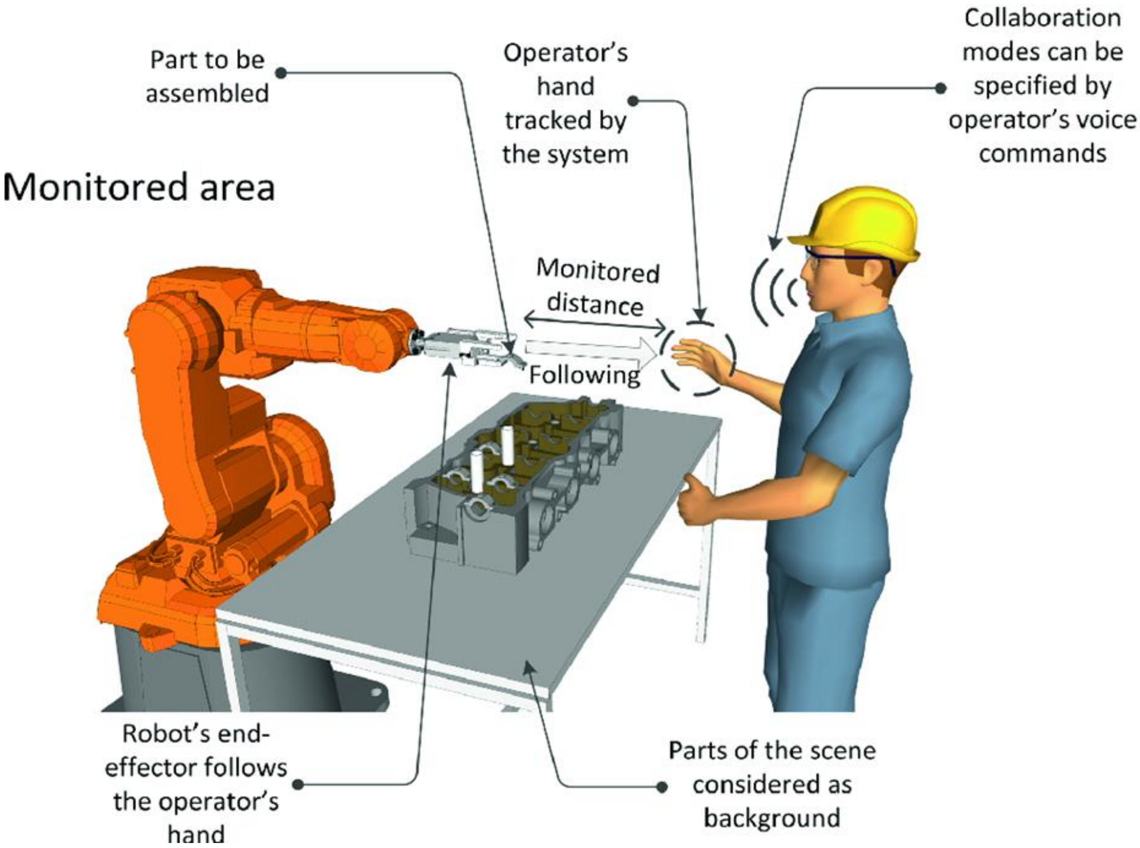

Figure 54. Human-robot collaboration for assembly operation [121]

Whether collaborative or cooperative, robotic technology is now an integral part of the smart factory, though robots will probably never completely substitute the common sense and problem-solving abilities of skilled human workers, they can successfully complement them by

[119] Bartholdi, J.J. 1993. Balancing two-sided assembly lines: a case study. International Journal of Production Research 31: 2447–2461. https://doi.org/10.1080/00207549308956868.
[120] Lee, T.O., Y. Kim, and Y.K. Kim. 2001. Two-sided assembly line balancing to maximize work relatedness and slackness. Computers & Industrial Engineering 40: 273–292. https://doi.org/10. 1016/S0360-8352(01)00029-8.
[121] Lihui Wang, Sichao Liu, Hongyi LiuXi, Vincent Wang. Overview of Human-Robot Collaboration in Manufacturing. Proceedings of 5th International Conference on the Industry 4.0 Model for Advanced Manufacturing pp 15-58|

taking charge of heavy, repetitive and monotonous tasks.[122] While cobots can be programmed to perform detailed and complex actions, they lack the ability to detect abnormalities, such as variation in raw materials or the correct placement of components. This makes them less flexible than human workers, who have to double-check the work completed by their automated colleagues.

Another challenge is precision in bin picking, one of the most sought-after tasks for cobots. collaborative robotics can be programmed very easily to pick up something at a specific location, but picking becomes more challenging when objects that the robot arm has to grab are mixed and overlap in a container. This is where vision systems and machine learning come into play. Using 3D vision systems and ultra-high-speed imaging processing facilitates applications such as identifying, counting, measuring or reading barcodes. This enables collaborative robotics to bin-pick random parts with unprecedented precision. Therefore, handling fragile or delicate materials without damaging it can also be problematic for a collaborative robotics. However, there are efforts to use static electricity, instead of traditional grabbers, for delicate pick and place applications.

To operate safely and not harm humans, collaborative robotics normally need to compromise on speed. This means high speed applications, such as sorting of packaging, are not best suited for a cobot. However, some of the most innovative cobots can calculate an alternative path when they sense the presence of an obstacle, such as an operator's hand. This allows them to carry on with their task in a safe way, without having to compromise on productivity.

Payload is another feature collaborative robotics lack for safety reasons. They can usually carry weights of between three to ten Kgs and very rarely heavier than that. Fanuc's CR-35iA Collaborative Robot is one of the strongest collaborative robotics on the market, capable of lifting 35 Kgs, which makes it a more suitable candidate for jobs in palletising and load transfer.

The technical challenges led by collaborative robotics use are highly linked to the fact that the introduction of a collaborative robot does not entail high integration costs. The robot is well suited for small batch manufacturers, as the robot can be easily reconfigured for other jobs. Due to the ergonomic design of the robot, there is no need to redesign the production layout and they are able to work even in small spaces and can be easily integrated into any existing application. Programming collaboration robots is easy and can be done by employees themselves. The big plus is that Universal Robot's collaborative robotics are practically maintenance-free. According to the obtained experiences screwdriver bits could be fitted as accessories or spare parts for the different types of screw bits in use (torx (TX), cross head (PH, PZ), hexagon (HEX), etc.) so that other type of screw can be used if required. As an option, it was also examined whether a torque of more than 3.6 Nm could be used if necessary and the manufacturer confirmed that this option existed.

Considerations such as safety, power requirements or precision are vital for the smooth operation of cobots alongside humans. collaborative robotics have a huge potential to overcome workplace limitations and transcend the boundaries of Industry 4.0, but only if manufacturers consider all the aspects related to their implementation.

122 https://www.euautomation.com/en/content/robotics-collaboration-or-cooperation

2.2.4.4 *Type 4: Spain and France*

- **Spain**

In terms of challenges, 2020 has been an exciting year. Everything has been accelerated, in Spain, the position of questioning automation has become a need. Generally, short-term solutions are sought, with immediate returns and which cover the image of transformation rather than the actual transformation itself. The legislation does not help much either: there are too many prohibitions, fears and lack of preparation, adaptation and qualification. The standardization of tools, languages and hardware, and especially the promotion of fast and efficient legislation in line with quality standards, are basic aspects to accelerate the transformation process.

Spain is facing great challenges and even when the availability of resources and capitalisation of companies is significantly weakened, it is essential for the administrations to get involved and take on the role of the government. They should take a coordinating role to promote actions and channel the dynamism of private companies and initiatives, as well as the aid that will allow them to accelerate and translate into tangible industrial realities[123].
Small and medium companies' strengths might be creativity, speed of adaptation and the absence of heavy burdens (such as complicated, expensive, and slow to change asset and personal infrastructures), which are the problem of any large company. Automation and new technologies as collaborative robotics allow for enormous efficiencies compared to conventional technology.

As described by the companies, just few of them had the proper skills to design the collaborative robot behaviour or program it. These designs, as well as the robotics arm, were designed or developed in most of the cases by integrators companies or even suppliers' companies due to the lack of skills of the most important part of companies. If there is one thing to learn from 2020: being free from external dependencies has become a need. Industrial automation is one of the only competitive ways to recover or create new sectors, in addition to improving existing ones.

In concrete sectors, as automotive, there is technology and state-of-art possibilities to automate almost everything, from a theoretical point of view. However, automation should have objective reasons, based on quality and process assurance needs, repeatability and traceability, overall equipment efficiency, operator ergonomics and, of course, cost reduction. Many of the processes could be automated, but a favorable cost-benefit ratio should be considered. For certain processes, it makes sense to adopt a mixed human-robot model using collaborative robots, although it is not necessary to have fully automated centers. In this regard, it should be born in mind that robots are not 100% autonomous. Each robot is supervised by an employee who has been specifically trained for this purpose.

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[123]General Guidelines of the New Spanish Industrial Policy 2030 https://industria.gob.es/es-es/Documents/Directrices%20Generales%20de%20la%20Pol%C3%ADtica%20industrial%20espa%C3%B1ola%2025.02.19%20FINAL.pdf

It is quite important for small and medium companies, after the initial analysis, to identify which processes are more automatable, and then measure their profitability and feasibility. This kind of efforts in small and medium companies should be made to implement change quickly and immediately. This immediacy is essential to boost team moral and motivation.

The technical level of Spanish companies in the field of applied engineering and technology is good. This has been demonstrated by the increase in exports in recent decades. The ease with which field or semi-standard elements are available at interesting prices and performance is making Spain capable of developing and applying competitive solutions in industrial installations. Spanish main contributions are related to system engineering and system architecture and not so much in the basic research needed for the development and production of key elements such as chips or other circuits.

In the last years, the advance of artificial intelligence and machine learning have allowed the automation of tasks that required the cognitive functions of the human mind. Artificial Intelligence has become essential in the industrial environment to help companies to solve challenging problems. Data management allows them to derive value from available data, which is another key tool in the development of automation. Another important step with potential for automation is the use of the could in processes, a digitisation that will increase productivity and increase efficiencies.

Concerning security issues, the companies were more familiar with ISO/TS 10218-1[124] and 10218-2[125] rather than ISO/TS 15066[126] which was not considered by the most companies.

- **France**

Concerning the main technical challenges faced by French companies while they implement or use collaborative robotics in their production line, the French case studies analysis has revealed that the automation of technical gestures was the main challenge.[127] This important point can become a limit at the use of collaborative robotics: if cobots need too much time to learn how to perform a task flawlessly, this could led to a loss of productivity, which is a limit at the use of collaborative robotics in production lines. This point of view is shared by small and medium companies as well as by huge companies. On the one hand, small and medium companies cannot take the risk to decrease their productivity rate, because their benefits could experience a loss.On the other hand, huge companies cannot take the risk to decrease their productivity rate, because they would face a scenario of not supplying the demand.

For French companies, it also appears that one of the main challenges to face while they implement collaborative robotics in their production line, is the choice of the right collaborative robotics. For this reason, collaborative robotics technical characteristics become central in the decision making. For example, Sanofi has chosen UR10 collaborative robotics models basing their choice only on the fact that the tools of arms were easily changeable[128]. Therefore, it appears that technical aspects presented by collaborative robotics is key for the industrial

[124] https://www.iso.org/obp/ui/#iso:std:iso:10218:-1:ed-2:v1:en
[125] https://www.iso.org/standard/41571.html
[126] https://www.iso.org/obp/ui/#iso:std:iso:ts:15066:ed-1:v1:en
[127] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/normaero/
[128] https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/

company using them. In this way, the technical challenge is both for the industrial company which will implement and use collaborative robotics in its production line, and also for co collaborative robotics bots' constructors, which will have to improve their technical aspects to gain market shares.

Furthermore, it appears that collaborative robotics use entails a cybersecurity risk. Indeed, cobots may need to collect and use more and more personal data from employees in order to optimise human-robot collaboration. Thanks to the advances in Artificial Intelligence (AI), collaborative robotics are increasingly sophisticated. They can learn new tasks in contact with humans, without the need for reprogramming. However, the question of the security of this data arises, because collaborative robots could be the victims of cyber-attacks. Consequently, the articulation of AI with the protection of this data is a major issue, as the CNIL and its counterparts recalled it in June 2021.[129] In the matter of the cybersecurity risk developed because of the collaborative robotics use, the French law is still undecided. The Artificial Intelligence Act[130] is the proposal for a regulation published by the European Commission, which aims to regulate AI:

> "However, on June 18, 2021, the National Commission for Informatics and Freedoms (CNIL), its counterparts and the European Data Protection Supervisor adopted an opinion on this future regulation. On its website, the CNIL noted the 4 fundamental points of this opinion:
>
> - The need to draw red lines for future uses of AI (to broaden the scope of prohibited AI systems and to clarify their definition).
> - The challenge of articulation with the General Data Protection Regulation (GDRP), which entered into force on May 25, 2018.
> - The importance of harmonized governance.
> - Support for essential innovation."[131]

Therefore, it appears that the cybersecurity challenge linked to the use of collaborative robotics has been identified by the legislation and is in process of being regulated.

Each collaborative robotics will need a maintenance service while running. But this maintenance can be performed either by the collaborative robotics constructor brand or by independent companies. As a result, it reveals two challenges, the first linked to the fact that independent companies have to know the model of the collaborative robotics they have to repair or on which they have to make a predictive maintenance. The second element is that the arm of tools can come from a different brand than the cobot. Thus, the company using the collaborative robotics will have to be able to identify from which elements the breakdown is coming from, leading to a machine shutdown during the breakdown analysis and repair and finally leading to a loss of productivity during this time.

2.2.4.5 *Comparison with the TOURINGS 'survey results*

[129] https://info.haas-avocats.com/droit-digital/essor-des-cobots-dans-lindustrie-comment-reagir?hs_amp=true

[130] https://info.haas-avocats.com/droit-digital/artifical-intelligence-act-le-projet-de-reglement-de-bruxelles

[131] https://info.haas-avocats.com/droit-digital/essor-des-cobots-dans-lindustrie-comment-reagir?hs_amp=true

As it was already mentioned in this report, the case studies might reflect some errors. In fact, we cannot forget that the case studies are public and belong to the promotional aspects of the collaborative robotics advantages. In this context, we can pose the hypothesis that the latest parts of this report do not reflect faithfully the reality. For this reason, the following figure (**Figure 55**) presents the main reasons why a company could be hesitant to implement collaborative robotics in its production line according to the respondents of the TOURINGS' questionnaire.

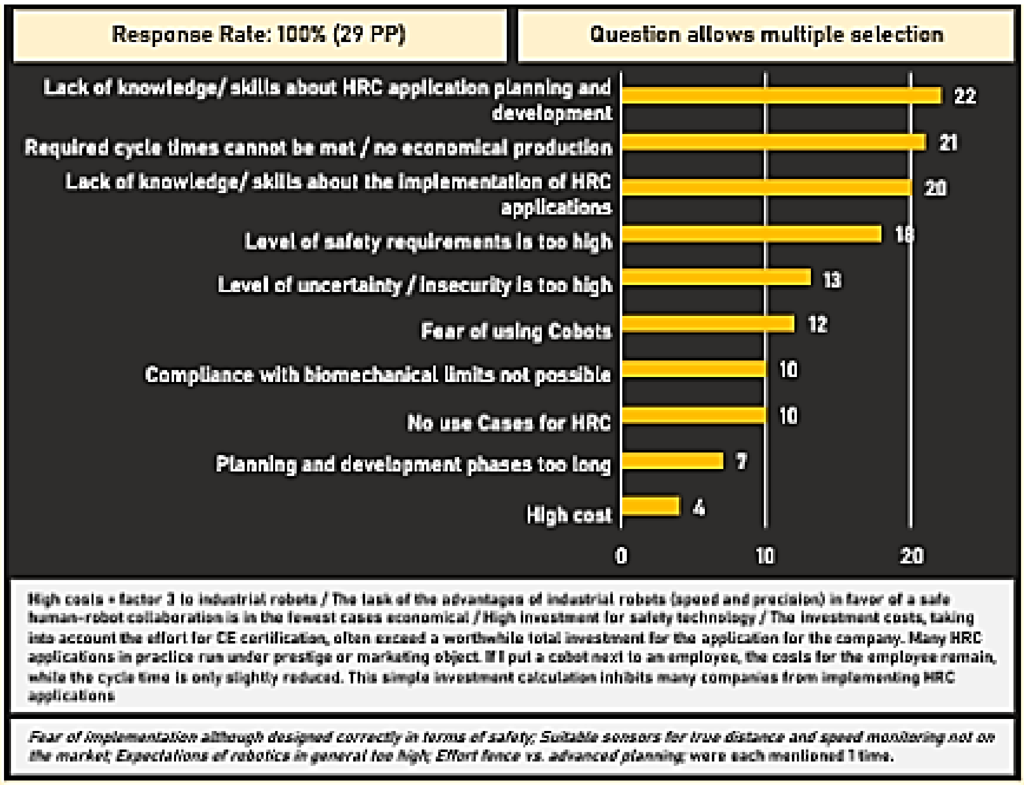


Figure 55. Main reasons why a company could be hesitant to implement collaborative robotics in its production line according to the respondents of the TOURINGS' questionnaire.

