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Opportunities and Challenges of Collaborative Robotics in a Human-Centric Automobile Assembly Process

Qualitative analysis

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ABSTRACT:

Mass customization and complex products have challenged the automobile industry in terms of quality, process capability, and efficiency. This evolution has made automotive assembly process a highly complex and human-centric. Compared to other shops in automobile manufacturing, assembly shop requires human skills such as cognitive decision making, dexterity, and adaptability as the product complexity is at its peak in that part of the process.

A Human-Robot Collaborative System (HRCS) provides a framework through which automation can be increased in automobile assembly domain. Simultaneously, productivity and quality performance can be improved with human-robot collaboration. A collaborative robot (commonly referred to as a cobot) is an integral part of the human-robot collaborative system. As a technology, it offers enhanced capabilities in efficiency and quality. It also promotes improved safety and ergonomics through inherent safety features. However, due to its reduced size and limited capabilities, especially in reach and payload, its applicability is not straight forward.

This study examined the opportunities and challenges of cobots in a human-centric automotive assembly line using qualitative methods through a literature review and an empirically study exploiting the Task-Technology-Fit (TTF) approach. The empirical part included a six-step approach to assess cobot capabilities with assembly task characteristics, identifying potential applications. Additionally, the study evaluated the characteristics of cobots and compared them to conventional industrial robots through expert interviews. Finally, the utilization evaluation for cobots were assessed based on the combination of findings in literature review and empirical study. The research was conducted at a Finnish automotive company, focusing on a single product and a low-volume assembly line.

As a result, the biggest opportunities for cobots can be found from operating collaboratively with humans at the same workstation without the need for external safety measures. According to the study, the feasible activities for collaborative robots include fastening operations, quality inspections, and lifting and moving parts. Despite their safety capabilities, convenient exploitation and mobilization, cobots tend to lose their competitive advantage if external safety measures are required, as lightweight industrial robots can perform collaborative processes with external safety measures while offering better payload capacity and more cost-effective system.

KEYWORDS: Collaborative Robot, Human Robot Collaboration, Human Centric Assembly line, Automobile Manufacturing

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TIIVISTELMÄ

Viime vuodet autoteollisuuden kokoonpanotuotannon laaduntuottokykyä kuin prosessien tehokkuutta on haastanut ajan saatossa monimutkaistuneet tuotteet sekä yleistynyt massakustomointi. Tämä on tehnyt auton valmistuksesta hyvin kompleksisen prosessin, jossa ihminen on vielä keskiössä. Verrattuna muihin osastoihin, auton kokoonpanotuotannossa vaaditaan vielä ihmiselle ominaisia taitoja kuten päättelykykyä, sorminäppäryyttä, sekä kykyä joustavuuteen. Ihmiskeskeisessä tuotannossa on tärkeää ottaa huomioon ihmisen tuomat rajoitteet sekä mahdollisuudet.

Ihmisen ja robotin välinen yhteistoiminnallinen järjestelmä (englanniksi HRCS) tarjoaa viitekehyksen, jonka avulla automaatioastetta voidaan kasvattaa kokoonpanotuotannossa. Samaan aikaan yhteistoiminnalla voidaan parantaa tuottavuutta ja laaduntuottokykyä. Yhteistyörobotti (englanniksi collaborative robot) eli cobotti on olennainen osa ihmisen ja robotin välistä yhteistoiminnallista järjestelmää. Teknologiana se kykenee tarjoamaan tehokkaampaa ja laadukkaampaa työskentelyä ja niiden paranneltu turvallisuus mahdollistaa turvallisemman työympäristön sekä parantaa työntekijöiden ergonomiaa. Kuitenkin kokonsa ja rajoitettujen toimintojensa vuoksi cobottia ei pystytä täysin hyödyntämään kaikissa prosesseissa ja työtehtävissä. Erityisesti laitteen kantokyky sekä pienempi koko vaikuttavat cobotin soveltuvuuteen.

Tässä työssä tutkittiin laadullisin menetelmin cobotin mahdollisia hyötyjä ja haittoja ihmiskeskeisessä autoteollisuuden kokoonpanotuotannossa. Tutkimus yhdisti kirjallisuutta sekä empiirisestä tietoa hyödyntämällä Task-Technology-Fit (TTF) menetelmää. Empiirinen osuus perustui kuusiportaiseen lähestymistapaa, jossa cobottien kyvykkyyksiä vertailtiin kokoonpanotuotannon työelementteihin ja niiden perusteella suoritettiin soveltuvuus analyysi. Lisäksi cobottien hyötyjä arvioitiin vertaamalla niitä tavallisiin kevyisiin teollisuusrobotteihin. Lopuksi määriteltiin soveltuvimmat käyttökohteet coboteille kirjallisuuskatsauksen ja empiiristen löydösten perusteella. Tutkimus suoritettiin tapausyrityksessä, joka oli suomalainen autoteollisuuden yritys. Yrityksen sisällä tutkimus rajattiin yhteen tuotantolinjaan, jossa valmistetaan yhtä tuotetta matalalla volyymilla. Muut tuotantolinjat sekä linjat, joissa käsitellään useita tuotteita, rajattiin pois tutkimuksen piiristä.

Cobotit ovat parhaimmillaan silloin kun ne toimivat yhteistoiminnallisesti ihmisen kanssa samalla työpisteellä ilman erillisiä turvalaitteita. Näitä toimia ovat tutkimuksen mukaan erityisesti autoteollisuuden kokoonpanossa tietyt kiristystoimenpiteet laaduntarkastukset sekä tavaroiden paikoitus ja siirtely. Cobotti kuitenkin häviää perinteiselle robotille, jos ylimääräisiä turvatoimia joudutaan asentamaan, sillä kevyet teollisuusrobotit pystyvät toimimaan yhteistoiminnallisessa prosessissa ulkoisten turvallistamistoimien avulla. Samalla robotit omaavat paremmat kyvykkyydet kantokyvyn sekä koon puolesta verrattuna cobotteihin.

AVAINSANAT: Collaborative Robot, Human Robot Collaboration, Human Centric Assembly line, Automobile Manufacturing

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Abbreviations

AGV – Automated Guided Vehicle
HRC – Human Robot Collaboration
HRCS – Human Robot Collaboration System
ISO – International Organization for Standardization
JIT – Just-In-Time
OEM – Original Equipment Manufacturer
OHS – Occupational Health and Safety
TTF – Task Technology Fit
SWOT – Strengths Weaknesses Opportunities and Threats

1 Introduction

1.1 Background

In the early 2010s, the Fourth Industrial Revolution, also known as Industry 4.0, was presented in Europe. The impact of the revolution was considered to be so highly significant, that few governments declared it to be part of their national strategies (Sergi, B.S. 2019, pages 3-7). Industry 4.0 established a framework for intelligent and interactive systems which are built upon seamless communication, data utilization, and human-to-machine interaction (Ustundag, A. 2018, page 5). The main objective of Industry 4.0 was to combine physical and digital world with concepts such as Internet of Things, Big data, Cloud Computing, Artificial Intelligence, and Advanced Robotics. These technologies can be seen as pivotal aspects of today’s manufacturing development (André, J-C. 2019, pages 1-5).

As the 2020s approached, Industry 4.0 technologically oriented approach did not appear inviting due to its limited capability to incorporate the human element. Thus, sustainability and worker well-being have been elevated to top priority in industrial organizations together with technological development. The Human Robot Collaboration (HRC) is seen as a great technological approach to this matter. (Liu, X. et al. 2022) HRC as a term refers to an environment where human and robot share workspace by working together effectively and safely (Bauer, W et. al. 2016).

With the interest towards HRC, collaborative robots, often referred to as cobots, have gained attention in recent years due to their potential impact on the manufacturing and industrial processes. (Keshvarparast, A. et al. 2023) These robots are designed to work alongside humans, enhancing productivity and efficiency while promoting safety in various industries. (Javaid, M. 2022) Cobots also play a crucial role in the digital transformation of industries. (Weiss, A. Wortmeier, A. K. & Kubicek, B. 2021)

Simultaneously, the global market trend has driven automotive manufacturers towards mass customization which creates a need for increased flexibility in manufacturing processes. Generally, roughly two thirds of the automobile manufacturing processes are automated, but the final assembly system has remained human-intensive since most of the product complexity concentrates on that part of the process. In this framework, the implementation of HRC can be seen as an effective approach and an opportunity to increase automation. (Michalos, G. 2010; Liu, X. et al. 2022)

This research is conducted by exploiting a Finnish automobile manufacturer as a research platform for the empirical study. The company faces challenges to increase the automation degree in their assembly process due to limited shop floor capacity and product complexity and within this research framework, they aim to identify possible implementation strategies to deploy cobots to increase flexibility, improve product quality and increase operational efficiency.

1.2 Research gap, questions, and objectives

Human Robot Collaboration (HRC) and Collaborative robots are contemporary, and overall, widely studied topics that have been researched with a wide range of methods. Various industrial disciplines are interested in exploring the capabilities and possibilities of deriving benefits from collaborative technology. The identification of the research gap was to understand the requirements of the case company, understanding the proper limitations of the study, and investigating contemporary source literature, which act a crucial role for setting up the research gap.

The gap analysis was conducted based on the source literature by searching literature with the keywords of this study from different databases. The time spam was limited to the research published after 2020. As a result of the gap analysis, numerous research is conducted around this topic. By examining the premises and end results of different studies and comparing how they align with the objectives of this thesis, more comprehensive outlook was gained.

Table 1 Research Gap analysis

Research area	Existing Studies	Identified Gaps
Automotive Industry	Stecke, K.E. & Mokhtarzadeh, M. (2022)	Limited research on subassembly system, material handling, transportation, or the feeding system.
Safety & Ergonomics in Human Centric Assembly	Chigbu, B & Nekhwevha, F, (2020); Huang, C. et al, (2023)	Limited research on the benefits in safety and ergonomics in Human Robot Collaboration Systems.
Case studies: Applications for specific use cases	Salunkhe, O. et al. (2023); International Federation of Robotics (January 16th, 2024)	Limited to a specific case without pursuing a holistic understanding of an assembly system by providing specific case studies.
General studies of Collaborative robotics or HRC	Huang, C. et al. (2023); Segura, P. et. al. (2021); Chutima, P. (2023)	Researching the topic on a general level and not targeted for any specific industry and therefore do not consider automotive factor.
Holistic review of automobile system	Johnson, P.A. (2023)	Limited research on automotive subassembly systems in a heavy automobile industry.

Based on the gap analysis presented in table 1, it appears that studies with a holistic approach to research possibilities and challenges for an assembly system in automobile industry are rare and most of the studies focus onto research the topic from either a very general or from very specific perspectives. Some studies pursuit to find specific application for specific issues within a distinguished case framework. Also, the benefits were often searched from the safety and ergonomics. If the holistic approach was performed, as Johnson, P. A. (2023) had, the study was not conducted directly in an automobile assembly system, but rather covering only a subassembly process.

This study aims to create a holistic view of the case company's assembly system by mapping the process, analysing the results, and identifying the assembly requirements. Thereafter, the study evaluates the possibilities and challenges of utilizing existing cobot technology available in the market for automobile assembly system purposes. Consequently, the study applies qualitative research methods to achieve its main objectives and answer the research question.

The research question derives from the main objectives and the case company's targets for future manufacturing. The research question is presented as follows:

What are the opportunities and challenges of collaborative robots in a human-centric automobile assembly line?

The main objectives of this study are:

1. To identify contemporary collaborative robot technologies suitable for an automobile assembly line.
2. To identify key factors, criteria and challenges that influence collaborative robot integration to a human-centric assembly.
3. To discover the benefits that collaborative robots can provide for the automobile assembly process.

1.3 Definitions and limitations

Human robot collaboration (HRC) can be defined as collaborative actions between a human and a robot. In HRC environment, a human and a robot work together in the same area, either on a shared or separated workspace by performing tasks sequentially or simultaneously. (Bauer, W et. al. 2016). HRC solutions have gotten attention in organizations where the automation level is low, or the process capabilities require maximized flexibility.

A collaborative robot is an industrial robot that has been designed with inherent safety features to comply with relevant standards and legislation. Therefore, cobots are often reduced in size and speed. Even if the cobots and robots share similar features, ultimately, overall design sets them apart. Collaborative robots are often utilized in a Human Robotic Collaborative environment; however, they can be applied outside that framework too. A collaborative robot is a diverse concept and thus it has its own technological taxonomy based on certain features. This taxonomy is based on the level of autonomy and mobilization, safety features, and interaction capabilities.