As we can notice it, the three-quarters of the TOURINGS' respondents points out that the main reason to be hesitant to implement collaborative robotics in production line comes from a human resources issue considering both the lack of knowledge and the lack of skills on human robot collaboration application planning and development. The other main reason linked to the implementation of collaborative robotics is related to the need of an improvement of production rate while the collaborative robotics' cost does not intervene that much in the companies' hesitation to implement collaborative robotics in their production line.

The analysis of the TOURINGS' questionnaire has revealed an important point, which was not obvious during the case studies analysis. it involves the compliance to the European norms while industrial companies implement or use collaborative robotics in their production line. This fact is shown through the two following figures (**Figure 56** and **57**).

Question allows free text
High effort [3]
Too inflexible, costly and slow
Very high scope and requirements
Lack of flexibility in designing/redesigning the direct environment of the robot after CE certification, thus transferring an existing solution to a similar environment is almost impossible.
Movements at head height [3]
Avoid movements at head height
Exclusion of several possible use cases due to limit values in the upper body/head area
Conflict Application to (head) height and speed (cycle time)
Lack of practical experience [1]
Implementation of the standard [1]
Accept that with compliance there will always be a residual risk (more likely then not to go to the person signing the declaration of conformity) [1]
Avoidance of nonsensical actions by the operator [1]
Estimation of cycle times depending on the achieved speed [1]
To delimit ignorance of the operator [1]
Communication of the previous point to decision makers / implementers in the company often very difficult ("Why then, the robot is collaborative") [1]

Figure 56. Challenges in complying with the requirements of ISO TS15066 according to the respondents of the TOURINGS' questionnaire (part 1)

Response Rate: 59% (17 PP)
Biomechanical limits [6]
The fact that the BG insists on adhering to the values, but the TS only deals with the onset of pain, but not with an injurious force, as required by the Machinery Directive 2006/42/EC.
Interpretation of the "informative" values from Annex A, often incorrect statements also from the BG, which regard the values as absolute limits, although these are pain onset values, but the Machinery Directive only starts at the onset of injury.
The pressure limits are difficult to comply with. A protective fence is therefore often necessary.
Compliance with pressure limits.
Compliance with the defined limit values for force and pressure not possible in all scenarios (e.g. the handling object). Limit values should rather be seen as guard rails and the measurement results must be interpreted in terms of safety.
High effort for measurement of biomech. limits
Economic efficiency [3]
Economic efficiency
Cost
Severe restriction of achievable cycle times with corresponding impact on economic efficiency
Power and force limitation [2]
designed too much for power and line monitoring
Power and force monitoring is slow, technology is missing for distance and speed monitoring

Figure 57. Challenges in complying with the requirements of ISO TS15066 according to the respondents of the TOURINGS' questionnaire (part 2)

Complying with the ISO standards (developed in the first section of this report) has been a challenge for professionals working direct or indirectly with collaborative robotics for several different reasons listed above gathered in the free text entry option given to the respondents.

Regarding the technical challenges entailed by the implementation and use of collaborative robotics in European Union manufacturing companies, it seems that the previous paragraph, which summarises the main challenges gathered through the case studies analysis, is quite the same to the one analysed in the TOURINGS' questionnaire results analysis; this becomes more obvious in the following figure (**Figure 58**).

Response Rate: 48% (14 PP)	Question allows free text
Due to the economics, customers quickly come to the conclusion that it is not worth it. Until now, requests have therefore not been prioritized.	
Discussions with BG and customer deposit security advisors	
0 HRC applications with approx. 300 cobot systems!	
Find applications	
Lack of mapping of the overall functionality in the digital twin (simulation). Lack of robot capabilities.	
In the end, economic efficiency always counts. Targeted search for applications that have automation potential.	
Clean risk assessment (application/robot at head height) incl. validation -> so far only possible on demonstrators.	
Main hurdles: a) Dealing with the issue of "safety"; b) Employee acceptance; c) Support in the context of a pilot project by the employers' liability insurance association; d) Participatory approach to employee involvement.	
HRC must prevail over other variants (manual work, partial automation, full automation).	
Compliance with economic efficiency while meeting safety requirements -> so far only feasible in demonstrators	
Estimation of cycle times depending on the achieved speed	
Fear of job losses	
Cost-benefit analysis	

Figure 58. Hurdles in the design and implementation of human robot collaboration applications according to the respondents of the TOOURINGS' questionnaire

As an rapid conclusion about the challenges faced by companies at the implementation of cobots in their production lines and in their use, the following table (**Table 13**) summarises all the challenges and disadvantages aforementioned.

Disadvantages of using collaborative robotics	Reasons why it is a disadvantage?
From a technical point of view	
Cobots implementation is a source of anxiety and hesitation:	• Identifying the right cobot which adapts perfectly to the needs of the company is complicated. • In the same way, it is difficult for new companies to spot the right task to be done by a cobot in a production line. Identifying what can be automatised and where to find the perfect combination cobot and human interaction is crucial.
Cobots implementation presents a challenge in its own technical characteristics:	• Analysing the changeability of the tools of arms of the cobot is important for companies before implementing it in order to have the

	most useful cobot in their production line. • Cobots can be programmed very easily to pick up something at a specific location but picking becomes more challenging when objects that the robot arm has to grab are mixed and overlap in a container. This is where vision systems and machine learning come into play. Using 3D vision systems and ultra-high-speed imaging processing facilitates applications such as identifying, counting, measuring or reading barcodes, which enables cobots to bin-pick random parts with unprecedented precision. Unfortunately, all cobots are not equipped with 3D vision systems. Therefore, handling fragile or delicate materials without damaging them can also be problematic for a cobot. • Payload is another feature cobots lack for safety reasons. They can usually carry weights of between three to ten kilos and very rarely heavier than that.
Cobots are not that productive because of the need for safety they imply:	• To operate safely and not to harm humans, cobots normally need to compromise on speed.
The use of cobots reveals contemporary weaknesses:	• Of course, cobots are connected, which can lead to a cybersecurity weakness. This challenge reveals that even if SMEs can take many benefits from cobots implementation in their production line, they are more exposed to the risks of cyber-attacks damages, because they have less skills and ways to defend their company in the case of cyber-attacks contrary to big companies.
Cobots may be hard to repair:	• Independent companies maintaining cobots have to know the model of the cobot the company uses in order to repair it or on which they have to make a predictive maintenance.

	• The second element is that the arm of tools can come from a different brand than the cobot. So, the company using the cobot will have to identify the origin of the breakdown, leading to a machine shutdown during the breakdown analysis and repair it and therefore, they will suffer a loss of productivity during this time.
From a human resources point of view	
Cobots implementation leads to certain fears for the companies:	• Regarding skills, it appears that companies are afraid of facing a lack of knowledge and of skills about human robot collaboration application planning and development. • This is the reason why the companies that want to implement cobots in their production line will take advantage of national companies with client support services which allow to talk about their breakdowns in their mother tongue. • Some employees or even managers can be afraid that there would be a gap between the real use of collaborative robotics and what is shown in the media. There would be a discrepancy between those two areas, leading to a skepticism to implement collaborative robotics in production lines.
Cobots implementation can face a high resistance to change:	• Employees can be skeptical towards collaborative robotics implementation and use, because their use will change their way to work, and some employees are not ready to change their way of working. • Cobots implementation also leads to a resistance to change by the employees, because the collaborative robotics implementation involves that the low-qualification jobs tend to be replaced by high-qualification ones which creates an anxiety for the current low-qualified employees.

Cobots implementation cannot fully replace human workers:	• The best choice is to combine the strength, precision and speed of cobots with the ingenuity, judgment and dexterity of human workers. Cobots will probably never completely substitute the common sense and problem-solving abilities of skilled human workers. While cobots can be programmed to perform detailed and complex actions, they lack the ability to detect abnormalities, such as variation in raw materials or the correct placement of components. This makes them less flexible than human workers, who have to double-check the work completed by their automated colleagues.
From a financial point of view	
Cobots implementation takes time:	• Cobots implementation takes time: research of the right cobot, of the right tool of arm, design, etc. During this time, the productivity rate will decrease because the person in charge of this task will not work on his common assignment and therefore it will have an impact on the general benefit of the company.
Cobots purchase can be dependent on national or regional subventions:	• As mentioned above, cobots price can change in function of the country concerned, this is due to the potential subventions in some countries. Therefore, some areas are more favorable than others for the collaborative robotics implementation. Thus, a partial competitiveness between areas arises.
Cobots implementation is easier for big companies, so their implementation is not *"fair"*:	• Of course, we may imply that the greater the benefits for the company, the easier the implementation, lowering the financial risks taken. This means that SMEs are less advantaged to get into 4.0 industry.
From a normative point of view	
It seems that for many companies there are too many standards that frame collaborative robotics implementation and use:	• During our interviews, one of the companies[132] has declared that it had stopped using cobots because of the numerous norms and standards

[132] Which prefers staying anonymous

	which frame the use of collaborative robotics considering that the legislative environment was too heavy around the use of cobots. It also appears that the standards environment is one of the most advanced reason why the companies refuse to implement collaborative robotics in their production line. • The case studies analysis has led to the conclusion that many companies were more familiar with ISO/TS 10218-1[133] and 10218-2[134] rather than ISO/TS 15066[135] which was not considered by most companies. In other words, it means that many companies do not respect the requirements linked to the use of collaborative robotics as suggested by the ISO/TS 15066, but continue to work with cobots as if they were traditional industrial robots.
From a communicational point of view	
Cobots implementation can lead to intra and extra communicational issues for the company:	• In many case studies, it appears that the vast majority of managers is favourable to the implementation of cobots in their production lines because of the numerous advantages provided by cobots on productivity while the vast majority of operators is afraid or unfavourable to the implementation of cobots in their production lines. They are scared away mainly because they think a cobot could "replace" them. Thus, for some companies cobots implementation can lead to the creation of a gap between the managers and the operators. Cobots implementation can also be seen as a disadvantage for consumers of some companies, final consumers having a negative perception of cobots.
From a management point of view	
The use of cobots implies new management technics:	• For instance, a task can only be performed collaboratively if neither the worker nor the robot are

[133] https://www.iso.org/obp/ui/#iso:std:iso:10218:-1:ed-2:v1:en
[134] https://www.iso.org/standard/41571.html
[135] https://www.iso.org/obp/ui/#iso:std:iso:ts:15066:ed-1:v1:en

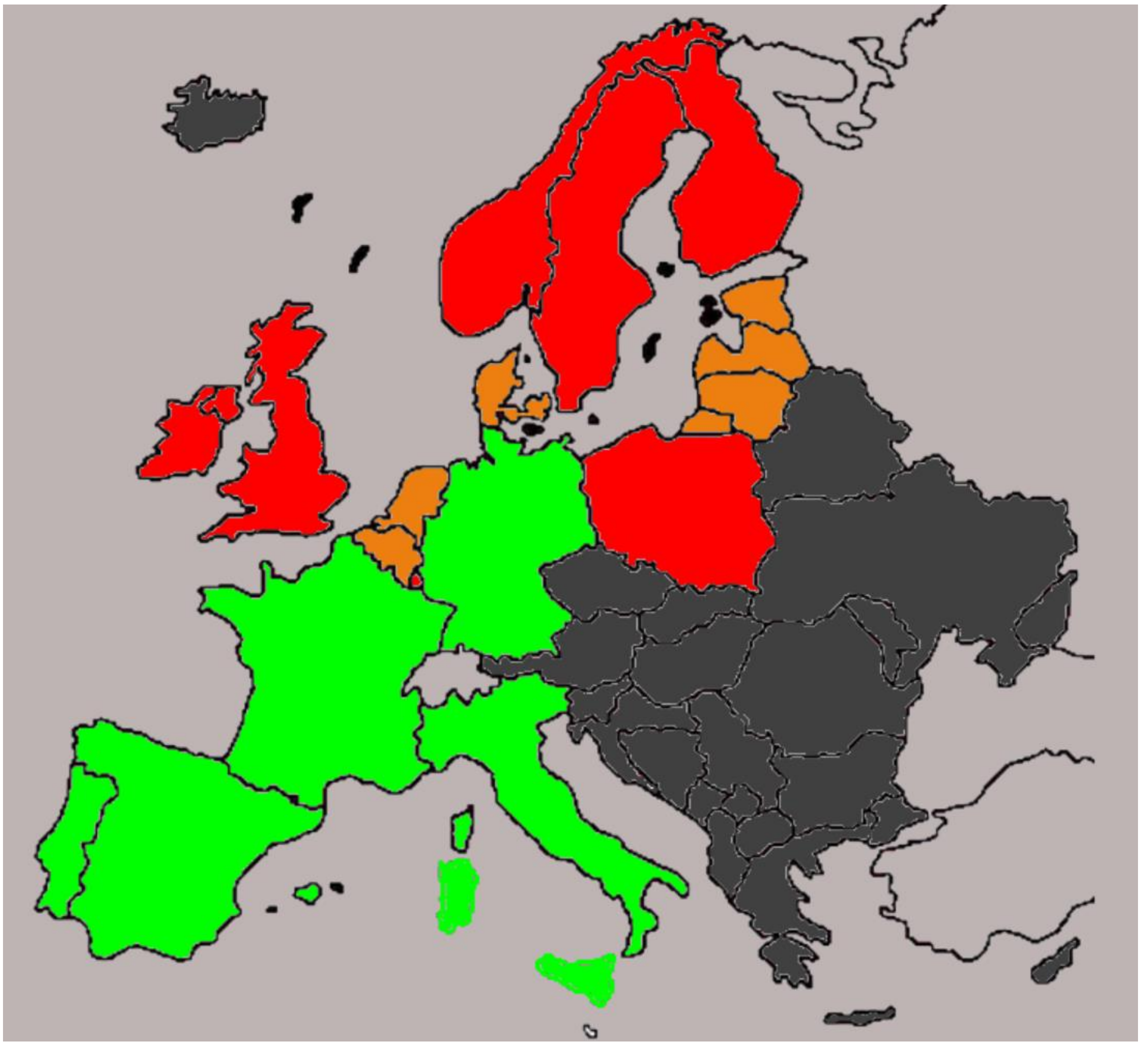
	occupied by a different task (scheduling with logical relations).
Both from a technical and a financial point of view	
Cobots present specific technical characteristics that can lead to financial challenges:	• a cobots feature is to have a limited speed of execution, and their use is limited by low-dynamic tasks; therefore we have to relativise the productivity rate gain provided by a collaborative robotics implantation in a production line.
Both from a human resources and a financial point of view	
Cobots implementation requires to train the employees in the use of collaborative robotics:	• Cobots implementation in a production line takes time from a human resource point of view. First, the company will have to train its employees and operators to the use of collaborative robotics which will take time; furthermore some trainings proposed by cobots constructors are not free. This means that the company will have to pay the training and will also experience a loss of productivity because during the time of the employees training, the operator will not work, so the implementation of collaborative robotics will lead to a loss of productivity and by extension to a lack of money.
Cobots implementation requires the recruitment of new profiles of workers:	• When a company implements collaborative robotics, the company has to recruit workers already familiar with the use of collaborative robotics. Thus, it takes time to find the right profile to recruit for the HR manager and therefore it implies an indirect cost for the company. Furthermore, there is a risk for the company to recruit a non-adapted worker, knowing the fact that a "bad casting" costs between 45k euros and 100k euros for a company, it appears that cobots implementation composes a human and a financial risk.[136]
The use of cobots implies an acceptance from the employees:	• If a company has a high resistance to change, it is a risk to invest in the collaborative robotics

[136] https://www.hr-voice.com/recrutement/recrutement-rate-quel-est-le-cout-pour-lentreprise/2019/02/11/

	implementation. In fact, if there is a high resistance to change one of the predictable consequences at the cobot implementation will be that the employees will take a lot of time to learn how to use cobots to use them in an optimal way of working.
From a human resources, financial and a technical point of view	
The use of cobots requires skills:	• As seen during the presentation of the case studies analysis it appears that only few companies have the proper skilled workers to design the collaborative robot behaviour or necessary to program it. Therefore, these designs, as well as the robotics arm, are designed or developed in most of the cases by integrators companies or even suppliers' companies due to the lack of skills of the most important part of companies, which, of course, implies new costs that the company will have to support while implementing collaborative robotics.
General consequence	
As we can see thanks to this chart resuming the disadvantages linked to the use of collaborative robotics and their implementation, most of those disadvantages is linked to the human resources challenge and the upskilling one. For those reasons, the TOURINGS project is beneficial for the upskilling of the collaborative robotics workers.	

Table 13. **Chart resuming all the challenges and disadvantages to implement and use collaborative robotics in production lines**

As a general conclusion concerning the advantages and challenges faced by companies at the implementation of collaborative robotics in their production lines, we could compare the two following figures (**Figure 59** and **Figure 60**).