A human centric assembly process refers to a principle of working and designing a system which meets basic human requirements including factors like ergonomics and safety (International Organization for Standardization, 2019). With the increased competition on automobile industry through mass customization, manufacturers are phasing difficult dilemma by choosing to invest and increase the automation or sustain the level to minimize the risk. In highly automated process quality is stabilized, cognitive ergonomics of workers are improved, and therefore more revenue can be earned. Although increasing automation can yield favourable outcomes, certain work is not feasible to automate, which then keeps the human in the picture. (International Organization for Standardization, 2019b)

Automobile manufacturing consists of three part-process: welding, painting, and general assembly where the assembly is the last in order. At the fundamental level, all remaining parts are assembled to the car body in sequential order in that part of the process, and thus it is the most human centric and complex process due to the nature of the product. (Han, Y-H. et al. 2003) Nonetheless, the final assembly line system can be divided into three different functions: main assembly, subassemblies, and transportation. The main assembly actions refer to all the tasks performed to the product which increases the value or assists on doing so, such as screwing, inserting, or tightening. Subassemblies prepare the utilized parts in a separate system to be assembled to the product in the main line. Transportation refers to a system that delivers materials within the assembly system with variative methods and technologies. (Omar, M.A. 2011)

The study is focused on the automotive manufacturing framework and the research takes place in an automobile manufacturer in Finland. The case organization's primary focus is exclusively on a low volume assembly line system which is currently capable of producing a single-model product with numerous highly customized variants. Therefore, this study focuses solely on this single line and limits all the other processes in-house or externally out of scope. In terms of the assembly tasks, the study focuses on comparing the technology characteristics to those task characteristics from production system that are not seen feasible for robots according to the classification provided by Scholer, M. Vette, M. & Rainer, M (2015). In addition, the global cobot market is wide with variative options on suppliers and models. The study does not turn to account on all models but focuses on suppliers with technology meeting the automobile manufacturing process requirements and are valid players on the European market.

1.4 Thesis structure

The thesis is structured with five different chapters each supporting the thesis statement and follow the academical standard. The thesis starts with abstracts in Finnish and in English, table of contents and list of figures, tables, and abbreviations. The thesis is then organized as follows: Chapter 1 works as an introduction presenting the background of the study, providing insight of the key objectives and gap analysis, and lastly establishing a good overview on definitions and limitations of the study. The second chapter, the literature review, establish the central foundation of the study by combining the knowledge on collaborative robotics in automobile manufacturing. It defines and explores key terminology and themes within the study's framework up to the point where empirical study is needed. Chapter 3 is dedicated to research methods which all originates to the theory by Goodhue, D. L., & Thompson, R. L. (1995) on task technology fit. Chapter 4 presents the results based on qualitative research methods and displays three differentiating analysis methods for establishing a holistic understanding on collaborative robots and their capabilities. This chapter aims to bring out author’s voice by displaying a brief discussion based on the acquired data and analysed results. Lastly, Chapter 5 concludes the thesis by summarizing the work, concluding the findings, and providing insight of author’s perspective on future research around the topic. Ultimately, all the references and appendix are located at the end of the thesis.

2 Literature review

Automobile industry is one of the most studied fields from the perspective of business, manufacturing, and technological innovations, as the internet, libraries, and archives offer overflowing supply of digital and physically written research in various languages from various countries and sectors. A literature review is a useful tool on exploiting existing knowledge by harnessing it into information for serve the purposes of a particular study. This approach allows the thesis to focus on the areas of empirical study that either have not been adequately addressed by existing literature or by not finding sufficient research. Therefore, it prevents the author from duplicating existing research and rather drive to seek only essential information from literature and put focus on pertinent topics empirical study scope. (Inyang, E, 2017 p. 89)

The literature review in this study takes an outlook on the collaborative robots in human centric automobile assembly system. It also aims to discuss human robot collaboration systems, which is vital for understanding collaborative actions between human and operator. The first subchapter discusses how automobile assembly systems are conventionally constructed and then reviewing the characteristics of a human centric assembly system. The second subchapter explains the basics of human robot collaboration system and describes the taxonomic classification of different settings. The last subchapter discusses of basic characteristics of collaborative robots, what are driving safety requirements, benefits and challenges, and what should be taken into consideration when cobots are integrated to the production setting.

2.1 Characteristics of an automobile assembly in a human-centric domain

Generally, in automobile manufacturing, all brands, especially models and variants under the brand have unique product structures which leads to varying production domains and systems with unanimous assembly settings and configurations. Yet they all have common characteristics as the basic principle is shared of the manufacturing system is shared (Han, Y-H. et. al. 2003; Krzywdzinski, M. 2020; Omar, M. A. 2011). Although the automotive industry has been the forerunner of technological innovation and development, an increased consumer demand on individualized options to choose from has gradually made the product more complex over the time which has driven the production towards more mass customization, sustaining the automobile assembly systems strongly human-intensive to enable flexible manufacturing. Thus, despite the strong motivation to increase automation degree in the assembly system, human centric design approach remains strong in automobile industry. (Krzywdzinski, M. 2020; Leng, J. et al. 2022)

Human centricity is not a newfound concept, but the focus of the key challenges has shifted from the conventional approach more towards search the human potential in manufacturing by establishing a collaborative system with machines. This type of process integration offers flexibility, and robustness enables handling of more complex systems. It also offers an alternative when balancing between safety, ergonomics, feasibility, and production resiliency. (Suomen Robotiikkayhdistys ry, 2023 p. 78-80; Leng, J. et al. 2022) In this subchapter, the fundamentals of automobile assembly systems are explained, and it is explored how the human-centric design can be integrated into the automobile assembly system through exiting literature and secondary data sources.

2.1.1 Fundamentals of an automobile assembly system

The automobile assembly system is an industrial process consisting of three main processes, commonly referred to as shops in a sequential order: body shop, paint shop and general assembly. Each of these shops serve a certain purpose for building and assembling the vehicle in the most efficient and cost-effective way possible. Body shop, first in order within the process, serves the purpose of joining metallic stamped parts together to formalize a body frame of the car. The joining methods vary based on the purpose and criticality of the joining, and the material which is joined. The most common joining methods in automobile building are welding, adhesive cluing, and riveting, but are not limited to these.

Paint shop, the second part of the process, serves the purpose of applying a protective coating to the body frame, thereby extending the product's lifecycle and providing astonishing outlook for the product. The paint shop process treats the body with protection materials such as paint, cavity wax, and sealing material and additionally provides an esthetical appearance for the product based on the customers demand and preferences. (Omar, M. A. 2011) Last in order comes the general assembly, wherein a substantial portion of components is installed to the welded and painted body frame. The process complexity stands out in this phase of the process especially as the product structure, design, and customization options vary between customer preferences. The higher the options for the customer to choose from, the higher the product and the process complexity. Thus, it forces the manufacturers to comply with the complexity by coming up with as flexible assembly domain as possible. (Han, Y-H. et al. 2003)

So generally, in automobile manufacturing, as the product maturity grows, the product complexity increases hand in hand, and thus the need for dexterity multiply. Therefore, the degree of automation increases over the course of the process which leaves the body shop as the most automated process by almost achieving the complete automation degree. The paint shop follows close behind, achieving automation degree of almost two thirds of the whole shop process. Lastly, the general assembly has the lowest automation degree as a significant share of the assembly tasks require dexterity. (Krzywdzinski, M. 2020) Overall, the complete automobile production process is designed upon the Lean principles that originates from the Toyota Production System. The operation model is a pull production which is an integral part of the Just-in-Time (JIT) management system. The main strategy of JIT is to increase efficiency and reduce waste by producing an exact quantity of products with an exact timing based on the direct customer demand. (Monden, Y. & Ohno, T. 2011)

As this thesis concentrates on examining collaborative robots within general assembly processes, a detailed review in this chapter is exclusively conducted within perspective of a general assembly domain which can be organized into several subsets. The core of the general assembly system is the main assembly line where all directly value adding activities take place and all other activities focus to support the function on that line. The sequential main line process is typically separated into three sections based on the product maturity. These three sections are referred to as a trim line, chassis line, and final assembly, each carrying out different types of tasks in the automobile assembly. Trim line activities encompass both interior and exterior installations of such parts as electronic components, wire harness, windshields, insulations, dashboard, and cockpit. The chassis line involves the installation of underfloor components, as well as some interior and exterior installations. This phase includes the most critical part of the assembly process, the chassis assembly, where the engine is attached to the car body, commonly referred to as the marriage point, which derives its name from the merging of two distinct ensembles. The last part of the system is the final assembly process where all the remaining installations will be performed before preparing the product for the final tests. In final assembly, the rest of the interior and exterior parts such as tires, doors, and moldings are assembled. Also, essential fluids (gas, brake fluids, windshield washer) are inserted into the vehicle. As the tires are assembled, which usually takes place in the beginning of the final assembly, the car will be laid down on the ground. Henceforth, the car stands on its own and is ready to be started for the first time after required fluids are inserted into the system. Ultimately, after the final assembly process, the product will be transported into the testing area. (Omar, M. A. 2011)

Besides the main line, a good share of tasks is also executed in subassembly systems. These separate processes are synchronized with the main line to prepare and preprocess subassembly parts for more convenient assembly in the main line. Conventionally, a subassembly is often a larger entity which is, for instance time consuming reasons, more beneficial to preassemble aside from the main process. An engine preassembly is a prominent example of a subassembly process where the complete structure of the engine is built in a separate line before installing it to the body in the main line. Also, parts such as doors, bumpers, and dashboards are preassembled in different subassembly systems for the same reasons. (Omar, M. A. 2011) An example outline for an assembly system with main line, subassemblies and transportations systems are presented in figure 1. It visualizes the outlines of the linear assembly process and the dependencies between the different subsets of the process.

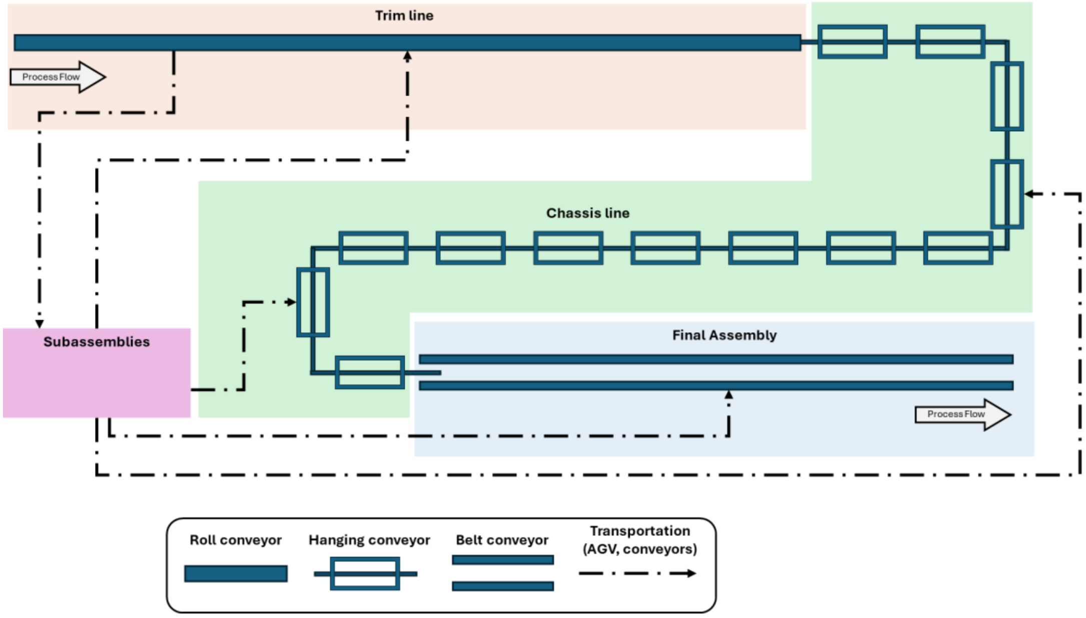


Figure 1 Automobile assembly system outline (Omar, M. A. 2011)

Transportation system is the third and last part of the assembly subset. Its purpose is to efficiently transport various materials between two locations within the assembly setting, employing the most feasible method. It should not be considered as a part of internal logistics as it has no interface with other assembly subsets but rather is an integrated system within the assembly domain. Transportation methods vary between different subsets as they are adjusted for different purposes and needs. Typically, the same pattern is being followed when implementing transportation systems to the assembly system. Overall, a roll conveyor is exploited in the trim line whereas a hanging conveyor is more commonly seen in the chassis line. In the final assembly, the car can stand on its own wheels and, therefore a belt conveyor is commonly utilized. Also, the car can be driven after the first ignition at the end of the final assembly. The materials between the main line and the subassemblies are conventionally transported with different conveyors or automated guided vehicles (AGVs). (Omar, M.A. 2011)

Recently original equipment manufacturers (OEM) have started to challenge the conventional assembly system to operate in a more agile, flexible, and cost-effective way to produce increasingly customized products for customers increasing individualized needs. Emerging trends such as smart manufacturing have been fore runner of this phenomena. Many OEM have their own program to enhance this change. For instance, Volvo Group has established *Factory 4 Tomorrow* program to find solutions to answer the market's demand by providing automation to support manual labor and seeking solutions for advanced assembly technologies (Volvo Group, 2021). German OEM Mercedes Benz has already concretely demonstrated the change by replacing conventional roll conveyors with AGVs to transport the product not only linearly, but also laterally if needed. With this they strive to gain flexibility by getting rid of the limitations of conventional conveyors. (Mercedes Benz AG, 2020)

2.1.2 A human-centric assembly system in automobile industry

The term human-centric is a commonly used word and often mixed with the term human intensive and therefore should be clearly separated by definition from one another. A word intensive "indicate that an industry or activity involves the use of a lot of a particular thing." (Collins Dictionary, n.d.). Therefore, assigning a great number of humans in the assembly system does not establish a human-centric assembly system if the fundamental of the system is not built upon the human-centric features. This means that human-centric assembly systems and domains place a human at the center of the design and planning (Lachvajderova, L et. al. 2023).