Legend:

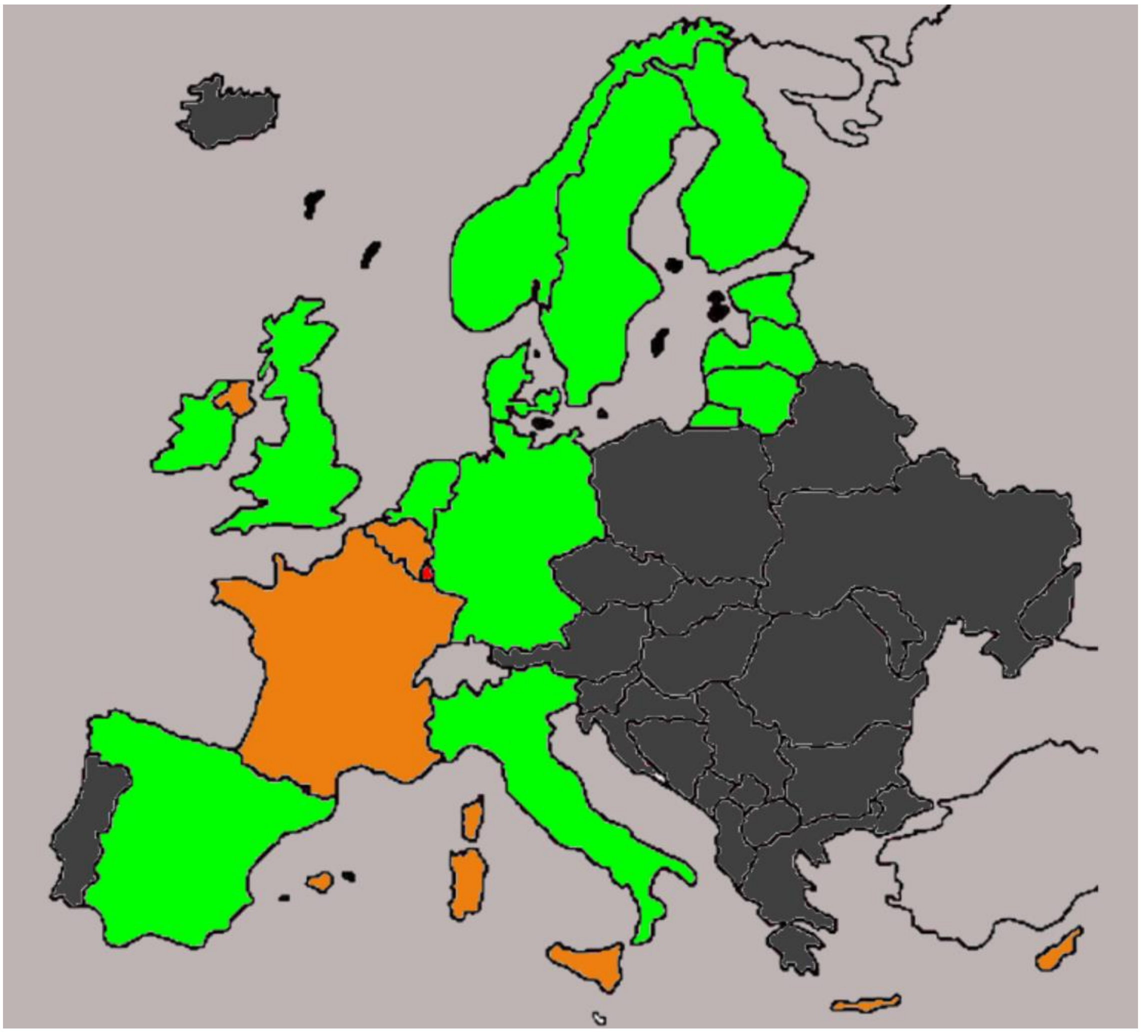
Countries where there are national and/or regional subventions to support the purchase of collaborative robotics in industrial companies.

Countries where there are national and/ or regional subventions to support the purchase of collaborative robotics in industrial companies (but less important than the green ones).

Countries where there are no national subventions to help to the implementation of collaborative robotics in the industrial companies.

Countries for which we do not have enough information.

Figure 59. Financial favourable areas for the implementation of collaborative robotics in production lines in the European Union



Legend:
Countries where there are a lot of national trainings on the use of collaborative robotics in industrial context.
Countries where there are few national trainings on the use of collaborative robotics in industrial context.
Countries for which we do not have enough information.

Figure 60. Human resources favourable areas for the implementation of collaborative robotics in production lines in the European Union

As we can see in both figures (**Figure 59** and **Figure 60**), the challenges aroused by the implementation of the collaborative robotics in production lines of industrial companies are balanced by the advantages provided by such installations. Therefore, it appears that the whole entire European Union is a favourable area for the implementation of collaborative robotics. But a question has aroused onthe use of collaborative robotics: is it only a trend effect or a real transformation of the robotics approach?

3. Jobs, skills required and training methods

Finally, to understand the current use of collaborative robotics through the European Union countries in a better way, we will focus on the jobs and skills required to practice such jobs. We will also focus on the existing training methods helping industrial companies to train their employees on those new tools. To study this point, first we will focus on the analysis of the jobs required to implement and use collaborative robotics in production lines. Then, we will focus on the skills required per each of those previous listed jobs analysed through the angle of the "Combine method".

3.1 Jobs required

3.1.1 Typology proposed by Fanuc.

The company constructing collaborative robots, Fanuc, has developed a typology of jobs required to implement and use collaborative robotics. Their typology assumes that: the practical use of robots in a company is primarily related to jobs in a specific field of implementation and this robot-based cell is more or less closely related to the production system. Digital manufacturing, which is dominating today, is a technology-based approach in manufacturing and is realised over the horizontal and vertical value chain of a company. Inin the following table (**Table 14**), the basic levels of the digital manufacturing are tightly integrated, which also causes the additional needs for competences.

Level	Characteristics
Business	Business model and business plan for achieving the goal
Facility	Factory plant with corresponding equipment and layout
Workshop	Production scheduling and resources allocation. Supervising the processes on the shop area
Robot Cell	Coordinate operations of multiple stations, sequencing the batches and material handling using different robot applications
Workstation	Fulfil the orders and coordinate operations, for increasing the flexibility and automation level could be used CR
Machine	The certain unit with corresponding technological possibilities for real-time operations. The integration of machine tool and industrial robot is a rising trend
Sensor / actuator	Controlling the individual subsystems for executing the task

Table 14. **The levels of manufacturing hierarchy**

In different levels of manufacturing: workshop, robot-cell, workstation, different knowledges and skills are needed. On the systems level system engineers to operate manufacturing processes, robot technicians to plan the production at a robot-cell and robot-operators to execute the manufacturing task are needed.

The following subsections will present the jobs required to implement and use collaborative robotics:

3.1.1.1 Robot operator

3.1.1.1.1 Presentation of the job

A robot operator run programs on the robot for producing the parts together with the collaborative robot. A robot operator performs the jobs, according to the working instructions in a certain technology process (assembly, pick-and-place, loading, welding, painting, polishing, etc.). Therefore, the specific knowledge about the manufacturing technology: assembly, welding, painting is also necessary. The position in a company is called welding robot operator, assembly robot operator, painting robot operator, etc.

3.1.1.1.2 Skills required

The robot operator requires mathematical-logical and analytical skills, systemic thinking, concentration, manual action and visual memory. Work requires precision of movements, coordination, adaptability. Correctness, accuracy, learning ability and responsibility, and co-operation skills are also important.

3.1.1.1.3 Objective

The robot operator job is to ensure that robots are in good working order, skillful operation and safety. The robot operator handles robots in the different industrial fields (for example: mechanical, medicine, electronics, food, wood and furniture) and logistics robots using information and communication technology (ICT) and other technological solutions. Working with collaborative robots requires a broader range of professional skills, as robotics work involves the installation, operation and testing of mechatronic devices, but also there is a need to consider the safety rules.

3.1.2 Robot systems technician (Robot technician)

3.1.2.1 *Presentation of the job*

Robot systems technicians are responsible for the operation and maintenance of individual robots and robot-based manufacturing systems. They use CAD/CAM platforms to perform their tasks, adaptive control systems with sensory feedback for realising the performance and information systems for data analysis, also IoT and M2M applications are their activity area.

3.1.2.2 *Skills required*

A robot systems technician is able to fulfil sophisticated manufacturing tasks, using needed fixtures and other equipment. Robot technician is working on the basis of given working instructions, but must be capable of making decisions according to the current situation. So smart thinking and quick respond to the industrial situations are necessary. These are general demands, but all the needed competences would be worked out during the project. The work of a robot technician requires mathematical-logical and analytical skills, systematic thinking, concentration, manual activity and visual memory. Dealing with work requires organisational, communication and expression skills, good focus, consistency, co-ordination, advanced responsibility and willingness to learn. They must be ready to lead and supervise the work of robot operators, be responsible for team performance, advise clients, and collaborate with mechatronics, automation engineers, technologists, IT and other related professionals.

3.1.2.3 *Objective*

Like the robot operator, the robot technician job is to ensure the robots are in good working order, skillful operation and safety. A robot technician handles robot systems in different industries and must operate logistics robots and systems (hereinafter robot systems) using information and communication technology and other technological solutions. Their tasks include off-line programming and simulation, installing communications and utility networks, drive, and sensor engineering, monitoring the performance, optimising operations and maintenance of robot systems.

3.1.3 Systems engineer

3.1.3.1 *Presentation of the job*

The systems engineer job consists in designing and managing composite systems over their life cycles. Their job is more or less similar to the project manager one. Their tasks derive from the company's needs identification, to the planification of the budget. They must also coordinate the different technical teams dealing with work processes, optimisation methods and risk management tools. The tasks included in a systems engineer job are presented in a chronological way on the following figure (**Figure 61**).

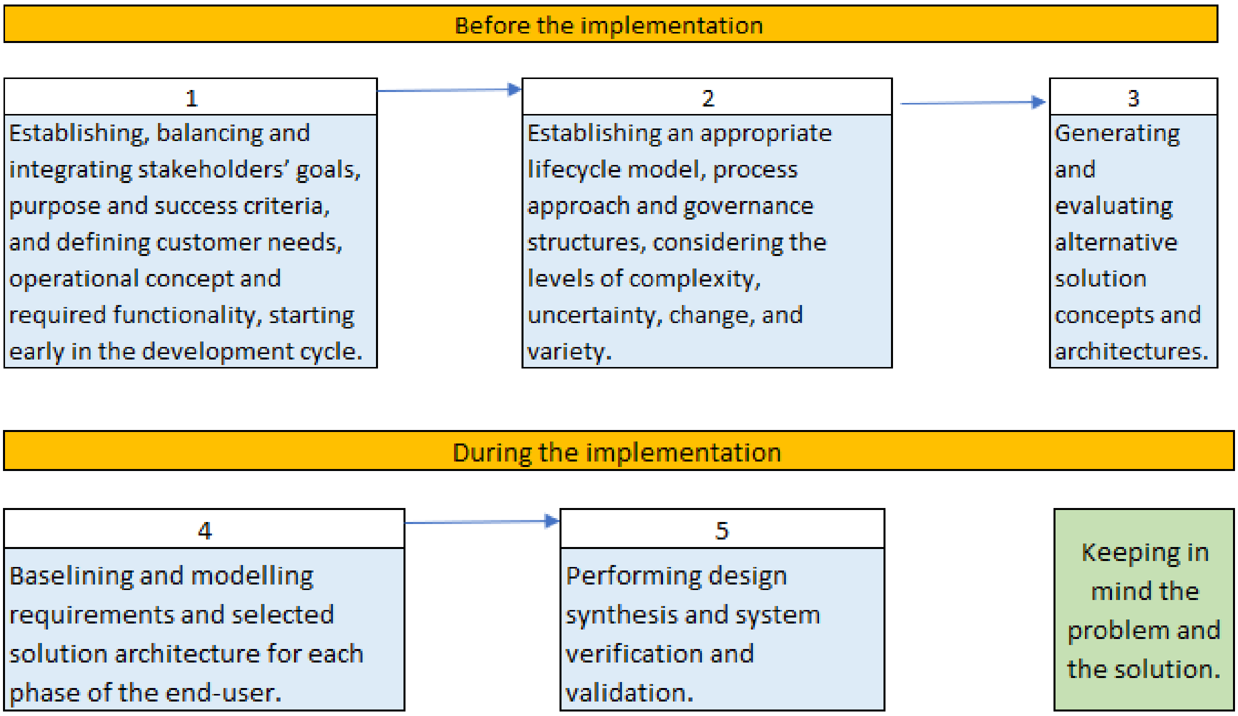


Figure 61. System engineer focuses

3.1.3.2 *Skills required*

The job of a systems engineer requires transdisciplinary knowledge and an integrative approach. Therefore, the systems engineer needs to have knowledge in systems principles and concepts, like in science, technology and management.

3.1.3.3 *Objective*

The objective of the systems engineer is to lead the implementation of collaborative robotics in a successful way.

3.1.4 Conclusions about the jobs required to implement and use collaborative robotics in industrial companies

The analysis clearly showed the differences in the knowledge and experiences of robot operators and robot system technicians. Robot operators basically have to execute the work order and must be able to operate the industrial robot at the workplace. The robot system technicians are higher level workers whose task is also to do the set-up, change end effectors, if necessary, to do the maintenance operations and organise the work in different robot-cells.

After gathering information and feedbacks from the industrial case studies, we can point out some conclusions about the human resources needs evoked by European Union manufacturing companies as presented in the following table (**Table 15**).

1. Critical comments presenting the companies' needs:	**2. Additional needs to be more efficient at the workplace:**
Companies express the need for: • more practical work experiences. • practice in searching fault in automation system. • greater understanding about the system as a whole. • greater understanding in setting and planning process. • cost efficiency and understanding of price forming process. • cooperation with companies.	Companies express the need for: • practical skills. • basics of programming (also for operators). • parameter settings. • action in exceptional circumstances. • electrical installation licenses (for the technicians). • off-line programming skills. • quicker adaption. • understanding of different possibilities. • responsibility and quality assurance.
3. Technical skills to think about:	**4. Additional skills to think about:**
Companies express the need for: • IT practical knowledge (concerning for example: APP performance, IoT possibilities, M2M, PLC, SCADA, etc.). • Data and information processing. • Data and information analytics. • Statistical knowledge. • Visualisation. • Process deep understanding (especially for assembly, welding, logistics tasks, etc.). • Digital twins. • Machine learning. • Computer programming. • Performance measurement and improvement. • Workplace organisation. • Basic of lean manufacturing. • Interdisciplinarity.	Companies express the need for: • Self and time management. • Adaptability and ability to change. • Team working abilities. • Decision making. • Social skills. • Communication skills. • Trust in new technologies. • Continuous improvement.

Table 15. **Current human resources' needs like expressed by manufacturing companies analysed through the case studies**

We have to note that those skills might be present in all the jobs previously presented: robot system technician, robot operator and systems engineer.

In this context, the Combine method analysis could be a great way to analyse those jobs.

3.1.5 Combine method

When it comes to "competencies", professionals have often different definitions and perspectives on what this concept covers. In these latest few years, the use and development concept of "soft skills" added confusion to this concept. This notion sometimes covers more than skills per se. For instance, values, personality traits are sometimes included into "soft skills" and are unfortunately not skills per se.

3.1.5.1 *A competence: a combination of willingness to act, power to act and know-how to act*

The "Combine" method aims at giving an easy definition (to grasp and to share) of competencies. It also aims at providing a structured method to analyse competencies at work in order to put in place competencies referential or training sessions.

This method is based on Dr. LE BORTEF's[137] approach. This French professional spent his professional life working on competencies as a researcher and professional. French researchers and professionals agree on one point when it comes to competencies. Competencies can only be "*seen*", noticed, analysed in action. In other words, assessing the ability of a person without them doing something before is impossible. For this reason, Dr. LE BORTEF asserts that a given competence is **the combination of willingness to act, power to act and know how to act**. Let's move forward and dig a little bit further:

- **Willingness to act** is related to motivation. This is the student on whose school report is written "*is able to do it, but doesn't want to do it"*. A person is able to do something if they have the willingness and motivation to do it.
- **Power to act** is related to the environment of a person. Does this person have the social, material, time and space means to do something? Imagine that you have been trained in the use of the last version of Excel, but you have no access to this last version on your computer.
- **Know how to act** is related to the ability to do something (to use a function of Excel, to make a presentation, to write a letter about a given topic).

In the "Combine" method, the choice was made to reduce the competence to "the know-how to act" or skills concept. Skills have the characteristic of being testable, during a recruitment processes for example, teachable, during training and skills development actions, and they are dependent on a person (unlike the power to act that can be linked to the means given, or not, by a manager, a team or a company).

3.1.5.2 *Know-How : a combination set of skills*

In the "Combine" method, a know-how is understood as the combination of bricks skills and knowledge, mobilised by an employee to perform his work in an efficient way. The

[137] https://www.babelio.com/auteur/Guy-Le-Boterf/118316#:~:text=Biographie%20%3A,Universit%C3%A9%20de%20Sherbrooke%20(Canada).

analysis of research in management and psychology has made it possible to identify five elementary bricks of skills and knowledge: the knowledge itself, the manual skills, the relational skills, the intra-personal skills and the cognitive skills. These five elementary bricks are presented below.

- **Knowledge** represents what I know to do my job. For example, the accounting rules to be applied for writing entries.
- **Manual skills** are linked to what I use to interact with inanimate objects. For example, my ability to perform gestures (screwing a screw, replacing a spark plug of an engine, etc.) to mount a piece of furniture, repair a motor.
- **Relational skills** represent what I use to interact with another person or a group of other people. For example, making a presentation in front of a group of 500 people, responding and calming a dissatisfied customer.
- **Intra-personal skills (or metacognitive skills)** represent what I implement to get to know myself better and regulate my practices at work. For example, becoming aware of my poor management of my e-mails and the answer(s) I bring to them, becoming aware of my mistakes during an oral presentation, and the answer(s) I give to it.
- **Cognitive skills** represent what I implement to process procedures, to perform actions such as writing, calculation.