Human-centric features conventionally in industrial setting have indicated to a combination of occupational health and safety factors which are regulated and surveilled by national legislation and common interest of the manufacturers. Nonetheless, human -centricity is not limited to previously mentioned factors. A gradually growing complexity in automobile assembly domain shifts the manufacturers to reconsider human potential as a resource, where conventionally it has been seen as an expense. (Lachvajderova, L et. al. 2023) An important part of human-centric design is to recognize the needs of an individual employee and ensure their health and safety. It should also, however, parallel consider the benefits of larger entities such as specific groups (workers, supervisors etc.) and larger pool of different stakeholders or functions (safety staff, management etc). (International Organization for Standardization, 2019) So to practice holistic human-centric design, both individual and common needs should be considered.

To properly understand the origin of human-centric design, it is beneficial to review the factors superficially. Occupational health and safety (OHS) procedures focus on preventing mainly health and safety risks occurring in a working place. (European Agency for Safety and Health at Work, 2020) The Finnish Occupational Safety law provides a foundation for the occupational safety operations in Finland by generally stating that the working conditions should be healthy for all employees regardless of the task or job description. Working conditions risk factors in the manufacturing process encompass elements of noise, air quality, and harsh environmental conditions like high temperature. It is specifically stated in the 29§ of this particular law that industrial machinery and systems need to be designed so that direct safety injury risk towards humans is not only mitigated but prevented. As the Finnish law act as a basis for the OHS practices companies need to obey the rules. Interestingly, companies in Finland do not only settle to the level of legislation but apply different standards and own regulations supplement safety design boundaries.

The law and standards protect workers from physical risks in the workplace, but besides these risks, cognitive ergonomics and mental health are constantly arising threats in the workplace, and correspondingly considered big decreasing factor of health and safety in Europe. (European Agency for Safety and Health at Work, 2020) A complex work environment challenges the cognitive ergonomics of an assembly worker in everyday operations. Work in an automobile assembly line is demanding, repeating, and high paced. These factors have a debilitating effect on cognitive ergonomics of shop floor workers in the automobile industry. Furthermore, workers have stated that poor resource management is considered to add to the negative cognitive load in addition to the other factors. (Wollter Bergman, M et al. 2021)

Ideally a human-centric system design considers both physical and cognitive ergonomic factors. Western OEM have worked towards better physical and cognitive ergonomics for decades, but the issue has still remained. A prominent example for driving ergonomic development was the case from Ford Motor Company when they established two decades ago an ergonomics development process to manage occupational safety related issues. These topics are carried out in joint labor and management teams to solve these topics. (Bradley, J.S. 2003) German OEM BMW has announced beginning the use of exoskeletons and lightweight collaborative robots where work tasks negatively impact the employee's physical health due to a challenging or loading working posture to improve worker ergonomics and productivity (BMW Group, 2017). Mercedes Benz, the domestic competitor for BMW, pursuits to improve cognitive ergonomics by involving factory workers to influence resource management. Mercedes Benz announced that factory workers are part of the decision-making process to influence working shifts to improve work life balance. (Mercedes Benz AG, 2020) All of these previous examples imply that the human-centric design is practiced both in the individual level and common entity level to achieve better working environment in terms of health and safety.

Due to a complex dexterity task, an automobile assembly system remains a human intensive process and therefore a lot of human labour is required in that process. An automobile assembly system requires high flexibility with complex products which provide a need for tolerance capabilities in the assembly that robots cannot achieve unlike humans. Therefore, humans cannot be replaced completely by robots on the assembly line. In contrast to conventional consensus, a human-centric design does not consider human labour only as an expense, but it establishes a framework where the best features from both human and robot capabilities are combined. (Leng, J. et al. 2022) Thus, rather than focusing on fully automating complex processes and separating machines from humans, process planners focus on to identify and separate the tasks which are efficient to execute by robots and which tasks should be allocated to operators. Besides the task allocation, operators should be given more advanced tools to maximize operational efficiency. (Lachvajderova, L et. al. 2023; Scholer, M., Vette, M., & Rainer, M. 2015)

2.2 Human Robot Collaboration system and taxonomy

Humans and robots are conventionally perceived to operate apart from one another due to the problematic dilemma to maintain prescribed level of safety and performance in balance. Until recent years, robots and humans have been kept separated and with minor allowed interaction in carefully monitored process. As technology has been developing, subsequentially the collaboration between humans and robots have gradually increased in the manufacturing domain. (Bauer, W et. al. 2016). This change has established a fruitful baseline for advancing the automation degree in assembly systems where it was not feasible before. The aim of this subchapter is to explain to open up Human Robot Collaboration in general terms and provide insight of the collaboration taxonomy in theoretical level. It also opens the factors behind the system design, which type of engagement within this taxonomy could be feasible through different scenarios.

Collaboration is an operation to work towards a common goal. In the context of this thesis, humans and robots are the ones operating together which indicates more precisely to an operative task performed together or separately by an operator and a robot in a predefined, commonly shared, workspace. (International Organization for Standardization, 2011a; Bauer, W et. al. 2016; International Organization for Standardization, 2021) The Human Robot Collaboration System (HRCS) is built upon the basis of the collaborative operations between the machine and a human. In theory, HRCS is well designed manufacturing domain with human robot engagement where both entities operate safely and efficiently. The in an individual system design, the baselines are the purpose of the system, safety, technological maturity, defined task, and allocated workspace. (Bauer, W et. al. 2016; Segura, P, 2022)

The first and the biggest threshold for defining the HRCS is safety. The basic principle in designing the HRCS is to comprehend the fact that the higher the degree of collaboration within the system, the more rigorous are the inherent safety requirements addressed towards technological characteristics. This implies that if the technology does not comprehend the safety regulations and standards, the human needs to be protected with external manners by for instance isolating the two entities from one another to prevent unintentional interaction. On the contrary, the highest forms of interactions require technological features which will not therefore expose humans to any safety risks. Current standardization underlines (International Organization for Standardization, 2011a; International Organization for Standardization, 2016) the features which are then recognized to be safe or unsafe, but practical implementation responsibility remains with the system designers. ISO standardization (2011a) provides four prerequisites for designers, which at least one needs to be integrated if the system and the device can have the permission for collaborative activities. These four prerequisites are safety rated monitoring stop, hand guiding, speed and separation monitoring, and force and torque limitation. (Bauer, W et. al. 2016; International Organization for Standardization, 2011a)

As people collaborate with each other in several different ways, also machines can collaborate with humans in various ways and domains. As described earlier, the type of collaboration between a robot and an operator can be defined as an operative activity in a workstation during a task or a process towards a common goal. The collaboration can be either direct or indirect, but the goal needs to be shared. Moreover, the executed tasks should occur in close proximity within a predetermined space and not well apart, for instance in a separate workstation. Mainly collaborative tasks can be performed independently, parallel, sequentially, or simultaneously. A robot and an operator work independently when they execute completely different tasks separated from one and other yet in the same workstation. Sequential work is when an operator and a robot execute task to a same object after one and other. Parallel activity is where both perform different tasks for different objects at the same time in close proximity. And lastly, the simultaneous activity is when both perform tasks at the same time to the same object. (Bauer, W et. al. 2016; Segura, P, 2022)

As some of the previously reviewed characteristics might overlap with one another, the predefined workspace watershed to establish HRCS taxonomy. In automobile manufacturing, a workstation is a core piece and important component of the complete process where the assembly operative tasks are performed. However, these workstations are often divided into more detailed individual workspaces where all different resources operate. (Omar, M.A. 2011) To evaluate collaboration in the workspace, different dynamic elements should be considered. Firstly, a workspace can be either independent or shared between the two entities, human and robot. After, the evaluation focus shifts assess whether the space is completely shared or just partly. (Bauer, W et. al. 2016; Segura, P, 2022) This means that the operator and robot can either share a workspace within a workstation or they have separate workspaces, but which collide.

In assessing the proper level of collaboration, the three previously mentioned characteristics create a framework for collaborative taxonomy. The taxonomy is visualized in figure 2. The first class in the figure is cell production and it has the lowest rate of engagement and requires heavy safety measures. Therefore, it is not necessary to be considered as part of HRCS. Gradually, while the rate of collaboration increases, more activities will be performed in shared workspace. It then consists of four taxonomical categories of engagement: co-existence, synchronized, co-operation, and collaboration (Bauer, W et. al. 2016)

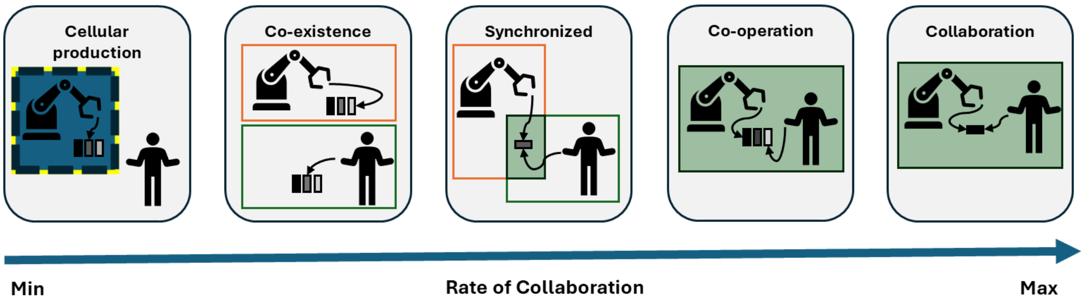


Figure 2 Human Robot Collaboration taxonomy (Bauer, W et. al. 2016)

In a co-existence engagement, the interaction level between an operator and a robot is very limited. They both operate completely independently in their own workspaces within the same workstation without crossing paths. The main difference between the co-existence engagement and cell production is that there are no heavy safety measures. The system is made safe with other manners. So, either the technology should include certain safety features necessary to ensure safety in the robot workspace or the system is externally made safe. In a synchronized engagement, both a robot and an operator have independent workspaces partly collide in certain point of the production cycle. Thus, the two operate sequentially by taking turns to execute tasks in that area. This system similar has safety measures similar to co-existence engagement, but the main difference is that the common goal is found from the product itself. (Bauer, W et. al. 2016; Segura, P. 2022; Suomen Robotiikkayhdistys ry, 2023 p. 75)

The third and fourth taxonomical categories differs from the previous two by having a completely unified workspace between human and robot. In the co-operative engagement, both a robot and an operator share workspace, as said, completely. In this space they both perform parallel tasks in shared space to different items. This type of engagement requires already inherent safety features from the robot due to the shared space. The collaborative engagement can be considered highest rate of engagement. In a system that obtains collaborative engagement, a robot and an operator execute tasks simultaneously to the same item in a completely mutually shared space. (Bauer, W et. al. 2016; Segura, P. 2022) In such system the robot ideally should adapt to the moves of the human by redirecting its path while executing the task. (Suomen Robotiikkayhdistys ry, 2023 p. 75). Therefore, the robot should be always a collaborative robot in this type of system. It is noteworthy that current technological maturity in an industrial setting cannot reach full collaborative engagement as adaptivity is not available in the market. However, with careful system design, collaborative engagement can be reached. Nonetheless, with improving collaborative robot technology the engagement will increase in industry overtime. (Industrial Federation of Robotics, 2020)

Finding the most suitable type for collaborative engagement can pose significant difficulties. Tasks in the workstations are typically designed to serve a very detailed purpose, and multiple tasks are performed within a single production cycle. Also, several resources perform multiple tasks simultaneously in the same workspace or station. This setting establishes an extremely difficult framework for an engagement assessment with holistic perspective. Defining the level of engagement for each task is a doable assignment but is not, however, considered feasible when discussing complete assembly process from holistic perspective. Nonetheless, assessing the engagement on workstation level can be a more feasible option and perceived achievable. In this type of evaluation, the sum of individual tasks and resources establish the engagement framework which can be reviewed at a system level. Only then it is possible to define the systems engagement based on the taxonomy. (Müller, R. Vette, M & Scholer, M. 2016; Salunkhe, O. et al. 2023).

2.3 An overview of cobots in automobile assembly processes

Currently known mass and lean production cannot be achieved without automation systems which robots are fundamental part of by enhancing efficiency and quality, while reducing operating costs (Singh, B. 2012). Most robots in factories are industrial robots which are defined according to the ISO 10218-1 (2011a) standard an “automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications”. A collaborative robot is classified as an industrial robot due to the matching structure to the ISO 10218-1 definition which is supplemented later in the same standard with a distinct definition by referring it as a “robot designed for direct interaction with a human within a defined collaborative workspace”.