These five elementary bricks were found in studies conducted by the HRM Digital Lab. They can be systematically described by the verb "to be able to". For the case of knowledge, "to be able to quote", "to be able to name", "to be able to define", etc.

3.1.5.3 *Building a matrix of analysis of the skills of a profession*

An employee's performance at work must be analysed as the result of a combination of several skills and meta-skills (principles of plurality and combination). To serve as a checklist, it is interesting to start from the four meta-skills that are manual, relational, intra-personal and cognitive skills. Depending on the profession, we do not systematically find all these meta-skills, but they are an excellent starting point for reflection. It is possible to add specific meta-skills: digital skills, transformative skills, creative skills. This list is far from being exhaustive. These meta-skills can be divided into sub-areas of skills. For example, we can find in digital skills, skills related to the use of email, the use of PowerPoint, or that of social networks

On this basis, it is possible to build a matrix of analysis of the skills of a profession containing:

- In columns the meta-skills necessary to be efficient in a profession. As already mentioned, these meta-skills can be specified by a set of sub-areas of skills.
- In rows the elementary bricks that constitute a skill. As a reminder, we find knowledge, manual know-how, relational know-how, intra-personal know-how, cognitive know-how.

3.2 Training methods and national educational systems

Two main ways of training for the required workers are co-existing in Europe: training sessions put in place by the collaborative robotics constructors and the national educational system of each European country.

3.2.1 Training sessions put in place by the collaborative robotics constructors

Those training sessions can be free (when a company buys a collaborative robotics for example) and other modules must be purchased. The cost of a training content is around 800 euros (1,000 USD). Most of the training contents developed by the robot constructors are divided into three levels of training: basics, medium and advanced. Every module lasts between 2 and 3 days, they can be a presence-based modality or e-learning modules. According to the information gathered, it seems that the training contents created by constructors are translated into 3 main languages: English, German and French. It also seems that those modules have oriented the national educational systems providing training contents about the use of collaborative robotics.

Mainly used as the base of the workers skills our case studies have reflected the fact that those trainings were more important than national educational trainings. For example, according to the collected feedbacks, the Spanish national education system is not responding to all the needs of companies in terms of human resources. Automation and robotics are key sectors for manufacturing companies and also, these are key to generate stable and quality jobs.

3.2.2 National educational system

As seen previously some European Union countries offer more training contents than others. Those elements can be resumed in the following table (**Table 16**) presenting the main important master’s degrees direct or indirectly linked to the use of collaborative robotics present in each country of our typology.

Co-funded by the Erasmus+ Programme of the European Union

tourings
training for collaborative robotics integration

Typology	Type 1	Type 2	Type 3	Type 4		Other European country
	Germany	Italy	Estonia	Spain	France	
Degrees	-Master's degree in Robotics, HsKA, Karlsruhe, Germany	- Master of Science in Nanotechnology Engineering, Sapienza University of Roma, Rome, Italy -Master in Artificial Intelligence and Robotics, Sapienza University of Rome, Rome, Italy -M.Sc. in Bio- and Nanomaterials Science and Technology Ca' Foscari University of Venice, Italy -Master of Science in Robotics Engineering (EMARO) University Of Genoa (Università Degli Studi Di Genova), Italy -Msc In Materials Engineering And Nanotechnology, Politecnico di Milano, Italy Staff training is always the key to the success of any innovative process. Companies must actively engage in appropriate retraining programs for employees to equip them with appropriate skills. HCR providers usually offer personalised training solutions to the company staff, which will operate in collaboration with the robot.	- Master in Robotics and Computer Engineering, University of Tartu, Estonia **List of official institutions supporting the companies in the field of digital technologies (also collaborative robotics)** - Ministry of Economic Affairs and Communication (www.mkm.ee/en) - Ministry of Education and Research (www.hm.ee/en) - Enterprise Estonia (www.eas.ee) - Estonian Qualification Agency SA (www.kutsekoda.ee) - Regional Development Centres (www.arenduskeskused.ee) - Federation of Estonian Engineering Industries (EML) (www.emliit.ee) - IMECC (www,imecc.ee) **List of activities illustrating the policy** Enterprise Estonia supporting programs: - Digital diagnostics The objective of the grant is to support the preparation of diagnostics for the digitisation and	-Master in Nanoscience and Nanotechnology, Universidade Santiago de Compostela, Santiago de Compostela, Spain In this changing and diverse scenario, education faces a great challenge: to discover the talents of each individual and to encourage them to develop them to their full potential. This new education is based on such fundamental aspects as experimentation, collaboration and integration, that amazing ability to create something new from the synthesis of the most varied components. It is a new education. A	- Specialised Master "Colrobots_ Expert in collaborative robotics for the future industry", Arts et Métiers, Lille, France - Master AIMove: Artificial Intelligence and Motion in Industries and Creation Mines ParisTech | PSL, Ile de France, France -Master in people and robots for sustainable work EIT Manufacturing, Palaiseau, France -Japan-Europe master's in advanced Robotics (JEMARO) Centrale Nantes, France	• MSc Nanotechnology, University of Dublin • Master in mechatronic systems, University of Oradea, Romania • MSc In Imaging And Light In Extended Reality – IMLEX, Joensuu, Finland • Master's Program in AI and Robotics, Örebro, Sweden • Master's Program in Information and Communication Technology: Intelligent Systems, University of Turku, Finland • Master of Science in automation, cybernetics and robotics with specialization in computer control systems, Gdańsk University of Technology, Poland • MSc in Engineering - Robotic Systems (advanced robotic technology / drones and autonomous systems), University of Southern Denmark, Odense, Denmark • Master in Robotics and Control, Umeå University - Faculty of Science and Technology, Umeå, Sweden • Master of Science in automation, cybernetics, and robotics with specialization in robotics and decision system, Gdańsk University of Technology, Poland

		The job market is constantly evolving and is increasingly focused on the search for scientific and technological profiles, which are not always available. This skills gap must be filled with up-to-date training in line with the needs and demands of companies. With this in mind, a significant example which could shed light on the current development is the project set up by Assolombarda, the Brigatti, Camerani and Pintaldi Foundations and the Politecnico, together with scientific partners ABB and iMages: Robo Lab Monza[138]. This is the first collaborative robotics E-Learning Centre in Italy, dedicated to primary and secondary school students who, through educational activities, can improve their theoretical knowledge and application skills in a STEM context. Six local schools are involved in the project in this first phase with over 1,200 students and teachers from all over Italy who started practicing at the Robo	automation of manufacturing and mining and quarrying. The maximum amount of grant depends on the sales revenue of the business year preceding the application for the grant of enterprise. If the enterprise's sales revenue (€) for the previous year is the following: 200,000–1 million, then the grant is 5,000 1 million–5 million, then the grant is 10,000 over 5 million, then the grant is 15,000 - Digitalisation grant With the help of the digitalisation grant, Estonia wishes to encourage enterprises in the industrial sector to invest in digital technologies, implementation of robots and automation. Maximum grant 200,000€ Own contribution is at least 50-90% - Enterprise Development Program The enterprise development program aims to support well-thought-out development, improved action planning, innovation implementation and product development. In the	radically human education in a world of machine. The future seems to be a combination of humans and machines, each doing what they do best; machines following procedures (routines, algorithms); human acting in face of unforeseen events and exceptions. We are just in the beginning of a great change, in where the collaboration between humans and robots may become commonplace. It will make sense to talk about ''intelligent resources'' (human and machine) thanks to the increasing combination of human and artificial intelligences.	-Master in Control and Advanced Robotics (CORO IMARO) Centrale Nantes, France -Master in Control and Robotics in Signal and Image Processing (CORO SIP) Centrale Nantes, France -MSc in Physics, Photonics and Nanotechnology (PPN), University of Burgundy Franche-Comté (UBFC), Dijon, France - MSc in photonics, micro nanotechnology, time-frequency metrology and complex systems (PICS), University of Burgundy Franche-Comté	• Master in Artificial Intelligence, Umeå University - Faculty of Science and Technology, Sweden • Master of Science in Information and Communication Technology – Robotics, University of Zagreb - Faculty of Electrical Engineering and Computing, Croatia • MSc in Human-Robot Interaction, University of Skövde, Sweden • Master's degree in advanced materials and nanotechnology, Jagiellonian University, Krakow, Poland - Master of Photonics and Nanotechnology Vilnius University, Lithuania - M.Sc. Robotics, Warsaw University of Technology, Poland - Master of Science in Cybernetics and Robotics, Czech Technical University in Prague, Prague 6, Czech Republic - Master's Program in Automation Engineering - Factory Automation and Robotics, Tampere University, Finland - MSc in Advanced Chemical Engineering and Nanotechnology, Wroclaw University of Science and Technology, Wrocław, Poland - MSc in Materials Physics for Nanoscale and Quantum Technology Linköping University, Sweden

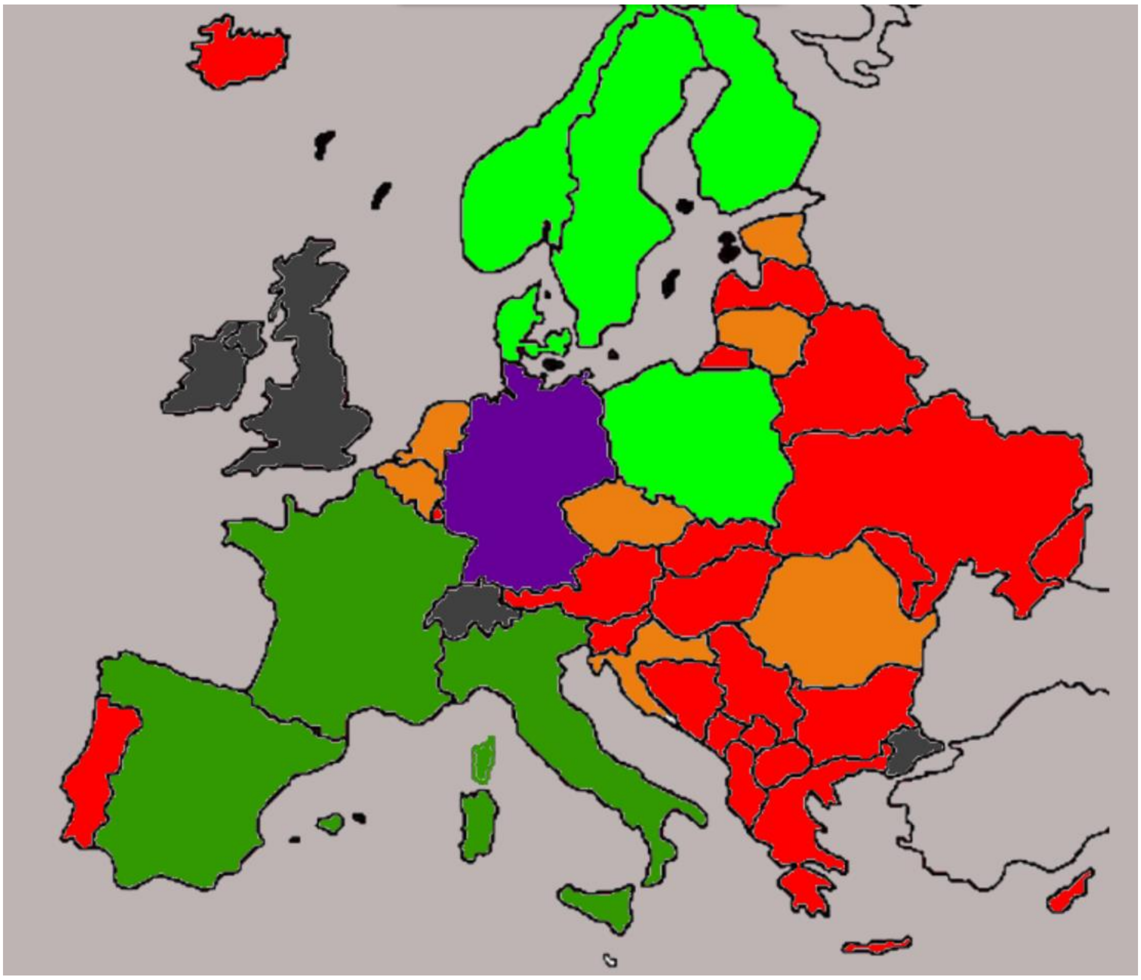
[138] https://www.assolombarda.it/media/comunicati-stampa/nasce-a-monza-il-primo-laboratorio-in-italia-con-robot-collaborativi

		Lab from 10 March 2021. The students will be able to learn how to make simple "Pick&Place" programs with the installed robots, completing their training through the acquisition of theoretical and practical skills thanks to the latest generation of robots. This initiative demonstrates the necessity for governments and companies to focus on providing current and future workers with the skills to ensure they can benefit in the future from the positive impact of robots on employment, job quality and remunerations.	course of the development program, each participating enterprise will launch new products and services that are more profitable than their predecessors. - Norway Grants Green ICT program 2014-2021 The program objective is to increase value creation and sustainable growth in Estonia's private sector. Green ICT aims to stimulate and develop innovation-led long-term business cooperation between Estonia and Norway. Program focuses on supporting business initiatives in three areas: digitalisation of industries, product development and application of innovative ICT-led green products and services; and development of new products and services in the area of Welfare Technology (personalised medicine).	It is true that the elimination of low-added tasks may have an immediate negative effect on the amount of low-skilled labor employed in these processes, but the implementation of more complex and sophisticated systems will in turn create a growing demand for other, more qualified professional profiles. The overall quantitative balance is likely to be negative and the surplus will have to be redirected to other activities through training.	(UBFC), Besançon, France -MSc In Marine And Maritime Intelligent Robotics University of Toulon coupled with Trondheim, Norway - Master in complex systems engineering, University of Toulon, France -master's in chemical Nanoengineering, Erasmus Mundus Master Chemical Nanoengineering, Marseille, France -Master 2 ARTIFICIAL INTELLIGENCE, École Nationale Supérieure d'Informatique pour l'Industrie et l'Entreprise, Courcouronnes, France	- M.Sc. in automatic control and robotics: intelligent aerospace and autonomous systems, Poznan University of Technology, Poland - M.Sc. in automatic control and robotics: intelligent aerospace and autonomous systems, Poznan University of Technology, Poland - Master of Science in Electronics and Nanotechnology, Aalto University, Espoo, Finland - Master of Science in Nanotechnology, KTH Royal Institute of Technology, Stockholm, Sweden - Master's in systems, Control and Robotics, KTH Royal Institute of Technology, Stockholm, Sweden - Erasmus Mundus Joint Master in Nanoscience and Nanotechnology (Leuven et al), KU Leuven, Leuven, Belgium - Master of Nanoscience, Nanotechnology and Nanoengineering (Leuven), KU Leuven, Leuven, Belgium - Master's Program in Robotics, Holly Xiao, Trollhättan, Sweden - Master in Micro and Nano Systems Technology, University College of Southeast Norway, Drammen, Norway

Constru-ctors' trainings languages						In green, there are the languages in which the training contents developed by collaborative robotics constructors are translated.

Table 16. **Table presenting the main national program to train workers in the field of collaborative robotic**

Thanks to the previous table, we can see that European Union countries do not offer the same number of national educational systems to training students in the use of collaborative robotics. This fact is visually represented in the following figure (**Figure 62**).



Countries where there are a lot of national trainings on the use of collaborative robotics in industrial context (more than 5 according to the previous chart)

Countries where there are few national trainings (between 3 and 5 according to the previous chart)

Countries where there are few national educational trainings (less than 3 according to the previous chart).

Countries where there are no national educational trainings on the use of collaborative robotics (according to the previous chart)

Countries for which we do not have enough information.

Figure 62. Map showing the European Union countries that have numerous national educational systems training on the use of collaborative robotics

Thanks to the addition of the previous elements, we can notice that European Union countries do not facilitate the training on collaborative robotics in the same proportions: some countries, like Finland or Sweden, are listed as really advanced while some others are listed as really late in the use of collaborative robotics, for example: Bosnia.

But new training methods are being experienced in order to compensate the lack of knowledge of the workers working direct or indirectly with collaborative robotics.

3.2.3 New training methods

In the past few decades, it appears that a phenomenon is happening in industrial companies: the requirements to comply for a job are increasing. An employee does not have to perform a specific task anymore but has to perform many different ones. It implies a need for better employees' qualifications. According to this statement, methodological processes have to be rethought, they should be more largely based on the use of digital techniques and the ability to use different materials, to be independent enough in the decision-making, and at the same time, employees should have the experience of working in teams.

This phenomenon leads to a decrease of traditional lectures, an increase of individual work, or teamwork, solving special cases or doing practical work including more simulations and visualisations. Employees also have to be trained at decision-making tasks with explanations.

Nowadays, almost all the equipment is related to mechatronics, as they are a combination of mechanics, informatics and electronics. This means, that the graduates must obtain versatile knowledge, not only specific knowledge in one narrow field. The symbiosis of technology and equipment is very important. It requires the understanding of the manufacturing technology and technological capacity of the equipment, to use it efficiently. To cope with the constant changes, we should not pay so much attention to static learning (lectures). It is not possible to obtain all the knowledge. Nowadays, internet is helping the employees greatly. Instead of that, the industrial companies' needed skills have to help them to be able to adapt themselves in new situations, obtain new useful competences and to put them into practice. How to obtain new skills quickly, how to evaluate new situations, how to integrate the knowledge from different fields and use it to solve different problems: these are the new challenges for students and learning process in general.

There is a need to use different didactic methods of organising the teaching-process. For this reason, industrial companies and universities are increasingly resorting to dual learning and case-based learning to train their employees or students.

3.2.3.1 *Dual learning*

Dual learning is a methodological approach that gives the trainee the possibilities to integrate theory and practice as presented in the following figure (**Figure 63**). The following figure is based on the example of servodrive in manufacture. [139]

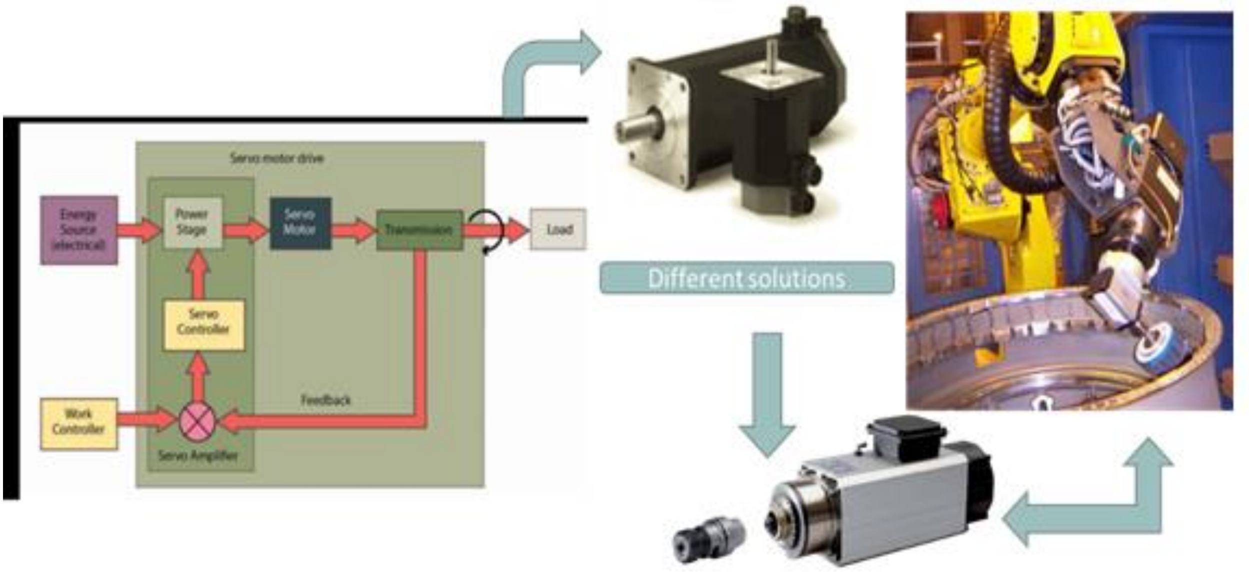


Figure 63. Summary diagram of an example of dual learning [140]

To sum up, dual learning suggests that students combine learning and practicing at a workplace. This means that students are practicing in a real professional space and real industrial tasks.

3.2.3.2 *Problem/case-based learning*

The problem-based, or also called case-based learning consists in presenting a real or a hypothetical issue that an industrial company could face and asking for a solution to the trainees or the students. The following figure (**Figure 64**) presents an example of those case-based exercises.

[139] http://www.ab.com/motion/servo/fseries.html
[140] http://www.ab.com/motion/servo/fseries.html

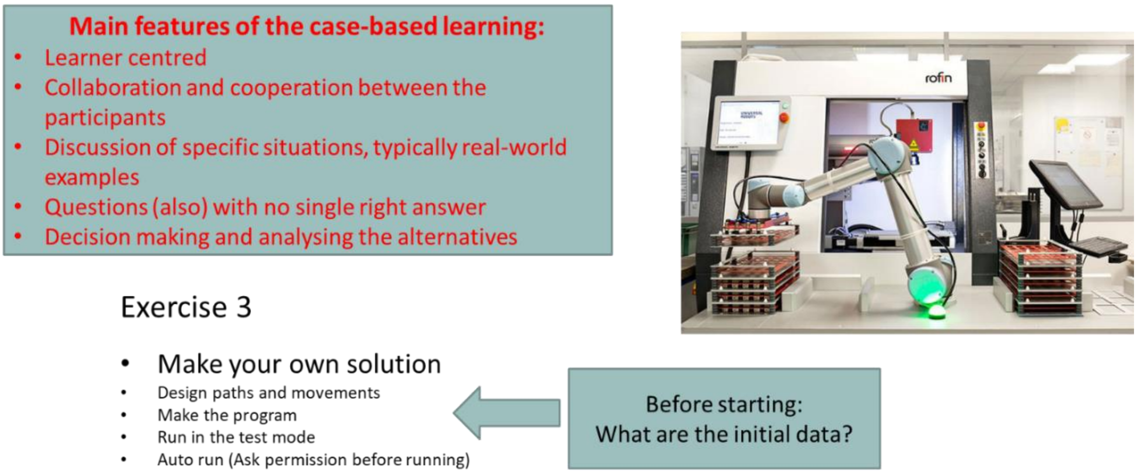


Figure 64. **Example of a case-based exercise**

The case-based or problem-based teaching method has mainly three basic steps:
- problem description,
- identifying what a person needs to know,
- learn and apply to solve the problem.

The efficiency of different teaching methods is given in the following figure (**Figure 65**).

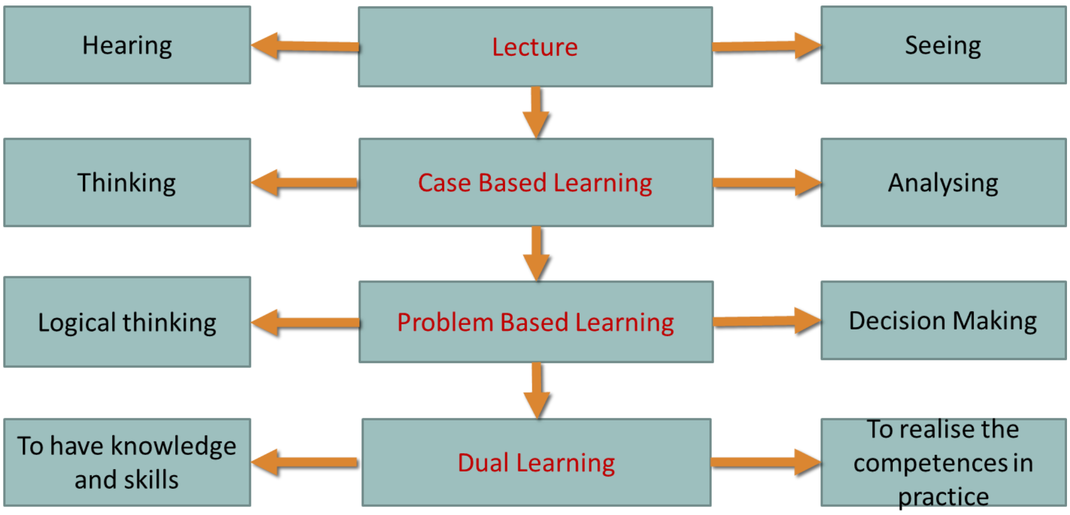


Figure 65. **Comparing teaching methods and their efficiency**

3.2.4 The need for change management

More important than any competence or skill adapted to the collaborative robotics use, the companies that implement collaborative robotics in their production lines need to go through change management.

The change management can be defined as "*referring to the approach that prepares, equips and supports individuals, teams and organisations in achieving organisational change. Change management is one of the six ITIL processes. It includes the methods that redirect or redefine the use of resources, business processes, budget allocations or other modes of operation that significantly change a business or organisation.*"[141]

Change management has to be operated at a multiscale level:

- The individual change management.
- The organisational one.
- And the enterprise change management capability.

As described by Javaid BUTT[142] "*Industry 4.0 (also referred to as digitization of manufacturing) is characterized by cyber physical systems, automation, and data exchange (…). However, the implementation of Industry 4.0 enabling technologies is a difficult task and becomes even more challenging without any standardized approach. The barriers include, but are not limited to, lack of knowledge, inability to realistically quantify the return on investment, and lack of a skilled workforce.*" Therefore, the companies that implement collaborative robotics in their production lines, which is an industry 4.0 implementation, should follow the following road map (**Figure 66**) while they implement collaborative robotics:

Figure 66. Strategic roadmap of change management for the implementation of Industry 4.0, based on lean six sigma approaches. [143]

[141] https://www.oracle.com/fr/cloud/change-management-organisation.html
[142] Javaid BUTT, *A static Roadmap for the manufacturing industry to implement industry 4.0, 2020Chelmford, UK*
[143] Javaid BUTT, *A static Roadmap for the manufacturing industry to implement industry 4.0, 2020Chelmford, UK*

As a conclusion on the collaborative robotics training section, we can state that national education systems have an importance in the use of collaborative robotics, because the younger generations of students will be trained at the use of collaborative robotics, the more the collaborative robotics will be used in industrial companies. We can also say that the change management is one of the keys to create the transition for the industry 4.0 in industrial companies.

3.2.5 New challenges for the European Union

It is also important to point out to the fact that nowadays, new poles of education are emerging such as Russia, which proposes master's degrees direct and indirectly linked to the use of collaborative robotics. The 9 main master's degrees linked direct or indirectly to the use of collaborative robotics in Russia are:

- Master of Electronics and Nanoelectronics, BAUMAN Moscow State Technical University, Moscow, Russia
- Master of Nanoengineering, BAUMAN Moscow State Technical University, Moscow, Russia
- Master of Mechatronics and Robotics, BAUMAN Moscow State Technical University, Moscow, Russia
- Master of Physics and Nanotechnology, St. Petersburg Academic University of the Russian Academy Of Sciences, St. Petersburg, Russia
- MSc in Nanotechnology and Materials for Micro and Nano Systems, National University of Science and Technology MISIS, Moscow, Russia
- MSc in Smart Nanostructures and Condensed Matter Physics, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
- Master of Science in Nanoelectronics and Quantum Technologies, HSE Higher School of Economics, Moscow, Russia
- Master of Science in Space Systems and Engineering, The Skolkovo Institute of Science and Technology (Skoltech), Moscow, Russia
- Master of Science in Robotics, Innopolis University, Kazan, Russia

Furthermore, Russia receives every year more than 250,000 students[144] which represents 15% of the students in international mobility. Considering that 18% of those students study sciences, Russia appears as an *El Dorado* for students wishing to learn the use of collaborative robotics.

Conclusion

[144] https://ressources.campusfrance.org/publications/chiffres_cles/fr/chiffres_cles_2020_fr.pdf

The number of collaborative robotics in the European Union countries is continuously growing thanks to all the advantages provided by the use of cobots compared to traditional industrial robots. Those new tools appear like a “promised land” for the automation and productivity growth of the European Union industrial companies.

Conversely, the advantages are counterbalanced by the fact that the implementation and the use of collaborative robotics arouse new human resources and financial challenges. The financial challenge became an obstacle in particular when a specific company is a small or medium-sized. Therefore, the implementation and use of collaborative robotics appears like a new source of inequity gap between large companies and small and medium-sized ones.

The present report also highlights the fact that manufacturing industries are lacking skilled workforce to implement and use collaborative robotics in an optimal way. We have to recall the fact that the present report is one of the bases for the training content development of the Tourings project, which aims to develop a free training content available within 2 years.

Appendices

Appendix 1: Questionnaire – Survey

This survey has been broadcasted on many platforms (LinkedIn, sent by email, etc.). The survey has unfortunately permitted to gather only 29 answers.

Introduction

As part of the ERASMUS+ project TOURINGS, we would like to provide a virtual training environment to foster the integration of collaborative robotics in companies and to train the necessary workforce. The training curriculum will cover the basics of collaborative robotics, modular design and behaviour of collaborative robots, installation of collaborative robotics on the assembly line, safety requirements for collaborative applications and interaction with collaborative robotics, especially ergonomic aspects.

Moreover, we will communicate and publish around this project (TOURINGS website, social networks, videos, etc.) and at least one national event will be held at the end of the project in each country to showcase the developed training environment.

Our consortium consists of 6 universities and research institutes from 5 different countries (Estonia, France, Germany, Italy and Spain).

For the success of the project, we would like to get in touch with companies that have successfully implemented collaborative robotics applications and build the training curriculum based on their experience and knowledge.

This survey includes the "Basics", "Process Suitability", "Training" and "Safety Requirements" modules of collaborative robotics and is intended for individuals who have worked with or in the field of collaborative robotics.

All your information will be treated anonymously. The research work is subject to the regulations of the data protection legislation. It is absolutely guaranteed that your information will not be associated with your person.

Opening Questions

1. How many years of collaborative robotics experience do you have?
   a. < 1 year
   b. 1 – 5 years
   c. > 5 years
2. How many HRC processes do you operate in your company?
   a. None
   b. 1
   c. > 1
3. Do you have experience in planning and implementing HRC applications?
   a. Yes
   b. No
4. If yes, in how many HRC applications were you involved in the planning and implementation phase?

   a. 1
   b. 2 – 5
   c. > 5

Collaborative Robotics Basics

5. In which operating modes do you deploy your HRC applications resp. in which operating modes have you mainly implemented HRC applications?
   a. Collaboration – Hand guiding
   b. Collaboration – Power and Force limiting
   c. Cooperation – Safety-rated monitored stop
   d. Cooperation – Speed and separation monitoring
   e. Coexistence – Safety-rated monitored stop
   f. Coexistence – Speed and separation monitoring
6. Please rank the operation modes in which you think HRC applications are most frequently implemented (the most frequent is in the first position).
   a. Collaboration – Hand guiding
   b. Collaboration – Power and Force limiting
   c. Cooperation – Safety-rated monitored stop
   d. Cooperation – Speed and separation monitoring
   e. Coexistence – Safety-rated monitored stop
   f. Coexistence – Speed and separation monitoring
7. Which robot do you use in your HRC applications or which robots do you mainly choose to use in HRC applications?
   a. Universal Robots – UR-Reihe
   b. KUKA – iiwa
   c. ABB – Yumi
   d. Omron – TM Reihe
   e. Rethink – Sawyer
   f. Franka Emika – Panda
   g. Standard industrial robot with additional safety technology
8. Do you use another, not listed, robot?
9. What type of gripping technology do you use in your HRC applications?
   a. Vacuum gripper
   b. Mechanical gripper
   c. Specific HRC gripper systems
   d. Self-developed gripper systems
10. Do you use another gripping technique that is not on the list?
11. Which manufacturer of gripping systems do you prefer?
    What type of process do you think is suitable for HRC applications?
    a. Assembly
    b. Handling / Pick and Place
    c. Screwing applications
    d. Welding applications
    e. Palletising
    f. Packing
    g. Lifting aid
    h. Positioning aid

i. Quality Assurance

12. Would you like to add another process type?

Process Suitability

13. In your opinion, which characteristics must a process have in order to be useful for an HRC application? (applies / does not apply)

	Applies	Does not apply
Monotonous process steps		
Heavy process steps		
Ergonomically stressful process steps		
Stressful process steps		
Processes that require human skills		
Improvement of cycle time		
Low quantities with high variance		
Short product life cycles		
High proportion of secondary steps		
High proportion of peripherals		
Processes requiring high flexibility		
Demand for transferability to other processes		
Increase in productivity		
Presence of complicated sub-processes / sub-processes		

14. In your opinion, what are the main advantages or disadvantages that HRC has over manual processes or full automation?