According to the International Federation of Robotics (2020), collaborative robots can be divided into two categories: the ones that comprehend with the inherent safety measures outlined in ISO 10218-1 standard, and the second ones which do not comprehend with the standard, but follow the guidelines and regulations determined by the company owning the operating process. Interestingly, not all robots which comply with the safety regulations of ISO 10218-1 are accountable as collaborative robots. A prominent example of this misconception is to categorize AGV as a collaborative robot. AGVs are service robots, which fail to meet the defining criteria of an industrial robot due to lacking robotic features outlined in the standard such as the requirement for axes. (International Federation of Robotics, 2020)

Typically, cobots are designed into an anthropomorphic model, but different options are available at market for variative purposes. As both cobots and robots share a similar characteristic, there can be found fundamental differences between both of them. The substantial difference between the two are the inherent safety features, which robots does not possess. (International Organization for Standardization, 2011a). Unlike robots, cobots can be easily exploited in human-centric assembly domains as their purpose is necessarily not to replace humans, but to assist operators and increase their performance by performing simple and repetitive tasks in a standardized environment. This offers a possibility for human operators to focus on more detail oriented, complex, and cognitively challenging tasks in a variative circumstances. (Scholer, M. Vette, M. & Rainer, M. 2015; Vido, M. et al. 2020)

The literature sources provide numerous cases where cobots can be exploited in automobile industry. Mostly they can be seen in material handling or lightweight tasks within an automobile assembly domain (Stecke, K.E. & Mokhtarzadeh, M. 2022). Depending on the working environment and process requirements line tasks such as assembly, screwing, inserting, positioning, adhesive cluing, fastening, scanning, and serving could be typical for cobots to execute in the automobile assembly. (Taesi, C. Aggogeri, F. & Pellegrini, N. 2023; Omar, M. A. 2011; Matúšová, M. Bučányová, M. & Hrušková, E. 2019)

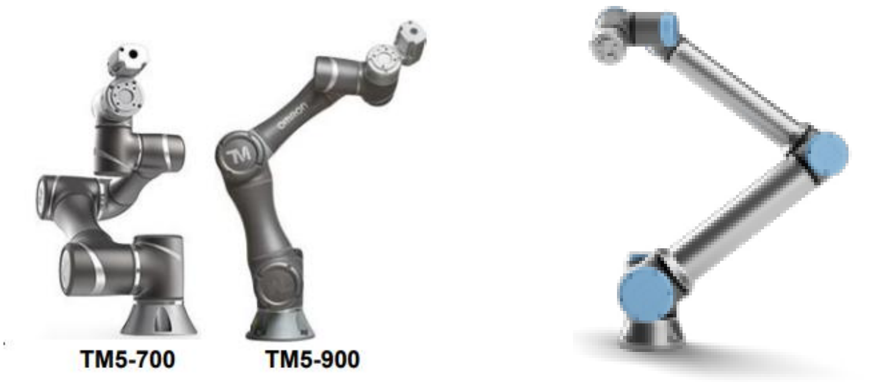


Figure 3 Collaborative robots ([Omron data sheets on TM series], n.d.; Universal robotics, n.d.)

2.3.1 Safety requirements

The fundamental of collaborative robots derives from their perspective to enable the technology to operate near human proximity without additional separation. Thus, it is important to understand what safety is and where does the regulation on safety derives from. Safety as a term is “the state of being safe from harm or danger.” (Collins Dictionary, n.d. b) which refers to a domain where no humans are exposed to harmful or danger situations. What comes to the safety measures or features, the ultimate goal is to decrease the capability to cause harm to surroundings (Collins Dictionary, n.d. b). Gradually, safety can be perceived differently by individuals. This establishes an environment with individual perspectives on safety. Hence, legislation and regulations exist to avoid varying perceptions and ensure a standardized approach. (Hale, A. 2000)

As previously discussed, the Finnish legislation work as a foundation of OHS in Finnish industrial sector. Thus, the machine and robot system safety requirements are under this legislation in terms of system design. The Finnish legislation is derived from the European Union Machinery and Amending Directive (2006/42/EC) which states appliance manufacturers are responsible for the safety assurance of their own devices by conducting a risk assessment and mitigation for all the manufactured devices. The ISO 10218-1 and -2 provide advanced additive regulations and guidelines to the EU directive to ensure system level safety and risk assessments. Besides ISO 10218-1, ISO/TS 15066 specifies the requirements and guidelines for the collaborative systems and devices when operating near human proximity without separation.

The safety requirements for collaborative robots aligns with same prerequisites as HRCS which is derived from ISO/TS 15066 (2016). It presents the four inherent safety requirements for collaborative systems where at least one needs to be complied with before collaborative operations can be conducted in production facilities. The first requirement is a safety rated monitored stop which ensures immediate stop of the machine actions after a human has entered a predefined operation zone. The second is hand guiding which provides human operators with a possibility for safe handling of the robotic device while simultaneously operating with it. The third is speed and separation monitoring method where a safety system is built so that as human approaches robotic devices, the speed reduces gradually and ultimately stops when a human gets immediate proximity. The fourth and last is power and force limiting which limits the force of the device to the degree where it is not possible to get injured from a collision between a human and a machine.

As EU directive (2006/42/EC) and standards declare, both robot systems and individual devices require risk assessment and mitigation. For a single collaborative device, ISO/TS 15066 (2016) specifies the safety requirements and provides comprehensive guidelines on where to limit the force generation capacity in terms of cobots. The guideline distinguishes limits according to the type and the body part affected by the collision. The first form of collision is an open contact between a human and a robot, and the second is a body part compression between the robot and a fixed obstacle. ISO/TS 15066 also categorizes different body parts based on the vulnerability for serious injury. For instance, regions of the upper body, including the head, neck, and back, are considered more vulnerable and thus require less force exposure, whereas lower body regions such as the legs can withstand greater force.

2.3.2 Capabilities, benefits, and challenges of cobots

Since cobots are required to follow the safety standards and regulations discussed in the previous subchapter, capabilities of cobots are remarkably reduced. Different manufacturers value different performance factors based on the purposes the devices are designed for. Generally, cobots are lightweight and designed for handling small and light parts and execute moderately simple tasks. The current development is, however, fast-paced, and heavier machines can be seen in the market in coming years. The weight and size have a huge effect on the device's payload and reach capabilities, which are the most critical factors. The payload of cobots varies between different models in around 5-20 kg and the reach of the arm 500-2000 mm. The maximum tool point velocity can vary between 0.5-6.0 m/s. (Matúšová, M. Bučányová, M. & Hrušková, E. 2019) but in collaborative systems it does not necessarily provide any benefit due to the top speed limit is 0,25 m/s for humans to work near the device. (Taesi, C. Aggogeri, F. & Pellegrini, N. 2023). Interestingly, the accuracy of a cobot is relatively high and can vary between 0,02-0,5mm. An exclusive capability only for cobots is the integrated sensors to detect external forces in the shell of the device (Matúšová, M. Bučányová, M. & Hrušková, E. 2019).

Overall, cobots are safety focused devices with limited speed, force, and reach capabilities when designed to operate in near human proximity. Therefore, the biggest benefit is the have minimal injury risk when operating together with humans. This enables production designers to free their shop floor capacity for different purposes when the cobots can be directly implemented into the production system. (Matúšová, M. Bučányová, M. & Hrušková, E. 2019) In this case, the size of a cobot has a huge impact. Cobots' relatively small size offers more facile and quicker production implementation and integration compared to conventional robots. Because of the light weight, cobots can be also mobilized which enables flexible utilization and provides alternative options for production balancing. (International Federation of Robotics, 2020) When operating effectively alongside humans, collaboration can yield into holistic process improvements in quality capability, process performance efficiency, and ergonomics. The cobotization also increases flexibility capability and decreases need for additional rework. (Scholer, M., Vette, M., & Rainer, M, 2015)

The biggest challenge cobots have is the capability to answer the process requirements. Cobots are not seen to provide improvements in cycle time and combining this together with limited capacity in the payload, reach, and reduced speed prevents cobots from performing various tasks. Therefore, alternative options can show up more favourable. As safety was the driving factor, it can have unfavourable effects on the process requirements. An automobile process is a high paced process with very limited cycle time. A collision between a human and a cobot or unintentional disturbance in the safety area will freeze the cobot from moving which might lead to an unwanted downtime. Collaborative spaces have higher possibility for these types of interruptions, effecting process uptime time which can consume all the benefits. This dilemma can lead to a conclusion where cobots are seen as an unintentional expense compared to human operators instead of beneficial investment to enhance process capabilities. (Matúšová, M. Bučányová, M. & Hrušková, E. 2019; Scholer, M., Vette, M., & Rainer, M. 2015)

2.3.3 Basic principles of workstation cobotization in an automobile assembly

An automobile assembly system is a combination of different tasks performed sequentially in predefined spaces in a predefined order. A workstation is an area where predetermined tasks are executed in a predefined order with an efficient number of resources. (Battini, D. Finco, S. & Sgarbossa, F. 2020) The aim for cobotization is to automate certain manufacturing processes to decrease operative costs, enhance productivity, increase quality, and produce less waste. Together with operating factors, ergonomic conditions for the factory workers can lead also to a decision for automating processes. (Suomen Robotiikkayhdistys ry, 2023 p. 78-80)

Workstation cobotization is a process where certain activities, individual tasks or complete processes are automated with collaborative robots. It is considered a similar process to workstation robotization, but instead of separating the machines from the humans, cobots are mainly integrated within the human operators on the shop floor level. (Bauer, W et. al. 2016) The workstation cobotization project starts with a top-down approach by understanding what is in fact automated (Suomen Robotiikkayhdistys, 2023 p. 78-82). In their study, Salunkhe, O et al. (2023) begins the evaluation process by recognizing the workstation level activities which could be intendent for automation. After the workstation level processes are recognized, these activities, such as wire harness assembly, is split into main tasks such as assembling, connecting, and lifting the wire harness. The main tasks are then divided into smaller subtasks, including detailed step-by-step description of what is then performed in order to achieve the target of the main process. In the wire harness case, this refers to accurately describing where the part is assembled or moved in every step. After recognizing the detailed tasks, cobotization process requires task allocation between a human and a cobot where complex, dexterity tasks which require cognitive decision making or senses, are allocated for human and simple, repetitive tasks should be allocated for cobots. In the wire harness case, the cobot took care of the simple tasks such as carrying the wire harness sockets near the couplings and human operator executed the dexterity intense task by attaching the sockets together. (Scholer, M., Vette, M., & Rainer, M., 2015; Salunkhe, O et al. 2023)

Automobile assembly consists of numerous diverse tasks and processes which vary based on the product, model, and brand. It can be difficult to recognize which tasks are suitable for automation, especially when considering cobots. In theory, all the activities can be automated, but it requires a lot of capital investments and research and development work and collaboration from manufacturing engineering, process engineers and product engineers. The main constraints are product complexity, process capability and tolerance demand which in an automated process can lead to severe quality issues and thus arising costs if poorly designed. (Dong, J. Xia, Z. & Zhao, Q. 2021; Omar, M. A. 2011)

Understanding the technological limits is the first step towards understanding the integration feasibility. If the technology is not proficient enough to execute given tasks or the product or part is not designed for automated activity, the task cannot be executed by collaborative robot. Then if the product is suitable for the action, can the technology answer the process requirements (uptime, cycle time, quality rate). Only after process feasibility calculations, the cost-benefit analysis can be conducted. It gives an overview of the fact if the investment is worth compared to the gained benefit. (Suomen Robotiikkayhdistys ry, 2023 p. 78-82) The benefits can be economical, ergonomic, or safety related, but also promoting green impact.

2.4 Summary of the theoretical framework

The literature review primarily focuses on the integration of collaborative robots in the human-centric automobile assembly systems by explaining the basic principles of automobile assembly system, dynamics between human and cobots within the industrial setting, and exploring the benefits, challenges, and criteria for cobot integration. The literature review established a clear correlation of the consolidating factors between human centricity and safety as they go hand in hand in regards of system and device design. Human presence in industrial domain triggers the safety requirements although the business-related characteristics such as efficiency, quality, and operational uptime remain as valid in daily operations. Still safety remains as the definitive factor on HRCS design and implementation. The literature review highlights the ideology of collaborative robots to support safety besides enabling operation in near human proximity. Thus, they can be seen as promising and prominent technology for HRCS.

Despite the favourable characteristics for HRCS, integrating collaborative robots for various assembly tasks within automobile assembly domain can be found challenging. Maintaining safety and improving ergonomic conditions, which are the targets for European OEMs, lower threshold for deployment and mobilization and advocated the cobot exploitation in future. However, the findings imply that the reduced payload, reach and size hinders development in the opposite direction. Also, not all the tasks are suitable for automation in automobile assembly domain. Therefore, understanding the constraints and success factors by performing task optimization will be key enabler for successful workstation cobotization.

Collaborative robots are seen having pivotal role in every level of HRCS design and they can be exploited in every level of engagement taxonomy. Cobotization of workstations or assembly processes consist of multivariable analysis from product design to manufacturing engineering solutions. As investigating the feasibility of cobotization, literature did not provide any direct answer on particular feasible assembly tasks. However, protocols and frameworks in which collaborative robots would be feasible in operational and financial terms were provided.

Interestingly, the literature does not provide clear identification of specific types of tasks suitable for collaborative robots within automobile assembly but can only provide certain framework for the task optimization. Also, the feasibility threshold between cobot and conventional robot is still unclear after investigating the literature. To properly understand these criteria and complete study objectives, this threshold in terms of safety, efficiency, and adaptability will be further studied in the empirical part of the study.

As a conclusion, while collaborative robots provide great potential to enhance safety and efficiency in HRCS framework, the integration can be complex due limitations in the technical capability. For a successful implementation, an expertise in process planning and design is essential together with a high knowledge of safety design in industrial domain.