	Advantage of HRC compared to manual process	Disadvantage of HRC compared to manual process	Advantage HRC compared to full automation	Disadvantage HRC compared to full automation
Improvement of cycle time				
Increase in productivity				
Low error rate / High quality				
Compliance with low tolerances				

Small Quantities / single-piece production				
High variance				
Fast reprogramming				
Fast adaptability to changing conditions				
Low space requirements				
Counteracting the shortage of manpower				
Easy to learn / operate / use				
Elimination of time consuming training				
Economic efficiency				
Low investment				
Fast amortization				
Precision				
Speed				
Repeatability				
Response to uncertainties				
Fast installation				
Collision detection				
Sensitivity				

15. What do you think is the main reason for the decision to implement an HRC application?
    a. Improvement of ergonomics
    b. (Partial) automation with low investment
    c. Saving labor / counteracting the labor shortage
16. Do you think there is another reason?
17. What do you think are the reasons for the hesitant adoption of HRC applications?
    a. Lack of knowledge/ skills on HRC application planning and development.
    b. Lack of knowledge/ skills on the implementation of HRC applications
    c. Level of safety requirements is too high
    d. Level of uncertainty / insecurity is too high
    e. Compliance with biomechanical limits not possible
    f. Required cycle times cannot be met / no economical production
    g. Planning and development phases too long
    h. Fear of using Cobots
    i. No use Cases for HRC

18. Would you like to add any barriers?
19. Can you please rank the following planning steps according to the order in which they should be processed when planning and implementing HRC applications? The first step should be in the first place.
    - → Evaluate the suitability for having a robot carry out the manufacturing steps
    - → Splitting the manual process into sub-processes
    - → Planning of cycle times
    - → Layout development
    - → Safety planning
    - → Risk assessment
    - → Simulation
    - → Measurement of biomechanical limits
    - → Cost-effectiveness analysis
20. Are there any process steps that were not mentioned? (Freitext)

Training

21. Please mark the skills you think a person whose work involves Cobots should have:

	Operator (the person who works with the cobot on a daily basis)	Maintainer (person responsible for maintenance, reprogramming and troubleshooting)	System Planner (responsible for planning and implementation of HRC systems)
Basic knowledge (what is a Cobot, how does the Cobot work, what safety technology does the Cobot have)			
Knowledge about the structure and functionality of Cobots			
Knowledge about the fields of application of Cobots			
Knowledge about the safety techniques			
Knowledge about the dangers of working with Cobots			
Knowledge about ergonomics			
How the cooperation / collaboration between humans			

and robots looks like / can look like			
Programming knowledge - programming application, teaching			
Programming knowledge - adaptation to changing conditions (new workpiece, new position, etc.)			
Implementing safety techniques (also: sensitivity functions)			
Application of simulation software			

22. In your opinion, what training content should be included in comprehensive training in the area of HRC? (Competencies/knowledge that a company needs to be able to implement MRK applications)
    a. Planning of HRC applications
    b. Simulation of HRC applications
    c. Implementation of HRC application
    d. Installation of HRC applications in the assembly line
    e. Economic feasibility of HRC applications / Human-Robot Interaction
    f. Ergonomic aspects to be considered
    g. Knowledge in Collaborative Robotics Safety Requirements
    h. Basic knowledge of Cobots (structure, operation, capabilities).
    i. Design of the environment, work process, and workflow
    j. Knowledge in Collaborative Robotics Modular Design and Behavior
23. Do you have any additional training content you would like to add?

Safety Requirements and Standards

24. Have you considered and implemented the following requirements for HRC applications (referring to ISO TS 15066):

	Applies	Does not apply
Boundaries / Collaboration space		
Ergonomic aspects		
Transitions of the operating modes		
Robot related hazards		
Hazards associated with the robot system		
Application-related hazards		
Task-related aspects		
Requirements for hand guiding		

Requirements for safety-rated monitored stop		
Requirements for Speed and separation monitoring		
Requirements for Power and Force limiting		
Measurement of biomechanical limits		

25. What problems / challenges do you see for an HRC application planner when complying with all the requirements of ISO TS 15066?
26. Are there any checklists or guidelines that you use when planning and implementing HRC applications? If yes, which ones?
27. Which main hurdles did you have to overcome during the conception and implementation of HRC applications and how did you manage this?

Socio Demographic Questions

28. In which country do you work?
29. What is your profession?
    a. Entrepreneur
    b. Manufacturer
    c. Consultant
    d. Integrator
    e. Service provider for HRC
30. In which industry sector do you work?
    a. Mechanical Engineering
    b. Automobile industry
    c. Electro industry
    d. Food industry
    e. Furniture industry
    f. Logistics
    g. Other
31. This brings us to the end of our survey. Do you have any comments on the topic of our survey or on the survey itself?

Thank you very much for your participation in the survey and your support of our project!

Visit https://tourings.eu/ for more information.

Appendix 2: Interview Guide

(1) Could you present your company?

a. Could you please give us more information about your company? (Products, size, etc.)

(2) Main question: For which reason have you decided to implement HRC in your company?

a. What kind of HRC have you decided to implement? (Brand, hands of tooling, at which stage of the production process (or assembly line), number robots, etc.) (Reports + VET module D)

b. What is the main advantage of HRC from your point of view? (Reports)

(3) Main question: How did you implement HRC in your company?

a. How did you make your choice about the kind of HRC required?

b. What kind of implementation method did you use? Did you have different phases?

c. How did you install HRC in the assembly line? (Did you change the production process? How did you design modular and behavior of cobots? Did you design interactions between workers and cobots) (VET Module C)?

d. What have been the impacts for workers? (What have been the impacts on the work environment? What have been the benefits for the workers to use HRC? How are safety issues considered?)

e. How do workers interact everyday with HRC? (IO1 and VET module E)

f. What are the main rules/norms to take into account while implementing and maintaining cobots in a production system: at the company level, at the worker level? Was ISO 15066 an obstacle to the HRC implementation in your company? How did they measure the biomechanical limits? (IO1)

g. What are the main impacts of the implementation of HRC in your company about productivity, quality and costs?

(4) Main question: what kind of jobs did you need to install HRC, and more generally, to make HRC work every day?

a. How did you proceed to get the number of workers necessary (Internal workers? New recruitments? Consultants? etc.)

b. Skills required per jobs (knowledge, manual skills, soft skills, cognitive skills, metacognitive skills)

c. Did you face lacks of knowledge in internal workers, recruited workers, consultants? If yes, how did you proceed to train them?

d. Did you put in place your own training system? If yes, what and for what results?

e. What do you think of your national educational system? (Does it make it possible to get the number of workers you need? Are they well skilled? What should be done?)

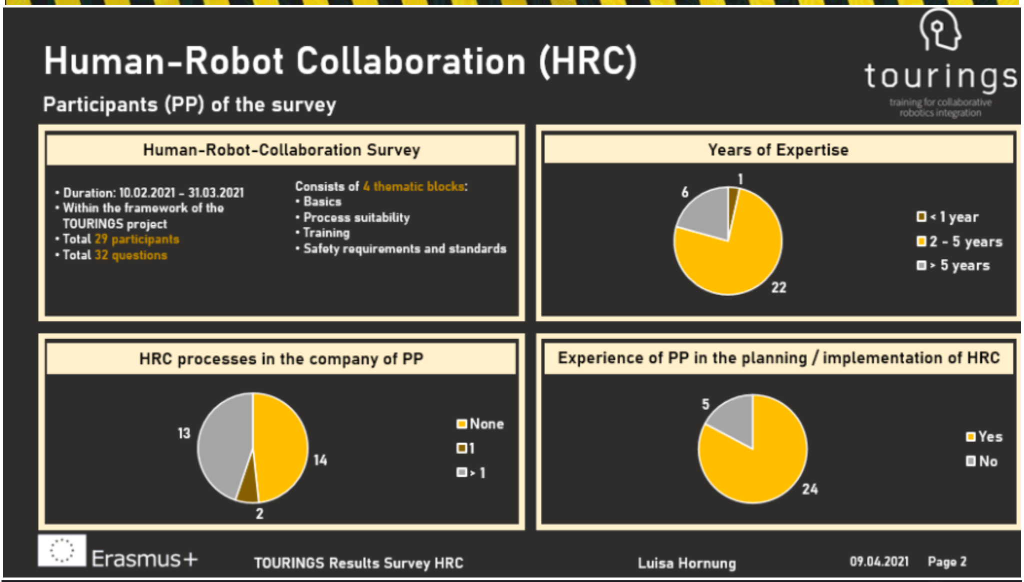
f. We will develop five modules about HRC (1. Basics 2. Modular and behavior design 3. Safety requirements 4. Installation in the assembly line 5. Integration, digital human model digital human simulation and RULA method) According to you, to whom would be this training interesting? Which elements should be taught in those modules?

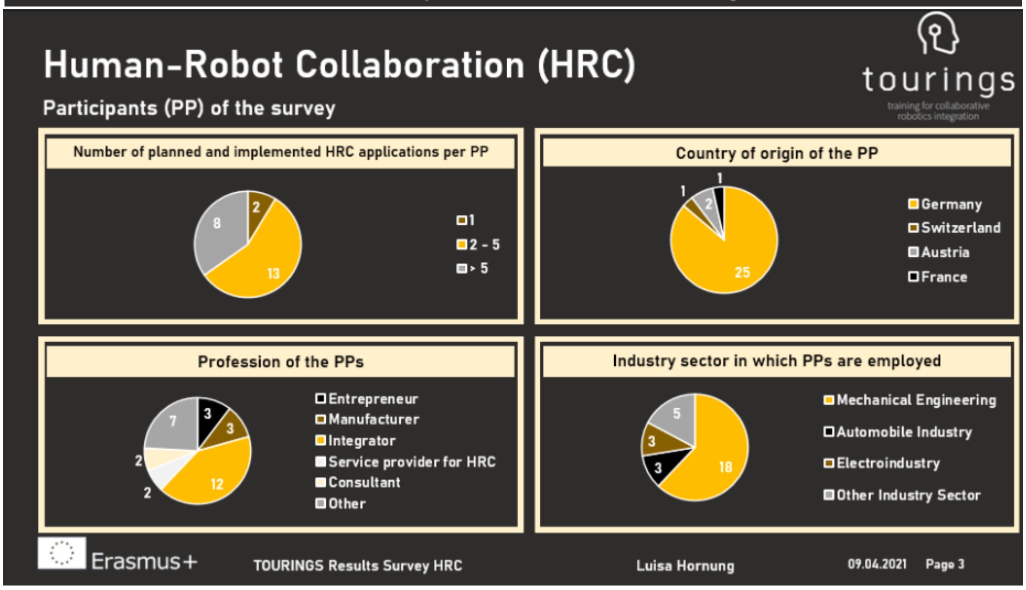
(5) Main question: (Final question and asked at the end, to avoid hurting our contact) Did you face any other challenges we didn't mention so far? What have been the main issues and disadvantages to face by implementing HRC in your company? ("Historical workers" fired? Financial issues? Main disadvantages to implement HRC?

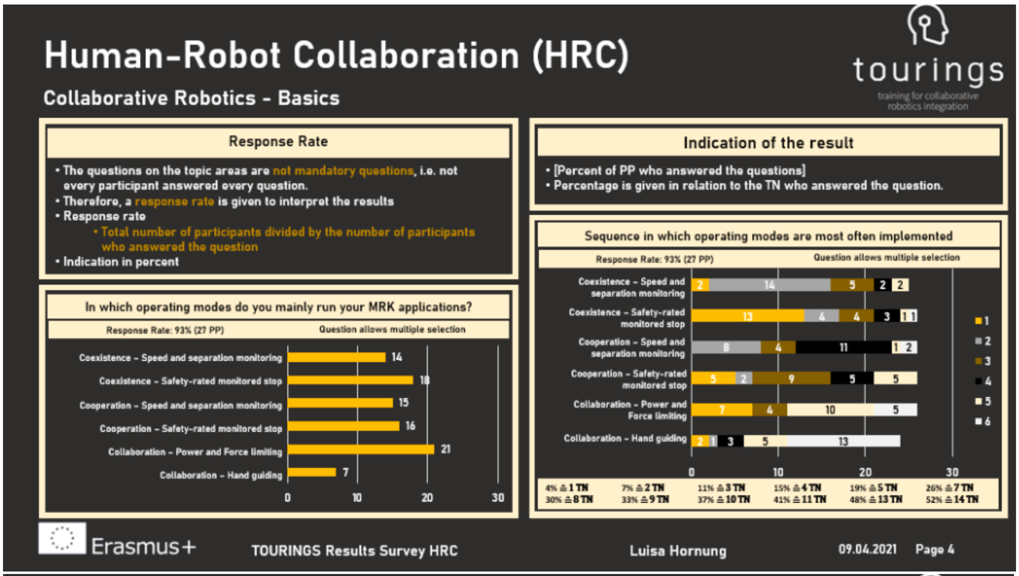
(6) Main question: Are you planning to go further on HRC implementation? If the answer is yes, what are the next steps in HRC implementation in your company?

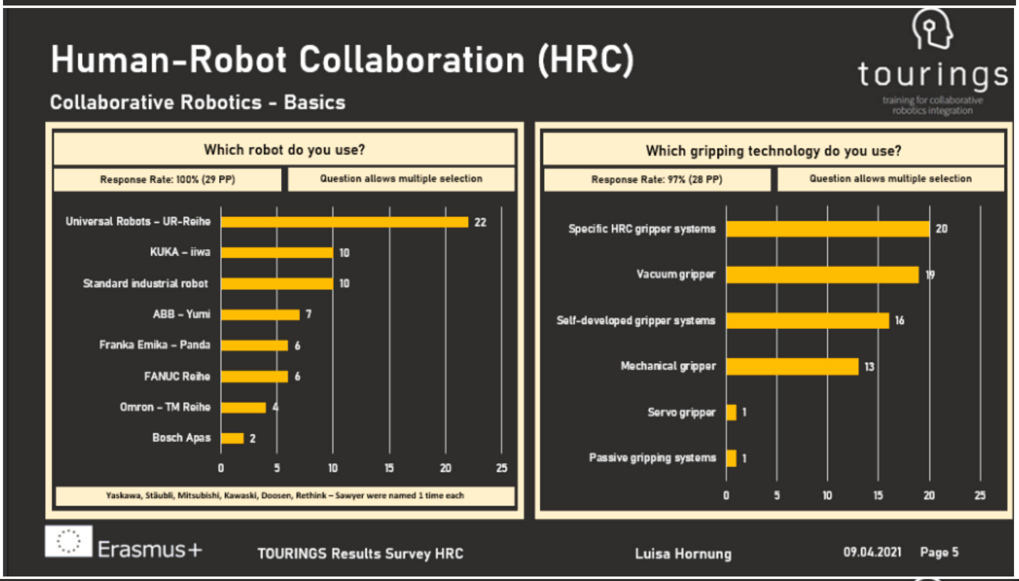
Appendix 3: Results of the TOURINGS' survey


tourings
training for collaborative robotics integration
Innovative Training Solution for the Installation of Collaborative Robotics in Manufacturing Sectors
Results Survey Human-Robot-C
Erasmus+


Human-Robot Collaboration (HRC)
Participants (PP) of the survey
tourings
training for collaborative robotics integration
Human-Robot-Collaboration Survey
• Duration: 10.02.2021 - 31.03.2021
• Within the framework of the TOURINGS project
• Total 29 participants
• Total 32 questions
Consists of 4 thematic blocks:
• Basics
• Process suitability
• Training
• Safety requirements and standards
Years of Expertise
1
6
22
< 1 year
2 - 5 years
> 5 years
HRC processes in the company of PP
13
14
2
None
1
> 1
Experience of PP in the planning / implementation of HRC
5
24
Yes
No
Erasmus+
TOURINGS Results Survey HRC
Luisa Hornung
09.04.2021
Page 2


Human-Robot Collaboration (HRC)
Participants (PP) of the survey
tourings
training for collaborative robotics integration
Number of planned and implemented HRC applications per PP
2
8
13
1
2 - 5
> 5
Country of origin of the PP
1
1
2
25
Germany
Switzerland
Austria
France
Profession of the PPs
7
3
3
2
2
12
Entrepreneur
Manufacturer
Integrator
Service provider for HRC
Consultant
Other
Industry sector in which PPs are employed
5
3
3
18
Mechanical Engineering
Automobile Industry
Electroindustry
Other Industry Sector
Erasmus+
TOURINGS Results Survey HRC
Luisa Hornung
09.04.2021
Page 3


Human-Robot Collaboration (HRC)
Collaborative Robotics - Basics
tourings
Response Rate
• The questions on the topic areas are not mandatory questions, i.e. not every participant answered every question.
• Therefore, a response rate is given to interpret the results
• Response rate
• Total number of participants divided by the number of participants who answered the question
• Indication in percent
Indication of the result
• [Percent of PP who answered the questions]
• Percentage is given in relation to the TN who answered the question.
In which operating modes do you mainly run your MRK applications?
Response Rate: 93% (27 PP)
Question allows multiple selection
Coexistence - Speed and separation monitoring 14
Coexistence - Safety-rated monitored stop 18
Cooperation - Speed and separation monitoring 15
Cooperation - Safety-rated monitored stop 16
Collaboration - Power and Force limiting 21
Collaboration - Hand guiding 7
Sequence in which operating modes are most often implemented
Response Rate: 93% (27 PP)
Question allows multiple selection
Coexistence - Speed and separation monitoring
Coexistence - Safety-rated monitored stop
Cooperation - Speed and separation monitoring
Cooperation - Safety-rated monitored stop
Collaboration - Power and Force limiting
Collaboration - Hand guiding
Erasmus+
TOURINGS Results Survey HRC
Luisa Hornung
09.04.2021
Page 4