3 Research method

The exploitation of robust methodologies in research is critical as it ensures the reliability and validity of the findings by providing a clear framework within which the study operates, and which can be additionally critically assessed. This thesis is conducted as qualitative research by collecting data from several sources both internally in case company and externally from experts from the field in question to strengthen the narrative and generalization. The empirical part pursuits to supplement the literature review by offering a real life setting to explain the phenomena and strengthen the factors behind the benefits and challenges of the discussed technology. (Inyang, E. 2017 p. 7 & 90)

This study exploits qualitative tools of a descriptive, explanatory, and thematic approach to understanding real-life phenomena and provide an outlook on the subject in hand, by utilizing data collection methods such as interviews and observations which serve as primary means of data collection. Nonetheless, the study exploits numerical data to provide insight into the context of the phenomenon. However, this data is invariably secondary data and therefore it is not used in a quantified manner. (Golafshani, N. 2015) The study adopts a deductive approach by looking for a validation from existing theory. Deductive reasoning starts with a hypothesis testing it against empirical evidence, pursuing to confirm existing theory. (Seale, C. et. al. 2004 p. 91) The main hypothesis of the study states that integrating collaborative robots will derive improvements in productivity and quality together with safety and ergonomics within automobile assembly domain. The empirical implications will be studied through a theoretical framework task technology fit (TTF) which is a sufficient tool to be exploited to explain the phenomena in a real-life setting in an automobile assembly process.

Task technology fit (TTF) is a theoretical framework to fulfil the research objectives and answer the research question. The concept of TTF compares task characteristics with technology characteristics by evaluating performance capabilities for decision-making purposes to determine whether a certain technology is suitable for executing assigned tasks. Task characteristics are the factors and methods needed to turn inputs into outputs and therefore can be seen as process requirements in an automobile assembly domain. The consideration of technology in this context limits to a tool, machine or robot, which enables process to perform more efficiently with task execution. In TTF, these two characteristics are exploited to assess performance impact and utilization. Performance impact indicates which factors, in terms of technology, have the most significant impact on execution of particular tasks. Utilization measures the practical ability of the technology to meet the requirements that the technology can provide but is limited by the task requirements. (Goodhue, D. L., & Thompson, R. L. 1995)

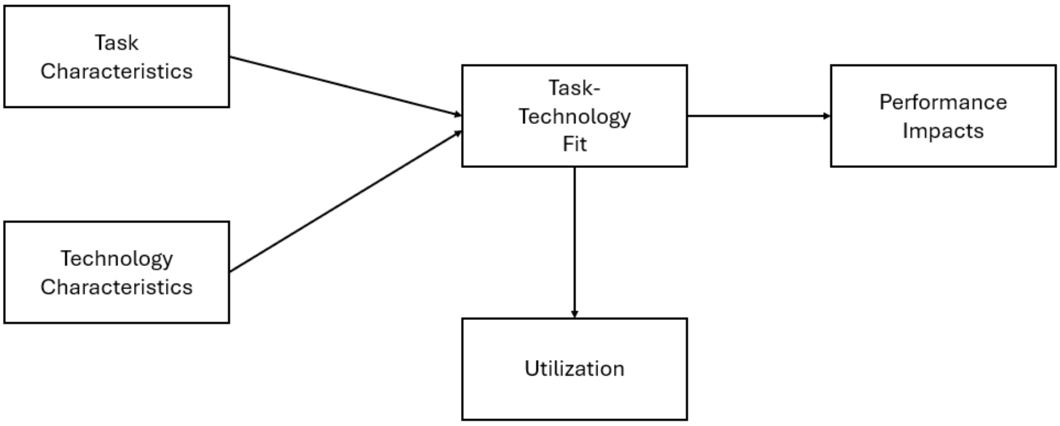


Figure 4 Task Technology Fit (Goodhue, D. L., & Thompson, R. L., 1995)

Hartelt, R. Wohlfeil, F & Terezidis, O (2015) applied TTF in their study by testing it empirically with multi-case study model. They utilized a systematic six-step approach to prove a potential technology to be fit with the use case tasks. This study is conducted with a similar six-step structure visualized in figure 4 and will work as a core of the data collection and analysis. The first two steps identify the technology and task characteristics which contain searching and analysing contemporary collaborative robot technologies and capabilities together with the task and process requirements within the case company. The third step, a selection of evaluation criteria, contains an assessment of selecting only relevant criteria for decision making. In the fourth step, technology assessment, the aim is to evaluate alternative technology for executing the presented tasks. Fifth step, the performance impact, assess which task would have the highest impact in respect to the evaluation criteria. The sixth and the last step, utilization evaluation, analyses the concrete feasibility on which the technology should be integrated into the process based on the information offered by the previous five steps. (Goodhue, D. L., & Thompson, R. L., 1995)

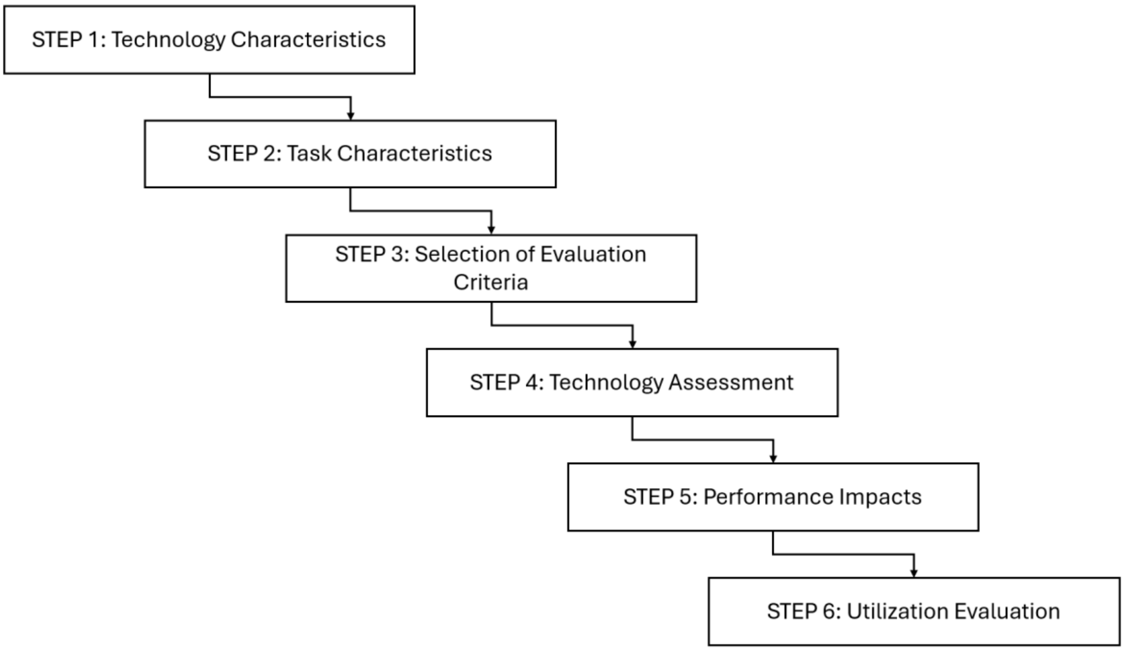


Figure 5 TTF Systematic approach (Hartelt, R. Wohlfeil, F.& Terezidis, O 2015)

3.1 Data collection and analysis

Data collection is a core part of the study and without it, the objectives of the thesis cannot be achieved. To reach these objectives, data collection and analysis are utilized with different methods. (Inyang, E. 2017, p. 16). This study’s main data sources are the case company’s materials, technology manufacturer catalogues, and interviews. The interview data will work as the primary data of the study which refers to a definition of “raw data collected from the field” (Inyang, E. 2017, p. 37). Technology and task characteristics stand as secondary data as they are already pre-existing data created and stored for other purposes than serving the objectives to this study. (Inyang, E. 2017, p. 12)

Typically, data without any analysis is irrelevant. In most cases the dataset alone does not provide any valuable information. To achieve rigorous and reliable results in a qualitative study, proper data analysis is an essential task to extract necessary information from the raw data and present it in an understandable format. Thematic analysis is an effective and flexible tool for exploring patterns and confirming theories in an industrial domain. It enables a systematic approach by categorizing explanatory results from the qualitative data. (Seale, C. et. al. 2004 p. 57-61) In addition to the thematic analysis, this study applies both descriptive, explanatory, and SWOT analysis methods by firstly describing technology and task characteristics. It also aims to present the technology assessment and performance impacts though data collected from the interviews. (Inyang, E. 2017 p. 20-21) Ultimately, both primary data and secondary data are converged into a comprehensive discussion where information from literature review is combined with the empirical results. Then the SWOT analysis is utilized as a supportive method for summarizing the studied phenomena.

3.1.1 Technology characteristics

Technology characteristics express the technical attributes and capabilities of a particular technology for certain purposes. However, these features are not only limited to numerical capabilities, but also logical experienced based assessments and assumptions. (Goodhue, D. L., & Thompson, R. L., 1995) For this study, it is not relevant to research all available technology in market, but rather select the commonly known brands and recognized European and Asian suppliers to ensure proper data reliability as the study relies on freely available market catalogues. Therefore, the sample size was limited to five suppliers and their products: ABB Robotics, KUKA AG, Universal Robots, Omron Automation, and Fanuc Ltd.

Taesi, C. Aggogeri, F. & Pellegrini, N. (2023) have recently investigated the capabilities of nearly hundred different models and variants. This thesis exploited the knowledge of their study in the literature review but yet is simultaneously forced to conduct a similar collection once again due to rapid development of technological capabilities. As Taesi, C.

Aggogeri, F. & Pellegrini, N. (2023), this study will utilize the same key attributes to study collaborative robots as they are the most relevant ones when compared to conventional robots. In addition, considering the fact that fastening tasks are common activities in automobile assembly systems, torque parameters should be considered as well. The data collection focused on investigating technical catalogues provided by the manufacturers and was limited only to anthropomorphic models.

The data processing and analysis aims to provide descriptive outlook of the technological characteristics and establish a baseline for further analysis in this study. Therefore, the individual attributes are not significant, and the focus is to recognize broader patterns. (Inyang, E. 2017, p. 16 & 20) Firstly, a systematic descriptive analysis is carried over based on the collected data to establish a framework of the current technological capabilities of cobots. The main attributes investigated are payload, reach, and torque capabilities. Interestingly, velocity should not be considered as a technological factor due to the ISO 10218 standard limits the maximum tool point velocity in a collaborative systems, where humans operate in a near proximity, to a 0,25 m/s. While all cobots will bypass this threshold of 0,25 m/s, the velocity was excluded from the categorization criteria. (Taesi, C. Aggogeri, F. & Pellegrini, N. 2023) Secondly, the data will be pre-processed into a more compact format to simplify analysis process. The data was categorized into three different categories based on the payload capacity as the information was available for every device and variant. The criteria based on the payload capacity is described in table 2. Category 1 is considering all devices with payload capacity under 10kg, category 2 with capacity between 10 to 20kg, and ultimately category 3 with capacity for over 20kg.

Table 2 Determination of technology characteristic categorization

x	Category 1	Category 2	Category 3
Payload	x≤10kg	10 kg<x<20kg	x>20kg

3.1.2 Task characteristics

Task characteristics are a set of requirements necessary to be attained to achieve a certain predefined goal. Tasks are straightforwardly linked with the process by turning inputs to outputs and thus task characteristics are also perceived as process characteristics. In TTF, task characteristics are compared with technology characteristics by assessing technology compatibility in respect to existing process. Therefore, the task characteristics needs to be predefined and aligned with the study's scope and objectives. (Goodhue, D. L., & Thompson, R. L., 1995) In this study, the set of task characteristics will be sorted out from the existing database of the case company and refined through observation and evaluation narrowing the scope to align with study objectives. The raw data is extracted in a tabular format by entailing a detailed explanation of each individual task performed in the line including such attributes as a description of the actual activities performed, the time required for task execution, the necessary tools, and the relevant parametric prerequisites. Additionally, it is possible to obtain an understanding on which section of the line particular tasks are executed on.

An individual automobile assembly process is a combination of thousands of distinct tasks, each of which contributes to the overall construction of the automobile vehicle. (Omar, M. A. 2011) The internal database contains very detailed descriptions of all of this activity, but not all individual pieces of information are useful for the study. In order to extract the relevant data for upcoming analysis, the raw data will be pre-processed and reduced to correspond to the objectives of the study and avoid distorting the results. The main principle behind the data exclusion was to consider whether the task is applicable to be performed by a collaborative robot. The assessment stemmed from the task distribution evaluation presented by Scholer, M. Vette, M. and Rainer, M (2015). Their methodology allocated all assembly tasks between a human operator and a cobot based on the criteria described in table 3. The most prominent factors were the need for human dexterity, capability for flexibility, and need for cognitive decision making.

Table 3 Task distribution (Scholer, M. Vette, M. & Rainer, M. 2015)

Cobot tasks	Operator tasks
• Repetitive, less ergonomic tasks • Simple standardized movements • Minor cognitive or sense dependent tasks with little decision making	• Complex movements • Flexibility and cognitive decision making • Dexterity requirements • Individualized movements specified tasks

Once the irrelevant tasks have been eliminated from the raw data, the remaining proportion is still too fragmented for qualitative analysis and therefore requires additional preprocessing by categorizing the remaining data based on the shared patterns. A nested categorization is an effective tool for distributing different attributes into smaller categories based on the shared features without excluding any important data. (Lee, S., Adair, W. L., Mannix, E. A., & Kim, J. 2012). To strengthen the holistic approach in this study, the first step was to identify the location in which an individual task is executed. The standard division of automobile assembly into a trim line, chassis line, or finishing line will be exploited for locating the tasks (Omar, M. A. 2011). After, the tasks were categorized according to their shared operational characteristics, which reflect the different nature of activities involved such as fastening. The third nest address the need for documentation after the task is completed, which is a crucial factor, especially from a quality perspective. For the final nest, the remaining tasks will be organized based on specific requirements, such as minimum torque specifications for fastening processes. This is nesting was conducted only if necessary. Figure 5 visualises the nesting categorization and description of each nest.

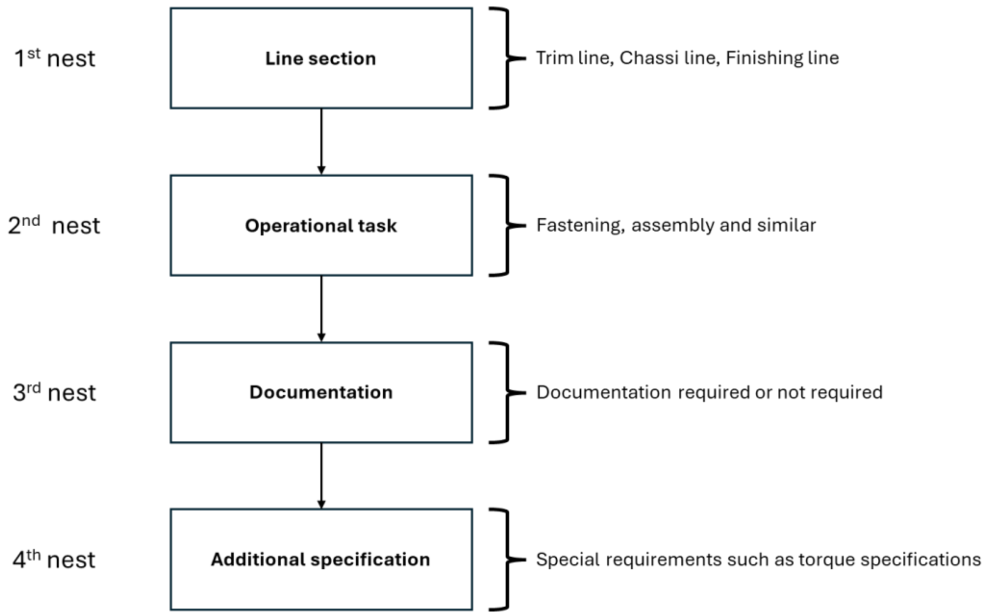


Figure 6 An illustration of a nested categorization

After pre-processing the task characteristic data by extracting unnecessary information and formulating holistic pattern with a nested categorization, a descriptive analysis is considered to discover the types of tasks cobots should be capable to perform within the case company's assembly domain. The aim of the analysis is to study the data through these predefined evaluation criteria and formulate a descriptive outlook on the tasks and find reasoning behind the phenomenon.

3.1.3 Selection of evaluation criteria

At this stage, technology and task characteristics were considered independently from one another. In the task technology fit framework, these two sets of data are essential to be compared to convert raw data into valuable information (Goodhue, D. L., & Thompson, R. L., 1995). For a large and multivariable data source, it is not feasible to compare these two attributes without establishing an evaluation criterion. It delivers the threshold for the analysis to assess whether the data supports the hypothesis or not. The criteria should be decided based on the parameters and measurable significance for the automobile industry and especially human-centric manufacturing system. (Scholer, M. Vette, M. & Rainer, M, 2015)

The most significant factors are focused on the process, safety, and ergonomics. Processual factors consist of the attributes from process performance and quality capabilities. Common parameters in an automobile assembly for process performance parameters are the cycle time, takt time, and productivity. (Munro, R. A., Ramu, G., & Zrymiak, D. J. 2015) When considering cobots, they have reduced capabilities in payload and size. Therefore, these factors should be investigated in respect to the process. From quality perspective, the focus is on control and assurance, both aiming to maintain visibility, produce high-quality products, and reduce costs (Monden, Y. & Ohno, T. 2011 p. 6). From safety and ergonomics perspective, attributes such as physical and cognitive safety and ergonomics of an individual human are considered important. In this study the baseline is established on occupational health and safety legislation and regulation together with relevant standards considering cobots such as ISO 10218 and ISO/TS15066. Lastly, the case company is interested increasingly in sustainability and green initiatives. Therefore, the green impact will be considered as one criterion in terms of the positive or negative impact from sustainable perspective when integrating collaborative robots.

As a conclusion the criteria is established based on the basic characteristics of automobile manufacturing and the case company which relies heavily on firstly on process capability, secondly quality, and thirdly safety. In addition, discovering possible enhancements in green initiative will be evaluated as a suggestion from the case company.

3.1.4 Technology assessment

Comparing technology capabilities with process requirements establish a profound base for evaluating whether certain technologies are suitable for operating within a desired process. (Goodhue, D. L., & Thompson, R. L., 1995) However, it does not consider if the studied technology is an optimal choice effectively completing the presented tasks. Technology assessment aims to critically analyse the feasibility of the technology in question by comparing alternative applications for perform given tasks. (Hartelt, R. Wohlfeil, F.& Terezidis, O 2015)

In the framework of qualitative research, it is difficult to concretely compare the capabilities between collaborative robots and conventional robots without utilizing quantitative methods. Thus, the explanatory analysis is a sufficient and suitable method for conducting the assessment and carry out adequate analysis to fulfil the objectives The data collection in this step was carried out through interviews with internal and external experts. Internal experts were chosen based on their long and profound experience in manufacturing, especially in automobile assembly process, automation and manufacturing engineering development within the case company. External experts were chosen to fulfil the extend the knowledge on collaborative robots and bring more general perspective to the study.

The interviews were conducted as semi-structured method which follows a predetermined structure established by the interviewer. The interviews were based on the evaluation criteria defined in the previous subchapter. Nevertheless, a basic characteristic of a semi-structured interview is the given freedom for interviewees to discuss the topic more casually from different aspects around and not limit their answers to strictly follow only the questions asked. (Inyang, E. 2017 p. 28) All the interviews were conducted in Finnish and documented in Finnish. All the questions are translated in English and are presented in table 4. The interview notes are visible in appendix 3 at the end of the study.

Table 4 Technology assessment interview questions

Nr.	Question description
1.	What are the positive and negative characteristics of collaborative robots in respect of automobile assembly process requirements?
2.	When comparing collaborative robots to conventional robots, what are the biggest benefits and challenges in respect to: a) Process performance capabilities b) Quality capabilities c) Safety and ergonomics d) Green impact
3.	In which domain conventional robot is seen more beneficial compared to the collaborative robot in respect to: a) Process performance capabilities b) Quality capabilities c) Safety and ergonomics d) Green impact

By combining the output of the two interviews, a comprehensive explanatory analysis is exploited to describe which type of tasks are seen difficult to execute with contemporary technology according to the interviewees. The data analysis pursuit to explore the reasons behind the reasons behind statements of the interviewees. (Inyang, E. 2017, p. 21) The interview questions and structure were intended to be designed so that the analysis is possible without acquiring extended data or further investigation. Notable is that with the internal experts, the interviews focus was on case company's assembly system, whereas with externals the focused on generally discussing the automobile manufacturing and assembly processes.

3.1.5 Performance impacts

Task technology fi (TTF) aims to discover the tasks which are the most suitable for technology integration by comparing two characteristics together. Performance impact measures this by aiming to discover the tasks where collaborative robot integration will have the biggest positive impact based on the factors defined by the predetermined criteria. (Goodhue, D. L., & Thompson, R. L., 1995) This evaluation will shift the focus onto tasks and condition on the collaborative robots can thrive in an automobile assembly domain. The evaluation will be carried out through data collection by conducting a semi-structured interview. Same people and setting were utilized in in this step as in previous ones. This time the sample size was extended by bringing in an internal specialist with comprehension on practical production activities. This aimed to enrich the data analysis by bringing up the perspective of an end user. The questions to these interviews are presented in table 5. The notes from all interviews are attached and found in Appendix 3. The aim of the analysis is to discover and describe the type of tasks within the case company's assembly process which have the highest impact on the influence of collaborative robot integration. The analysis is designed to conduct as an explanatory analysis as the previous step analysis to delve deeper into the reasons.

Table 5 Performance impact interview questions

Nr.	Question description
1.	Considering technological constraints of collaborative cobots, which tasks would have the highest impact with the implementation of a collaborative robot in respect of: a) Process performance capabilities b) Quality capabilities c) Safety and ergonomics d) Green impact
2.	On which of these four criteria, the cobots would have the biggest impact on in generally?

3.1.6 Utilization evaluation

In previous steps, data have been collected and analysed to construct a holistic understanding of the capabilities of collaborative robots in context of automobile manufacturing. Each and every step has deepened the knowledge by piling additional information from carefully selected samples. However, none of the steps will provide a proper holistic analysis, but rather discuss the relevant topics independently with an influence of the previous steps. The last part of the six-step approach is the utilization evaluation which aims to evaluate the concrete usability of the technology within the defined framework by making a well-reasoned assumption on which processes within the assembly processes are feasible to cobotize. (Hartelt, R. Wohlfeil, F.& Terezidis, O. 2015)

The utilization impact assessment in this study exploits triangularization method by combining primary (empirical findings and interviews) and secondary data (technology and tasks characteristics) together with the findings in the literature review to finally testing the theory and provide holistic answer for the research question and objectives. (Inyang, E. 2017 p. 34) Thematic analysis is a prominent method for executing the triangulation method with study having the consistent and strong theme built around well-structured research question and objectives. The data collected before utilization evaluation will answer to the research objectives and question, but utilization evaluation brings everything together. The analysis will be carried out to discover the deeper meaning behind the data and portray it into a holistic analytical result. (Braun, V. & Clarke, V. 2006)

3.2 Validity and reliability of the study

Successful scientific study relies on results that can be classified as reliable and valid not only from the author’s perspective but also from the peers in academic field and in industry (Inyang, E. 2017 p. 5-6). There are various methodologies and approaches to ensure validity and reliability of the study, each depending on the research strategy and methods exploited (Golafshani, N. 2015). This chapter focuses on explaining and clarifying the characteristics of validity and reliability in general and in addition provide an outlook on how validity and reliability are maintained and carried through this study.

Whereas systematic research planning and obeying academical standards are perceived as main principles of research quality in general, validity and reliability can be considered the tools or methods to maintain and assure the research quality over the course of research execution. (Inyang, E. 2017 p. 7) In a research, validity can be perceived as a question “whether the research truly measures that which it was intended to measure” and “how truthful the research results are” (Golafshani, N. 2015).

The validity in qualitative study is considered through two different perspectives: internal, and external. By ensuring internal validity of the study, the research should understand the goals and objectives of the study and design the research so that a clear conclusion can be derived from the research data without providing false information mistakenly. For instance, the data should be collected from variative sources in order to declare the results to be truth. External validity ensures that the study can be generalized so that the results can be perceived generally valid in a scientific context. (Inyang, E. 2017 p. 7-9) This means that when, for example, if an author study declares that collaborative robots can be used for certain purpose in automobile manufacturing process, high external validity of the study shows that this statement imply every time and not only in a particular case studied. The high external validity is not essential necessarily in study, but it should be at least very well acknowledged by the author (Inyang, E. 2017 p. 7-9).

To ensure high validity of the study, firstly the study structure is planned to follow academic standards. Secondly, the theoretical framework and research methods are considered to fulfil the objectives of the study well and serve purpose of the qualitative research. In addition, a triangulation was employed to analyze multiple sources of data, including both internal data (task characteristics) and external data (technology characteristics), interviews, and a comprehensive literature review. To strengthen the generalization, the interviews were extended to external experts besides internal ones to provide more robust and comprehensive data for studied phenomena. Additionally, selecting interview questions and evaluation criteria together with internal experts was crucial to properly aligning the results with the main research question and objectives. Lastly, interviewees had the opportunity to check and counter interview notes to avoid factual or subjective errors.

Reliability of the study refers to a degree which academic peers can trust the study results after precise and well-designed research methods and documentation is exploited to provide results. Hence, the study should be repeatable without difficulties and end up with moderately similar results over again. Therefore, in a qualitative study, if reliability is carefully considered, results will have a significant impact on author's subjective perspective which can lead biased intention or unintentional biased results. (Inyang, E. 2017 p. 8) Reliability in this study has been ensured through several key methods. Foremost, mostly peer-reviewed academic sources were mostly utilized to ensure the credibility and consistency of the information. Also, academic standards of conducting research were followed throughout the whole study. Additionally, the conducted interviews had time after time the same structure with every interviewee, ensuring consistency in data collection.

The biggest challenge of the study in terms of reliability and validity are the case company setting and missing quantitative analysis. A case company is a unique entity and in this study the author is only conducting study within one assembly line. Therefore, generalization can be difficult which directly has an effect on the external validity as well. Thus, the research setting creates a figurative curtain between the public and private information, and it was not possible to publish all the utilized data but only an overview, summaries, and insights was published. To mitigate this issue, the methodologies are very carefully described in chapter 3 so that the study is at least repeatable. As the study is conducted with quantitative methods, it enables the authors to utilize more their own interpretation. As the quantitative methods are missing the findings can be questioned. Taking experts perceptions into account to support the assumptions and observations derived on the raw data can be seen as sufficient validation in this study. Also, examples of author’s interpretation are given in chapter 4 to provide more transparency to the research process itself.