Human-Robot Collaboration (HRC)
Collaborative Robotics - Basics
tourings
Which robot do you use?
Response Rate: 100% (29 PP)
Question allows multiple selection
Universal Robots - UR-Reihe 22
KUKA - iiwa 10
Standard industrial robot 10
ABB - Yumi 7
Franka Emika - Panda 6
FANUC Reihe 6
Omron - TM Reihe 4
Bosch Apas 2
Yaskawa, Stäubli, Mitsubishi, Kawaski, Doosen, Rethink - Sawyer were named 1 time each
Which gripping technology do you use?
Response Rate: 97% (28 PP)
Question allows multiple selection
Specific HRC gripper systems 20
Vacuum gripper 19
Self-developed gripper systems 16
Mechanical gripper 13
Servo gripper 1
Passive gripping systems 1
Erasmus+
TOURINGS Results Survey HRC
Luisa Hornung
09.04.2021
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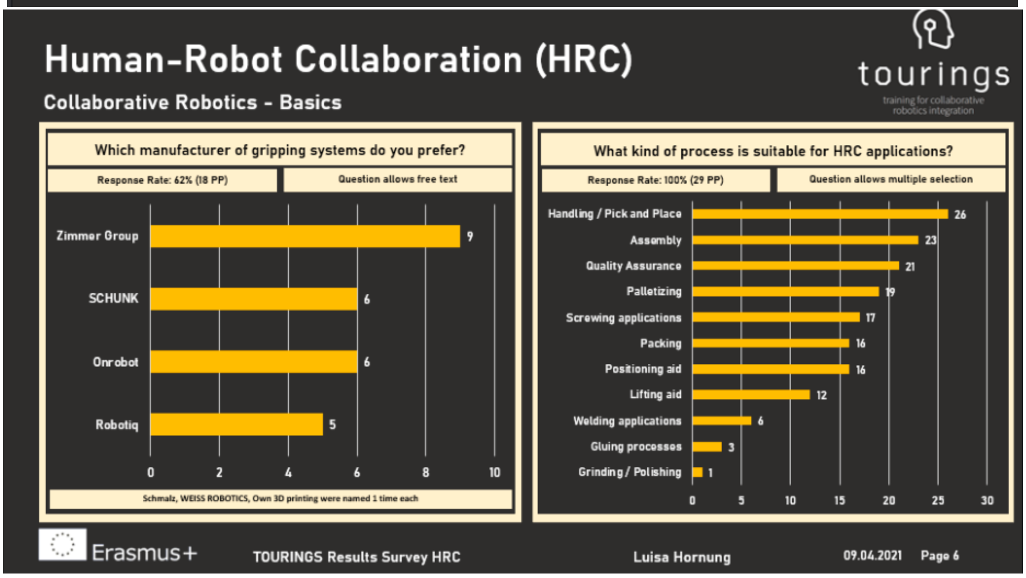
Human-Robot Collaboration (HRC)
Collaborative Robotics - Basics
tourings
Which manufacturer of gripping systems do you prefer?
Response Rate: 62% (18 PP)
Question allows free text
Zimmer Group 9
SCHUNK 6
Onrobot 6
Robotiq 5
Schmalz, WEISS ROBOTICS, Own 3D printing were named 1 time each
What kind of process is suitable for HRC applications?
Response Rate: 100% (29 PP)
Question allows multiple selection
Handling / Pick and Place 26
Assembly 23
Quality Assurance 21
Palletizing 19
Screwing applications 17
Packing 16
Positioning aid 16
Lifting aid 12
Welding applications 6
Gluing processes 3
Grinding / Polishing 1
Erasmus+
TOURINGS Results Survey HRC
Luisa Hornung
09.04.2021
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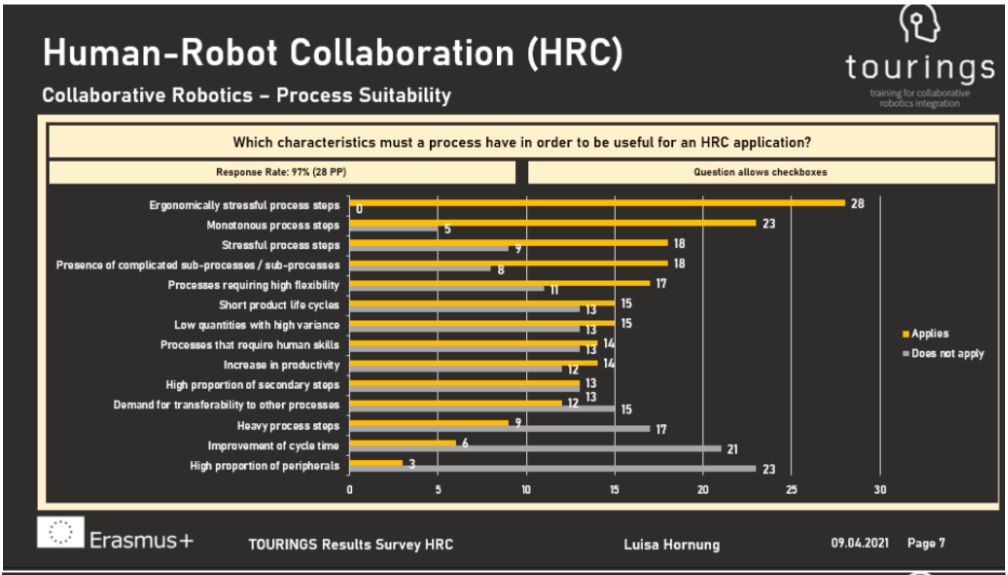
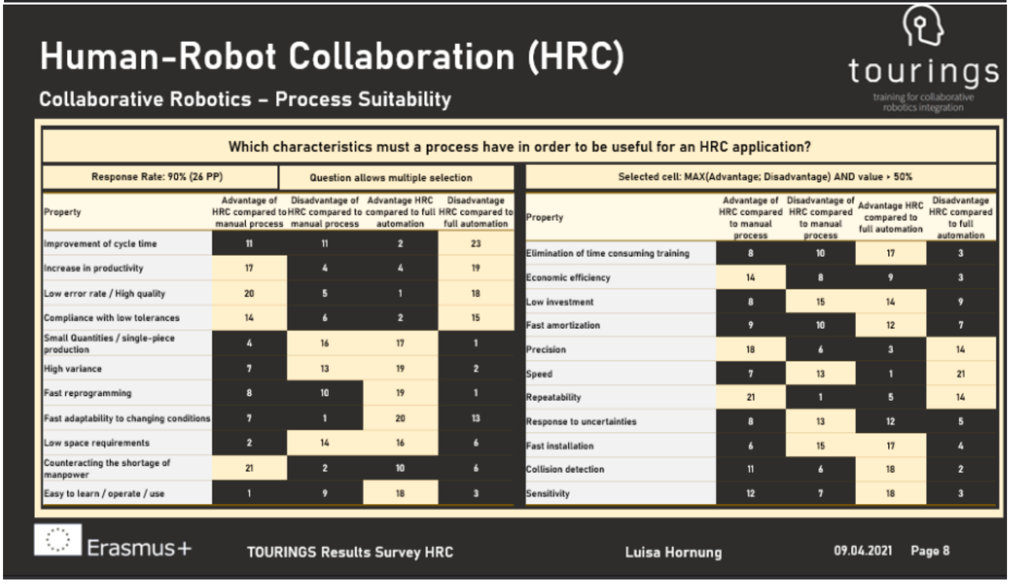


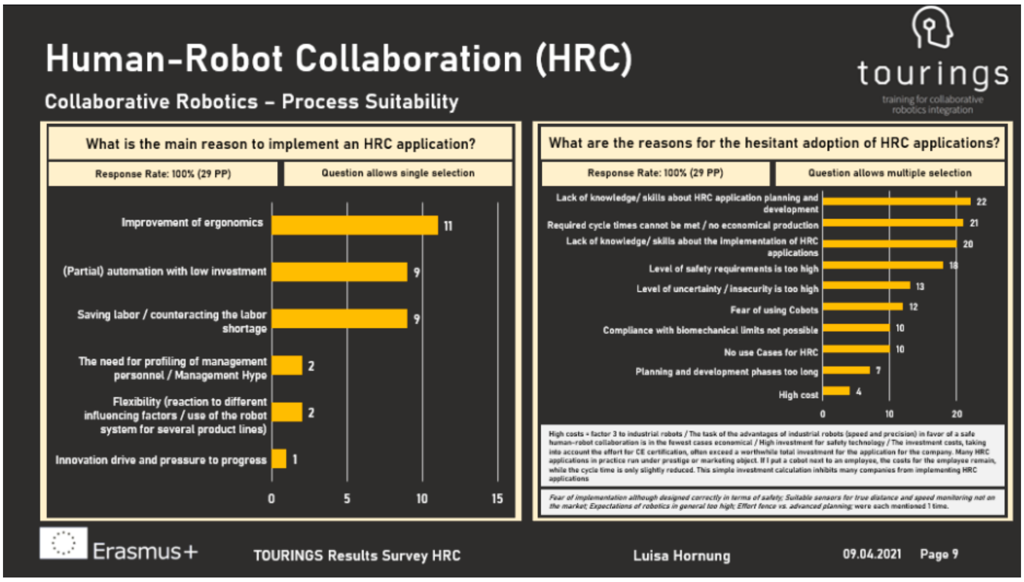


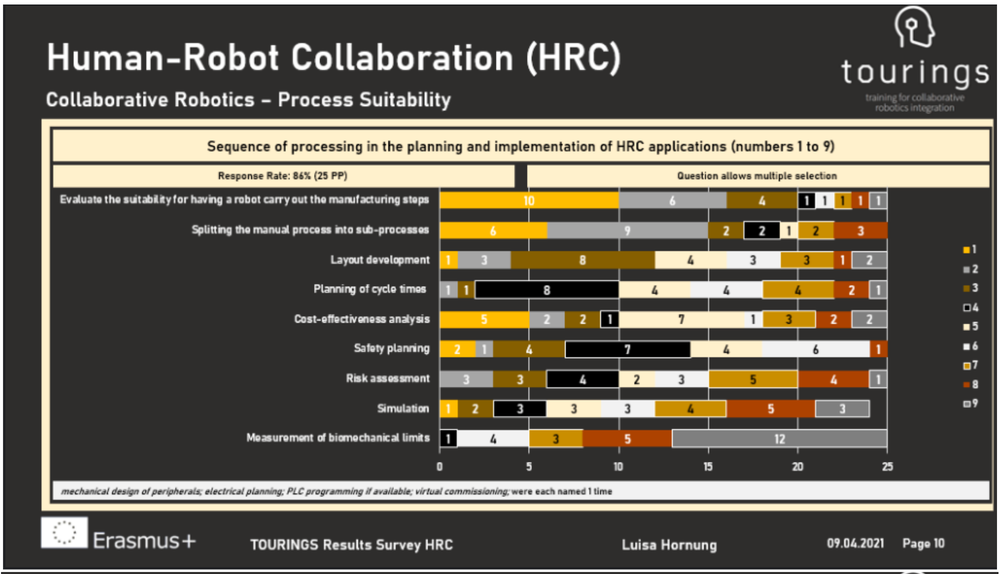
Which characteristics must a process have in order to be useful for an HRC application?

Response Rate: 90% (26 PP) | Question allows multiple selection | Selected cell: MAX(Advantage; Disadvantage) AND value › 50%

Property	Advantage of HRC compared to manual process	Disadvantage of HRC compared to manual process	Advantage HRC compared to full automation	Disadvantage HRC compared to full automation
Improvement of cycle time	11	11	2	23
Increase in productivity	17	4	4	19
Low error rate / High quality	20	5	1	18
Compliance with low tolerances	14	6	2	15
Small Quantities / single-piece production	4	16	17	1
High variance	7	13	19	2
Fast reprogramming	8	10	19	1
Fast adaptability to changing conditions	7	1	20	13
Low space requirements	2	14	16	6
Counteracting the shortage of manpower	21	2	10	6
Easy to learn / operate / use	1	9	18	3

Property	Advantage of HRC compared to manual process	Disadvantage of HRC compared to manual process	Advantage HRC compared to full automation	Disadvantage HRC compared to full automation
Elimination of time consuming training	8	10	17	3
Economic efficiency	14	8	9	3
Low investment	8	15	14	9
Fast amortization	9	10	12	7
Precision	18	6	3	14
Speed	7	13	1	21
Repeatability	21	1	5	14
Response to uncertainties	8	13	12	5
Fast installation	6	15	17	4
Collision detection	11	6	18	2
Sensitivity	12	7	18	3




Human-Robot Collaboration (HRC)
Collaborative Robotics – Process Suitability
tourings
training for collaborative robotics integration
Sequence of processing in the planning and implementation of HRC applications (numbers 1 to 9)
Response Rate: 86% (25 PP)
Question allows multiple selection
Evaluate the suitability for having a robot carry out the manufacturing steps
Splitting the manual process into sub-processes
Layout development
Planning of cycle times
Cost-effectiveness analysis
Safety planning
Risk assessment
Simulation
Measurement of biomechanical limits
0
5
10
15
20
25
mechanical design of peripherals; electrical planning; PLC programming if available; virtual commissioning; were each named 1 time
Erasmus+
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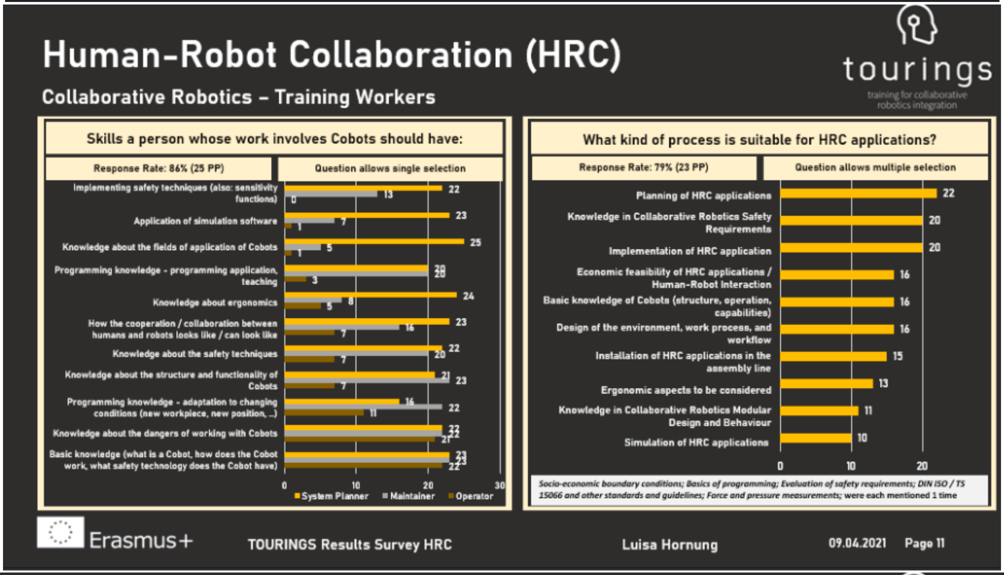
Human-Robot Collaboration (HRC)
Collaborative Robotics – Training Workers
tourings
training for collaborative robotics integration
Skills a person whose work involves Cobots should have:
Response Rate: 86% (25 PP)
Question allows single selection
Implementing safety techniques (also: sensitivity functions)
Application of simulation software
Knowledge about the fields of application of Cobots
Programming knowledge - programming application, teaching
Knowledge about ergonomics
How the cooperation / collaboration between humans and robots looks like / can look like
Knowledge about the safety techniques
Knowledge about the structure and functionality of Cobots
Programming knowledge - adaptation to changing conditions (new workpiece, new position, ...)
Knowledge about the dangers of working with Cobots
Basic knowledge (what is a Cobot, how does the Cobot work, what safety technology does the Cobot have)
System Planner
Maintainer
Operator
What kind of process is suitable for HRC applications?
Response Rate: 79% (23 PP)
Question allows multiple selection
Planning of HRC applications
Knowledge in Collaborative Robotics Safety Requirements
Implementation of HRC application
Economic feasibility of HRC applications / Human-Robot Interaction
Basic knowledge of Cobots (structure, operation, capabilities)
Design of the environment, work process, and workflow
Installation of HRC applications in the assembly line
Ergonomic aspects to be considered
Knowledge in Collaborative Robotics Modular Design and Behaviour
Simulation of HRC applications
Socio-economic boundary conditions; Basics of programming; Evaluation of safety requirements; DIN ISO / TS 15066 and other standards and guidelines; Force and pressure measurements; were each mentioned 1 time
Erasmus+
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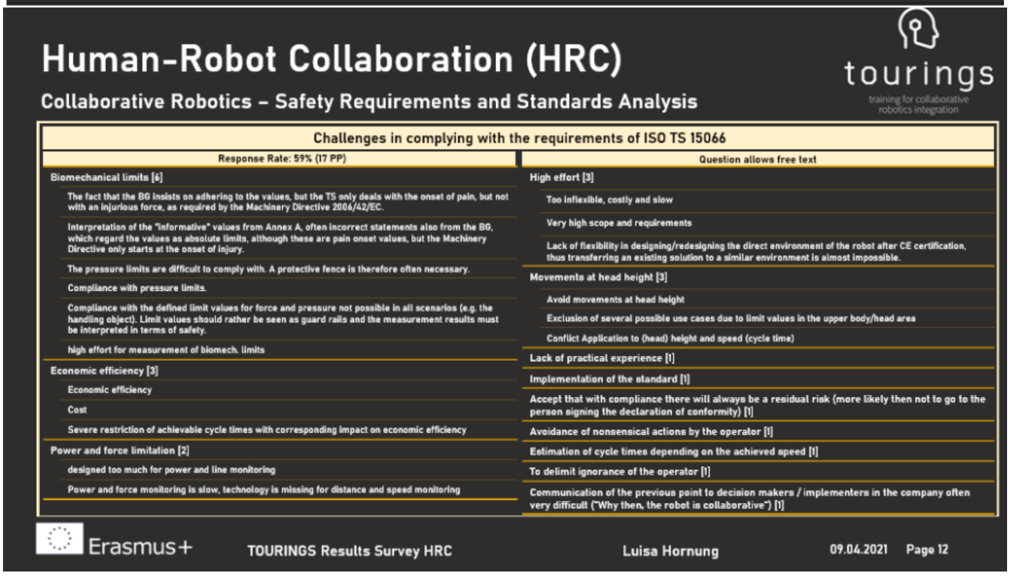
Human-Robot Collaboration (HRC)
Collaborative Robotics – Safety Requirements and Standards Analysis
tourings
training for collaborative robotics integration
Challenges in complying with the requirements of ISO TS 15066
Response Rate: 59% (17 PP)
Question allows free text
Biomechanical limits [6]
The fact that the BG insists on adhering to the values, but the TS only deals with the onset of pain, but not with an injurious force, as required by the Machinery Directive 2006/42/EC.
Interpretation of the "informative" values from Annex A, often incorrect statements also from the BG, which regard the values as absolute limits, although these are pain onset values, but the Machinery Directive only starts at the onset of injury.
The pressure limits are difficult to comply with. A protective fence is therefore often necessary.
Compliance with pressure limits.
Compliance with the defined limit values for force and pressure not possible in all scenarios (e.g. the handling object). Limit values should rather be seen as guard rails and the measurement results must be interpreted in terms of safety.
high effort for measurement of biomech. limits
Economic efficiency [3]
Economic efficiency
Cost
Severe restriction of achievable cycle times with corresponding impact on economic efficiency
Power and force limitation [2]
designed too much for power and line monitoring
Power and force monitoring is slow, technology is missing for distance and speed monitoring
High effort [3]
Too inflexible, costly and slow
Very high scope and requirements
Lack of flexibility in designing/redesigning the direct environment of the robot after CE certification, thus transferring an existing solution to a similar environment is almost impossible.
Movements at head height [3]
Avoid movements at head height
Exclusion of several possible use cases due to limit values in the upper body/head area
Conflict Application to (head) height and speed (cycle time)
Lack of practical experience [1]
Implementation of the standard [1]
Accept that with compliance there will always be a residual risk (more likely then not to go to the person signing the declaration of conformity) [1]
Avoidance of nonsensical actions by the operator [1]
Estimation of cycle times depending on the achieved speed [1]
To delimit ignorance of the operator [1]
Communication of the previous point to decision makers / implementers in the company often very difficult ("Why then, the robot is collaborative") [1]
Erasmus+
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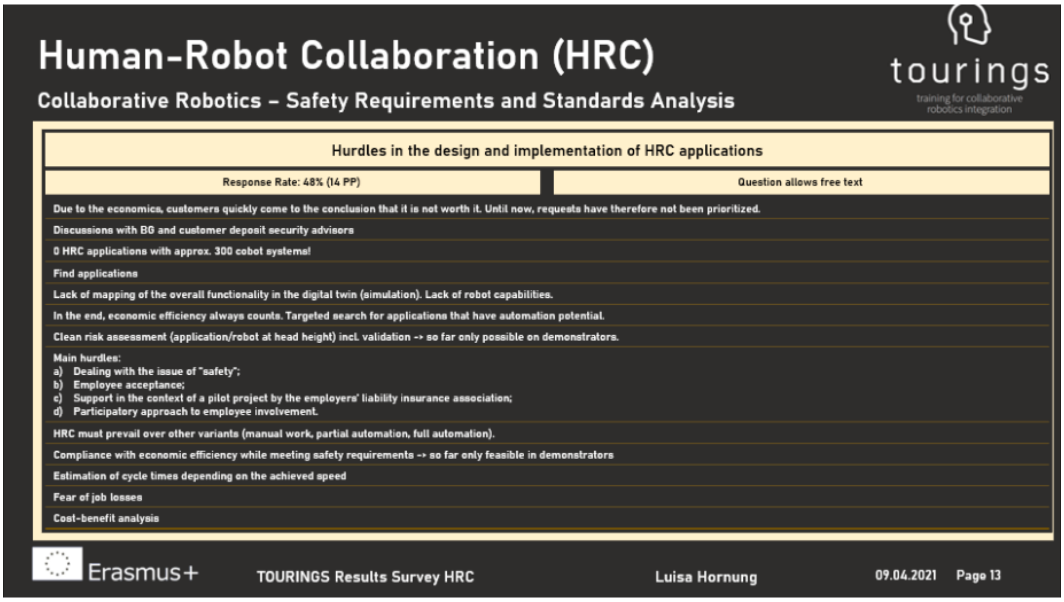
Human-Robot Collaboration (HRC)
Collaborative Robotics – Safety Requirements and Standards Analysis
tourings
training for collaborative robotics integration
Hurdles in the design and implementation of HRC applications
Response Rate: 48% (14 PP)
Question allows free text
Due to the economics, customers quickly come to the conclusion that it is not worth it. Until now, requests have therefore not been prioritized.
Discussions with BG and customer deposit security advisors
0 HRC applications with approx. 300 cobot systems!
Find applications
Lack of mapping of the overall functionality in the digital twin (simulation). Lack of robot capabilities.
In the end, economic efficiency always counts. Targeted search for applications that have automation potential.
Clean risk assessment (application/robot at head height) incl. validation -> so far only possible on demonstrators.
Main hurdles:
a) Dealing with the issue of "safety";
b) Employee acceptance;
c) Support in the context of a pilot project by the employers' liability insurance association;
d) Participatory approach to employee involvement.
HRC must prevail over other variants (manual work, partial automation, full automation).
Compliance with economic efficiency while meeting safety requirements -> so far only feasible in demonstrators
Estimation of cycle times depending on the achieved speed
Fear of job losses
Cost-benefit analysis
Erasmus+
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Appendix 4: List of case studies identified and analysed through the TOURINGS' Project (available in Open source)

TOURINGS' partner	Country	Case study identified
IMT-BS	France	L'Oréal[145]
		PSA[146]
		Mademoiselle Desserts (ETI)[147]
		Dassault Aviation[148]
		Sanofi[149]
		Tyssenkrupp presta France[150]
		SNCF[151]
		Normaero[152]
		Thalès
		Altran[153]
		Airbus space
		LVMH
		Jacquemet[154]
		Flex
IMECC	Estonia	Ensto Ensek
		Lasertool
CETEM	Spain	COVAP Ibéricos
		NUTAI
		M&C Aplicaciones
		FANUC
HKA and KIT	Germany	Albrecht Jung GmbH & Co. KG[155]
		Sennheiser GmbH & Co. KG[156]
		Miele & Cie. KG

145 https://www.bfmtv.com/economie/comment-l-oreal-fait-appel-aux-robots-pour-sa-r-d-capillaire_AN-202011190108.html
146 https://www.universal-robots.com/fr/%C3%A0-propos-duniversal-robots/actualit%C3%A9s-universal-robots/universal-robots-implante-des-cobots-%C3%A0-l-usine-de-sochaux-du-groupe-psa/
147 https://www.usinenouvelle.com/article/prix-marque-employeur-responsabilite-sociale-2020-mademoiselle-desserts-des-cobots-aux-fourneaux.N1004134
148 https://www.infoprotection.fr/des-cobots-pour-limiter-la-penibilite-dans-les-ateliers/
149 https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/sanofi/
150 https://www.youtube.com/watch?v=JUMpaIxSLRM
151 https://www.digital.sncf.com/actualites/fiche-tendance-cobot
152 https://www.universal-robots.com/fr/%C3%A9tudes-de-cas/normaero/
153 https://ignition.altran.com/fr/article/quoi-ressemble-lindustrie-du-futur/
154 https://www.youtube.com/watch?v=Ek5ZvnhGDgU
155 https://mrk-blog.de/echte-mensch-roboter-kollaboration/
156 https://www.mrk-montage.de/anwendungsf%C3%A4lle/

		[157]
		LSG Sky Chefs Frankfurt ZD GmbH[158]
		BMW[159]
		Ford[160]
		Schnorr GmbH (ProBot)
		Volkswagen AG[161]
		Maus GmbH (ProBot)
		Adam Opel AG[162]
		Yanfeng Automotive[163]
		Elektro-Praga[164]
		H. P. Kaysser[165]
		ICM e.V.[166]
		SITEC Industrietechnologie GmbH
		WätaS Wäremtauscher Sachsen
		Thyssenkrupp System Engineering[167]
		lenze operations gmbh
		Lorch Schweißtechnik
		Pongratz
		Schulz systemtechnik Integrator
		Cloos Cobot welding System
		Rauch (ProBot)
		Metabowerke GmbH
		ZF Friedrichshafen AG
		SOMA

[157] https://www.mrk-montage.de/anwendungsf%C3%A4lle/
[158] https://www.mrk-montage.de/anwendungsf%C3%A4lle/
[159] https://www.kuka.com/de-de/future-production/mensch-roboter-kollaboration
[160] https://www.kuka.com/de-de/future-production/mensch-roboter-kollaboration
[161] https://www.fraunhofer.de/de/presse/presseinformationen/2020/april/hhi-fraunhofer-ermglicht-reibungslose-kooperation-zwischen-mensch-und-roboter.html
[162] https://www.industrial-production.de/mrk---cobots/assistenzroboter-in-der-produktion-fachkonferenz-fokussiert-mrk.htm
[163] https://www.ke-next.de/robotik/so-greifen-cobots-in-ihre-produktion-ein-ein-fallbeispiel-267.html
[164] https://www.it-production.com/automation-und-robotik/yumi-applikation-bei-abb-elektro-praga/
[165] https://www.kollegeroboter.de/industrie/schweiss-cobot-beim-blechverarbeiter-so-lief-der-einstieg-122.html?emi=sAczixKfuS&utm_campaign=20210126_NL_KRO-NL_KRO&utm_source=kollegeroboter_newsletter&utm_medium=email
[166] https://icm-chemnitz.de/schaz/fe-schwerpunkte/mensch-roboter-kollaboration
[167] https://www.youtube.com/watch?v=hTM282ggGh8

Appendix 5: List of experts having reviewed the present report and who have accepted to be quoted, per country

TOURINGS' partner	Country	Experts' name having reviewed the present report	Company or entity of the expert
IMT-BS	France	Richard BEAREE	Arts et Métiers Institute of technology
		Vincent ROUET	Valeurs et ressources
		Julien PLAULT	HMI-MBS
		Jeremy CROCQUEFER	Niryo
		Christophe SABOURIN	Université Paris Est Créteil
		Sacha STOJANOVIC	Meanwhile Robot Mobile Autonome
		Christopher SCHNEIDER	YASKAWA Europe
		Aurélien FIEUX	Saint-Gobin Weber
		Frédéric ROSELLO	IDEATECH
		Emmanuel BAUDOIN	IMT-BS
		Mathilde CAVALIE	IMT-BS
CETEM	Spain	Carlos González	CETEM
		Antonio García	CETEM
		Vicente Román	CETEM
		Sergio García	CETEM
HKA	Germany	Luisa HORNUNG	HKA
UNINFO	Italy	Helen CARNAVALE	UNINFO

Glossary

- **CAD models:** *"Computer-aided design (CAD) is the use of computers (or workstations) to aid in the creation, modification, analysis or optimisation of a design."*[168]

- **CMMS:** « *A computerised maintenance management system or CMMS is software that centralises maintenance information and facilitates the processes of maintenance operations. It helps optimise the utilisation and availability of physical equipment like vehicles, machinery, communications, plant infrastructures and other assets. Also referred to as CMMIS or computerised maintenance management information system, CMMS systems are found in manufacturing, oil and gas production, power generation, construction, transportation and other industries where physical infrastructure is critical. The core of a CMMS is its database. It has a data model that organises information about the assets a maintenance organisation is charged with maintaining, as well as the equipment, materials and other resources to do so."*[169]

- **COBOTS:** *"Cobotics is the field of human-robot collaboration, that is to say the interaction, direct or teleoperated, between man and robot to achieve a common goal."*[170]

- **COLLABORATIVE ROBOTICS:** Synonymous of *"cobots"*.

- **ESD:** *"Electrostatic discharge (ESD) is the passage of electric current between two objects with different electric potentials in an extremely short time. The term is often used in electronics and industry to describe unwanted fleeting currents that*

[168] Narayan, K. Lalit (2008). *Computer Aided Design and Manufacturing*. New Delhi: Prentice Hall of India. p. 3.
[169] https://www.ibm.com/topics/what-is-a-cmms
[170] Bernard Claverie, Benoit Le Blanc et Pascal Fouillat, «La Cobotique », *Presses univ. de Bordeaux "Communication & Organisation"*, 2013, p. 203-214.

can damage electronic equipment. Electrostatic discharge is a serious problem in solid-state electronics, such as integrated circuits."[171]

- **GDP:** "*Gross Domestic Product (GDP) is the standard measure of the value added created through the production of goods and services in a country during a certain period. As such, it also measures the income earned from that production, or the total amount spent on final goods and services (less imports). While GDP is the single most important indicator to capture economic activity, it falls short of providing a suitable measure of people's material well-being for which alternative indicators may be more appropriate. This indicator is based on nominal GDP (also called GDP at current prices or GDP in value) and is available in different measures: US dollars and US dollars per capita (current PPPs). All OECD countries compile their data according to the 2008 System of National Accounts (SNA). This indicator is less suited for comparisons over time, as developments are not only caused by real growth, but also by changes in prices and PPPs.*" [172]

- **HRC:** "*Human Robot Collaboration is the study of collaborative processes in human and robot agents work together to achieve shared goals. Many new applications for robots require them to work alongside people as capable members of human-robot teams. These include robots for homes, hospitals and offices, space exploration and manufacturing. Human-Robot Collaboration (HRC) is an interdisciplinary research area comprising classical robotics, human-computer interaction, artificial intelligence, design, cognitive sciences and psychology*."[173]

- **ICT:** "*Abbreviation for information and communication technology: the use of computers and other electronic equipment and systems to collect, store, use and send data electronically: ICT can improve transparency and accountability in government and private sector operations.*" [174]

- **MES:** "*In technical terms, a manufacturing execution system is a system that connects and monitors machines and work centers on the factory floor. The main goal of an MES is to ensure successful implementation of manufacturing operations and improve production efficiency.*"[175]

[171] https://fr.wikipedia.org/wiki/D%C3%A9charge_%C3%A9lectrostatique
[172] https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
[173] Bauer, Andrea; Wollherr, Dirk; Buss, Martin (2008). "Human–Robot Collaboration: A Survey". *International Journal of Humanoid Robotics*. **05**: 47–66.
[174] https://dictionary.cambridge.org/fr/dictionnaire/anglais/ict
[175] https://www.epicor.com/en-us/resource-center/articles/what-is-a-manufacturing-execution-system/#:~:text=In%20technical%20terms%2C%20a%20manufacturing,operations%20and%20improve%20production%20efficiency.

- **OECD:** «*The Organization for Economic Co-operation and Development (OECD) is an international organisation that works to build better policies for better lives. Our goal is to shape policies that foster prosperity, equality, opportunity and well-being for all.”* [176]

- **ROI** : «*Return on investment (ROI) is a performance measure used to evaluate the efficiency or profitability of an investment or compare the efficiency of a number of different investments. ROI tries to directly measure the amount of return on a particular investment, relative to the investment’s cost. To calculate ROI, the benefit (or return) of an investment is divided by the cost of the investment. The result is expressed as a percentage or a ratio.”*[177]

- **SME:** *“Small and medium-sized enterprises consist of enterprises which employ less than 250 people and either have an annual turnover not exceeding EUR 50 million or a balance sheet total not exceeding EUR 43 million. Micro-enterprises are included in this category. Micro-enterprises which consist of enterprises which employ less than 10 persons and either have an annual turnover or a total balance sheet not exceeding 2 million euros.”*[178]

- **TRS: “***The synthetic rate of return (or TRS) is an indicator intended to track the rate of use of machines. It is defined by the formula: TRS = Actual production / theoretical maximum production”*.[179]

- **VET:** *“Vocational Education and Training (VET) qualifications have been developed with the specific goal of preparing students with skills for work. VET is designed to help people to join or re-join the workforce, move into a new career or gain additional skills in their existing career.”*[180]

- **WMSDs (Work-related Musculoskeletal Disorders):** *“A work related musculoskeletal disorder (WMSD) is an injury or disease that affects the body's structural systems. A WMSD may affect the bones, tissue, nervous or circulatory system. These musculoskeletal disorders are often caused by repetitive strain or trauma to the musculoskeletal system. When this type of harm occurs in the*

[176]https://www.oecd.org/about/#:~:text=The%20Organisation%20for%20Economic%20Co,and%20well%2Dbeing%20for%20all.
[177] https://www.investopedia.com/terms/r/returnoninvestment.asp
[178] This category of enterprise is defined by the Application Decree (n°2008-1354) of Article 51 of the Law on Modernisation of the Economy, relating to the criteria for determining the category of an enterprise for the purposes of statistical and economic analysis.
[179] https://fr.wikipedia.org/wiki/Taux_de_rendement_synth%C3%A9tique
[180] https://www.upskilled.edu.au/faq/qualifications/vocational-education-versus-higher-education

workplace, the disorder is referred to as a work-related musculoskeletal disorder."[181]

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- R. Raamat *(Green Book of Estonian Industry – in Estonian), Estonian Entrepreneurship Growth Strategy 2014-2020,* IKT Valdkonna arenguprogramm, 2017

ISO norms:

[181] https://www.workplacetesting.com/definition/4027/work-related-musculoskeletal-disorder-wmsd

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