4 Results and analysis

Presenting results and analysis is critical for every research and study. It allows a systematic examination of the collected data by aiming for comprehensive, accessible, and cohesive data analysis and presentation (Inyang, E. 2017 p.17). The presentation of results in a qualitative study typically exploits a descriptive and thematic explanation of the prevailing phenomena, which help to summarize the data and test the research hypotheses (Braun, V. & Clarke, V. 2006). Tables, figures, and charts are utilized to enhance the clarity of the results, providing visual representations and supporting the written description. Results and analysis reflect the six-step approach presented in the previous chapter to ensure clarity and increase comprehension. (Inyang, E. 2017 p.17). This structured approach allows a detailed and comprehensive discussion between empirical findings and the context of the literature review. Combining a theoretical perspective with empirical findings, a robust evaluation of TTF, in a contextual framework, presents key insights and delivers a baseline for future research (Inyang, E. 2017 p. 89-90).

4.1 Analysing technology capabilities in respect to task requirements

In this study, comparing the relevant technology and task characteristics forms the foundation of the task technology fit (TTF) framework. This approach is particularly essential for identifying activities that are suitable for collaborative robots to perform in the automobile assembly domain. The initial step in this process is conducting a thorough comparison between the technological capabilities of cobots and the nature of the tasks within automotive settings, aiming to uncover feasible opportunities for cobot integration. This chapter is divided into three sections by first presenting the results in terms of key attributes of contemporary technology of collaborative robots in market and task requirements utilizing source material harnessed from the case company database. Lastly, the technological capabilities of cobots will be assessed and analyzed in relation to the task requirements in automobile assembly.

4.1.1 Technological maturity of collaborative robots

The technological characteristics in the TTF framework are considered of different technical attributes. In this study, these characteristics refer to technical capabilities of collaborative robots. The attributes were collected from open-source catalogues provided by five major cobot manufacturers in Europe and Asia, narrowing the sample size focus exclusively on anthropomorphic models. The data collection revealed in total 41 devices which established the baseline of the data sample. Out of the 41 devices, each manufacturer entailed approximately 5 to 10 different models and variants with variative capabilities. All relevant data related to collaborative robots is presented in appendix 2.

As described in chapter 3.1.1, the primary objective was to develop a preliminary classification into three groups based on the predetermined criteria, enabling more convenient data analysis. As a result of the data preprocessing, 54 % of the devices were distributed into category 1 (0.5-10 kg payload), 32 % to category 2 (10-20 kg payload), and the remaining 14 % was left for category 3 which was generally the heaviest and strongest with payload ranging between 20 to 35 kg. As interpreting the data (figure 7) the manufacturers clearly focus on smaller devices dedicated for lighter tasks operating within a close proximity of the cobot’s centre point. Although the heavier and stronger models were moderately rare, the maturity of the technology is not yet at its peak and the development is clearly in progress, as more capable models appear to the market yearly (Taesi, C. Aggogeri, F. & Pellegrini, N. 2023).

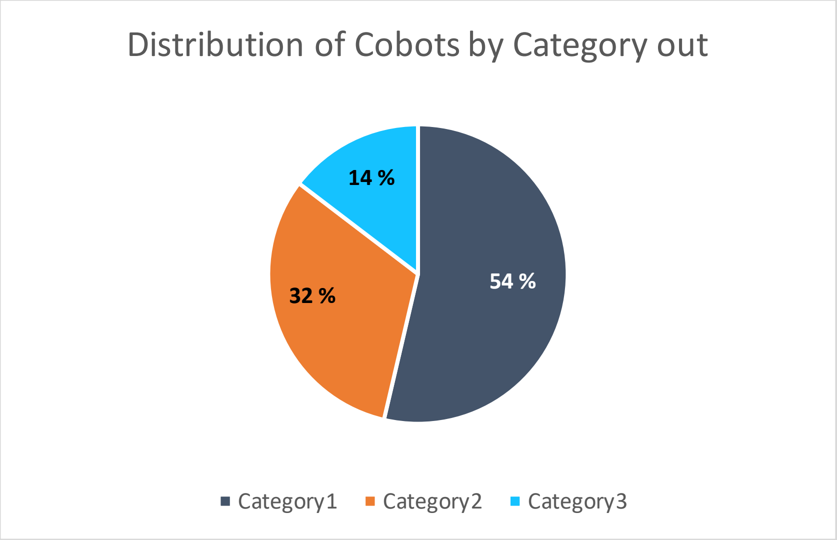


Figure 7 Distribution of cobots by category

The payload, as used for the main attribute, provides only a certain understanding of the cobot capabilities. It is not the single most critical factor, and proper evaluation requires studying various other attributes in parallel with payload capabilities. Therefore, other significant characteristics, such as reach, torque, and weight, in all categories were investigated. Additionally, to demonstrate deeper perception, peak (highest and lowest) and average values were defined in all attributes for each category. These three attributes were selected by assessing the importance for the final evaluation of cobot utilization. For instance, the reach as a parameter becomes interesting as the assembly domain is predefined and so are the workspace dimensions. Therefore, the reach can come up as a limiting factor for technology integration and implementation. Secondly, the torque ability is crucial to understand as the automobile assembly process is heavily reliant on fastening tasks (Omar, M.A 2011). If the technology is not capable of comprehending the given specification, integrating such technology to perform the given task is ineffective. Lastly, weight as parameter is interesting as it might indicate the relation between the power generation capability and size. Table 6 provides the information categorized.

Table 6 Summary of the technological characteristics

	Category 1	Category 2	Category 3
Avg. reach	0,95 m	1,19m	1,55m
Lowest reach	0,47 m	0,9 m	1,3 m
Highest reach	1,42 m	1,62 m	1,9 m
Avg. torque	19 Nm	19 Nm	64 Nm
Lowest torque	9 Nm	10 Nm	20 Nm
Highest torque	35 Nm	31 Nm	110 Nm
Avg. weight	39 kg	84 kg	137 kg
Lowest weight	9,5 kg	33,1 kg	36 kg
Highest weight	79 kg	255 kg	386 kg

The data set above demonstrates that reach and payload capabilities go nearly hand in hand with the size of the cobot in terms of weight. Hence, a bigger device grants certain extended capabilities in respect of reach and payload. Even though the data argues against the evidence of linear consistency in this manner, the general pattern can be recognized. As seen from the list of torque capabilities, categories 1 and 2 demonstrate relatively similar average values, and the data does not provide a direct understanding of the reasons behind the difference. However, it's clear that category 3 stands out again as the strongest in terms of torque, by having significantly higher average and maximum torque capabilities compared to the other categories. Nonetheless, all categories were unexpectedly capable of providing a decent level of torque resistance.

4.1.2 Task requirements in automobile assembly line

The tasks within the case company's assembly line were investigated by collecting, processing, and analysing data from the company's internal and classified database. The extracted data included roughly over 1800 different individual tasks listed in a tabular format and it entailed all the performed tasks within the assembly line. As previously discussed in chapter 3.2.1, not all tasks are relevant for automation and especially for cobotization. Therefore, a significant number of tasks were pre-processed out from the original number of 1800. The preprocessing was conducted through an assessment based on a detailed investigation of the data set, relying on the task allocation presented by Scholer, M. Vette, M. & Rainer, M (2015) as mentioned in table 4 in chapter 3.1.2. The assessment was supported and supplemented by observations collected during line walks within the case assembly line. Unfortunately, a more detailed level description cannot be provided in this study as the information is classified, but results are presented through examples and rough generalizations based on the source material.

To establish a better image of tasks under assessment, three archetype examples were provided to clarify the analysis. Through these archetypes, different varieties of tasks found in the data set are illustrated, offering the reader a clearer understanding of the basis for the evaluation. The first type of tasks can be referred to as a single level task entailing only a simple one step process. Usually, these tasks were straightforward and little time consuming and tended to be repetitive. Also, these types of tasks required only one or fewer tools. The second archetype can be considered as a dual level task, entailing clearly two different process phases. As an example, described in table 7, the dual level tasks had clearly two separate steps with different tooling and attributes. Typically, within this research scope, they required not only assembly but also another activity which was often a fastening activity. Therefore, these tasks required usually one or more tools. The last and third archetype was considered as a multilevel task typically containing activities like task preparation, material handling, assembly, installing, and possibly a quality inspection. As archetype 2, type three usually required one or more tools, and in some cases attained more than one resource for finishing the task. As the data is classified, the examples are not directly copied from the data set. Therefore, table 7 contains only generalized examples of real types of tasks and provides only a prominent reflection of real-life activities. Nonetheless, it establishes a framework where reader can better understand the analysis process, author’s interpretation, and the data source.

Table 7 Task arch types based on the source material

Arch Type	Name	Documentation	Type	Description
1	Fastening 6 screws	No	Fastening	Take 6 screws (certain type) and fasten them to a dedicated location described in work instructions.
2	Assembling a plastic cover	Yes	Assembly	Take the plastic cover and position it to its dedicated position as described in work instructions. Fasten it with 4 (certain type) screws.
3	Wire harness assembly	Yes	Assembly	Pick the wire harness out of the material crate. Place the wire in the middle and spread the connectors near to their dedicated positions. Install the connectors to the sockets. Check that all the connectors are connected with pull push method.

In the beginning of the preprocessing, the first step was to identify only relevant tasks for cobots according to the classification presented by Scholer, M. Vette, M. & Rainer, M (2015) and exclude the excessive tasks out of the study. The preprocessing revealed that only 399 out of 1800 relevant tasks remained feasible, which is merely 22 % out of the total quantity. As a result, all of the three archetypes were found from the sample of 399 tasks. The excluded activities typically entailed a certain degree of dexterity, need for flexibility, or complex assembly postures resembling human capabilities. In this case, presenting an example can be valuable for the reader to retrospectively understand the evaluation approach. For instance, several tasks required the assembly of a connector into a socket which itself requires a certain level of dexterity. In addition, these tasks involved a verification check relying on the operator's somatosensory sense to confirm task completion. Therefore, this task currently is too reliable on human senses and dexterity abilities that they needed to be limited out of the scope. Furthermore, tasks that were potentially too focused on specific, individual movements were excluded as there could not been found a case to automate or it was not seen feasible in the case assembly framework. For instance, picking and placing lightweight objects difficult to handle, like certain accessories such as charging cables, were not seen as prominent tasks for automation.

To complete the comparison between technology capabilities and task characteristics in the TTF framework, the remaining 399 tasks were further analysed. As the data was still highly scattered, a nested categorization was conducted to discover patterns to simplify the analysis process by offering a holistic overview of the assembly line activities (Lee, S., Adair, W. L., Mannix, E. A., & Kim, J. 2012). Nested categorization established a base for understanding of automobile assembly line characteristics in terms of cobotization. The first nest represented the automobile assembly line sections in which the tasks take place. The categorization was embraced from the basic structure of an automobile assembly: trim line, chassis line, and finishing line (Omar, M.A. 2011). The second category focused on the type of activity ladled in the dataset. The three main categories were assembly tasks, checking tasks, and assisting tasks. Besides these three types, fastening, applying (adhesives/primer), and sifting parts were chosen as main types among the data set as they have a significant role in automobile assembly (Omar, M.A. 2011). Lastly, it was important to understand whether the action was documentative or not documentative, as documentative actions entailed specifications relevant for the activity and thus had an obligating impact on task execution.

The nested categorization revealed that the third main part of the assembly, the finishing line, was not applicable in this study due to the study limitation excluding mixed model lines out of the scope, which the finishing line in the case company was at the time. Also, a complete extraction of subassembly, transportation, or other specific tasks were not found feasible as the data did not provide extensive information. Only information provided by source data was an understanding if the tasks is performed either on the trim line or on the chassis line.

To offer proper data presentation, both table 8 and table 9 gives a prominent outlook on the nested categorization and illustrates the current setting in quantitative format. Table 8 represents the tasks on the trim line and table 9 on the chassis line. Data interpretation clearly demonstrates that assembly and fastening tasks are the most dominating activities in terms of quantity in both sections of the line. From a quality assurance perspective, checking activities seem to focus mainly on the chassis line and nearly all of them were documentative tasks. Same number of tasks entailed description of shifting and moving parts feasible for collaborative robots. The last and smallest share of tasks were applying and assisting tasks. Nonetheless, no applying and assisting tasks were found from the chassis line. These tasks were usually gluing applications for windshields or other bigger parts.

Table 8 Trim line task categorization

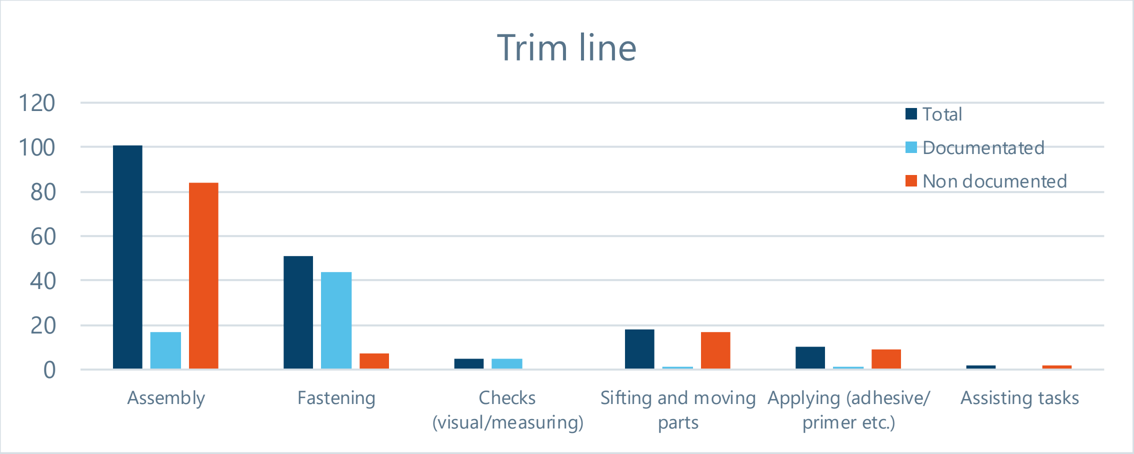
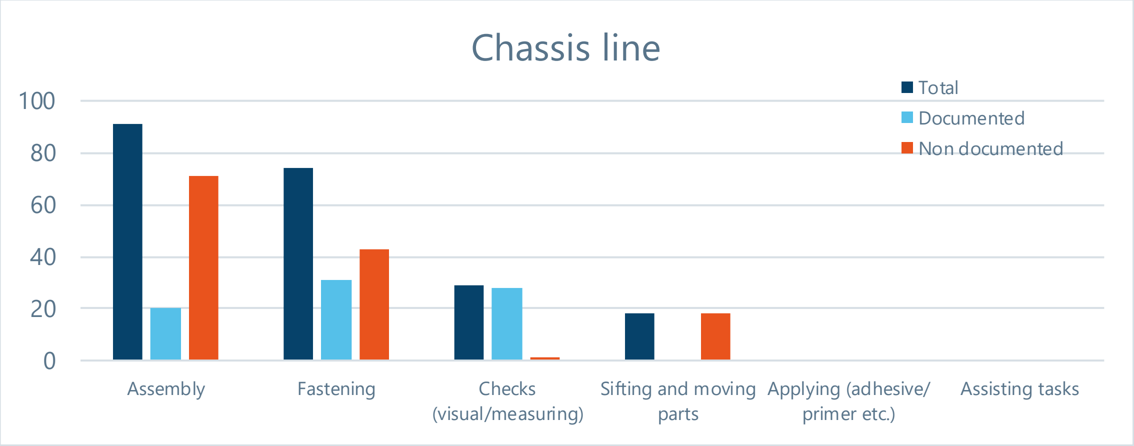


Table 9 Chassis line task categorization



To properly understand technological requirements in an automobile assembly line, special characteristics for tasks need to be evaluated. These special characteristics can be equated to process capability parameters, of which the most crucial parameters are uptime, cycle time, payload, and other task specific requirements typical for the automobile assembly process, for instance torque specifications. (Matúšová, M. Bučányová, M. & Hrušková, E. 2019; Scholer, M., Vette, M., & Rainer, M. 2015; Suomen Robotiikkayhdistys ry, 2023 p. 78-80)

When discussing assembly tasks, the most limiting factors are the cycle time requirement and the payload. As the payload could not been provided for each individual task by the source material, the remaining parameter was the cycle time. In the industrial domain, the cycle time requirements are measured by using different units. While the study successfully addressed the research question and achieved its objectives, certain challenges—such as the incomplete and classified nature of the dataset—highlight areas where further work is needed to ensure greater robustness the commonly known sexagesimal system. This commonly unknown unit Time Measurement Unit (TMU) provides accurate results as measuring time requirements for certain individual tasks. In comparison, 1 TMU represents 0.036 seconds and approximately 1 second equals 28 TMU. (Hanash, E. A. H et al. 2017) For each individual task the TMU is defined in the source material. According to that, the calculated cycle time requirements varied from 35-8000 TMU, which ranges approximately from 1,2s to 285.7s (4min 45s). Typically, the tasks with lowest TMU values were archetype 1 single level tasks with simple one step actions. In contrast, the highest TMU values were multilevel tasks including several varying steps. Ideally all operations should pursue that theoretically defined cycle time otherwise the ideal process capability is not achieved. Therefore, if the technology does not achieve the established limitations and requirements, it cannot be a feasible solution for the assembly process.

Fastening was considered as the second largest nest in terms of quantity of the task. For fastening operations, torque requirements were defined for each and every individual activity. According to the source material, there were in total 206 fastening activities with torque specifications. Out of these 206 fastening operations, 125 tasks were dedicated only for fastening as perceived from table 8 and 9. The rest 81 fastening tasks were dual level activities embedded to assembly activities as described in table 7. These 81 tasks take over 42% of all assembly tasks being the most frequent task category to be considered feasible for collaborative robots.

The fastening activities are performed in all line sections both in trim line and in chassis line with a high frequency rate. Tables 10 and 11 provide a descriptive outlook between these two assembly lines in terms of torque requirements. According to the data analysis, the torque specifications vary between 1,5Nm to 180Nm and the most frequently appearing requirement was 10Nm which appeared in 17 tasks in total as a specification. Nonetheless, the major share of the fastening activities had the specification up to 20Nm. In trim line the average torque requirement was 16 Nm and as seen from the table 10, 75% of the tasks are below that specification. On the other hand, in chassis line the average value was around 43Nm which covers 67% of all fastening tasks in that line. As comparing the lines, the torque generation capability specifications in trim line are not as high as in chassis line due to the heavy fastening installations in chassis line. All operations with the specification over 100Nm were located to that part of the line.

Table 10 Torque specifications for fastening activities in trim line

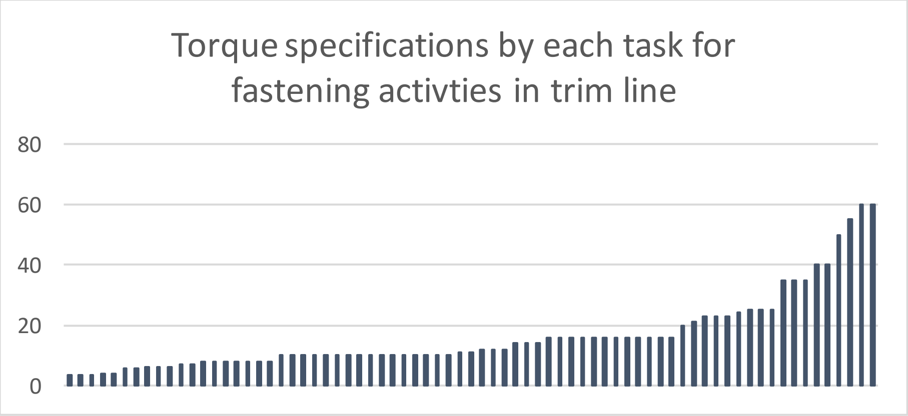
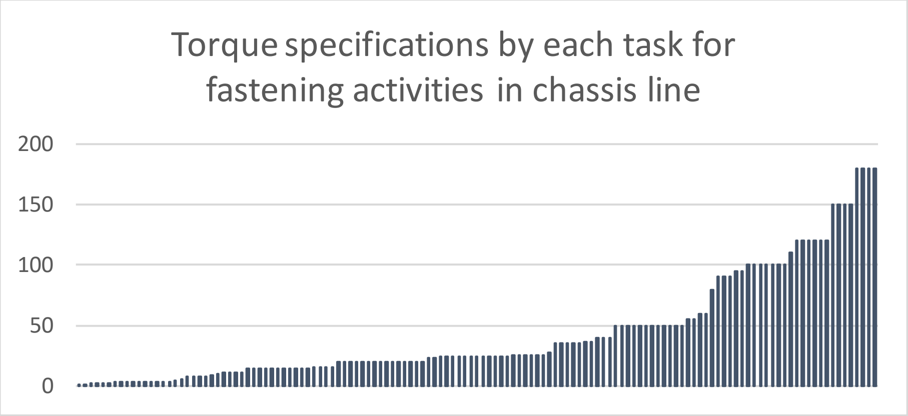


Table 11 Torque specifications for fastening activities in chassis line



Lastly, as cobots are widely exploited in material handling operations outside of the direct assembly line domain, they are seen as prominent devices for shifting and moving the parts within the assembly process activities as well. Most of the sifting and moving tasks are considered as dual level tasks including assembly and installation activities as well. Also, some assisting tasks were considered as part handling. An example was lifting the task to lift and lay down a hood for operator to work underneath it. The feasibility of shifting, moving, and placing parts derives single handily from the payload requirement and thus from the weight of the part. As stated above, the dataset did not provide any information regarding the payloads of each individual task. Also, feasibility of the material handling is a considerable factor for evaluating the competence of the technology. This, however, should be considered case by case together with the weight of the part.

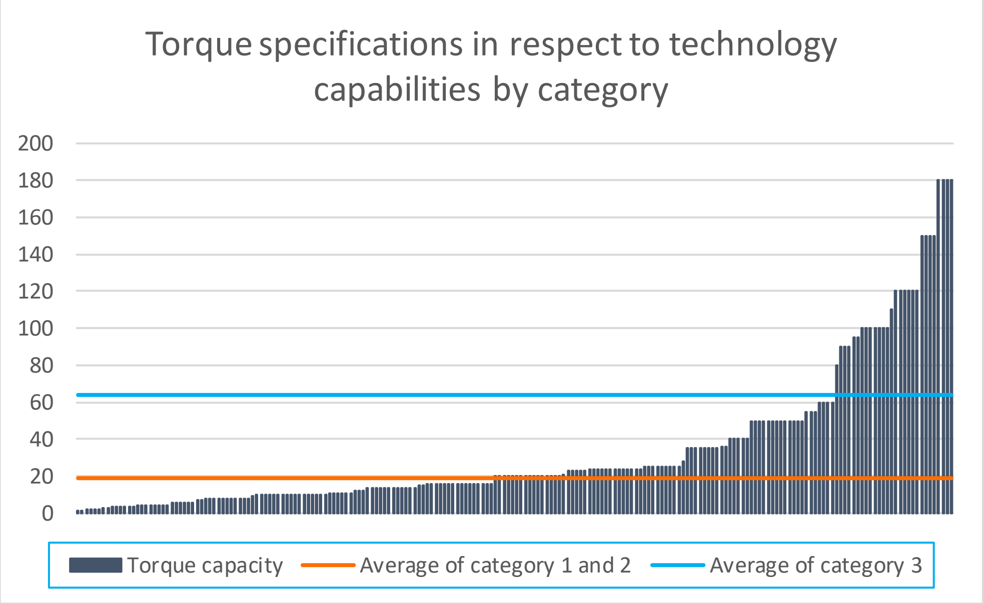
4.1.3 Descriptive analysis of cobots' technological capabilities aligned with task requirements in automobile assembly

Descriptive analysis aims to achieve the level of systematic description of the phenomena in question. By interpreting collected data from two different sources and describing interrelationships between the two data sets, a sufficient description is achievable. (Inyang, E. 2017 p. 21) The objective is to discover appropriate tasks suitable for collaborative robots in a holistic framework. In this subchapter, the main task attributes, presented in chapter 4.1.2, will be brought along side with the technology capabilities presented in chapter 4.1.1 to establish an understanding of cobot capabilities in the automobile manufacturing framework. In chapter 4.1.1, collaborative robots are divided into three categories based on their payload capabilities as it gives prominent perception on their general capabilities in terms of torque, reach, and tool point velocity.

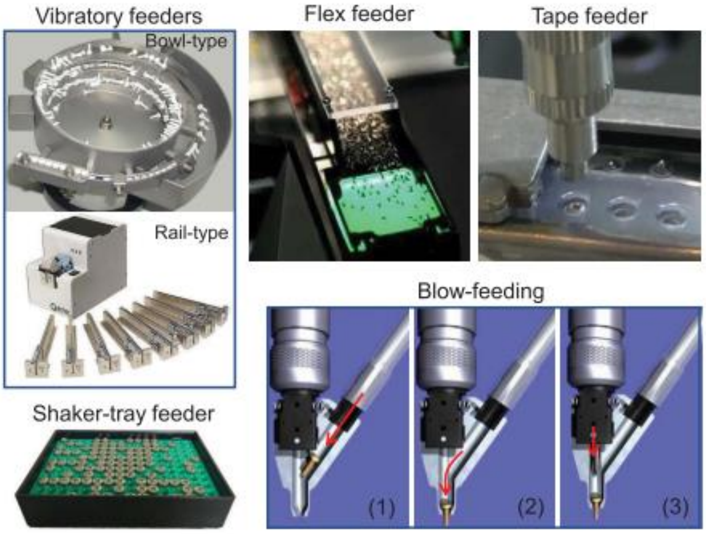
Based on table 6, payload capabilities are clearly defined per each category. The aim was to firstly understand the capability to execute the task based on that attribute. However, when assessing the feasibility of the technology on task execution, the case company's data sample could not provide any values regarding the weight of the parts. The data interpretation demonstrates that stronger devices enable extended capabilities in various forms despite the different manufacturers. It also showed that cobots are capable of operating with objects maximum weight of 35kg and heavier objects are not feasible for current technological maturity. It is considerable that even knowing the weight of the part could not solely provide full understanding of the feasibility. The total payload requirement derives from the combination of the part itself added to the weight of the tool or additional equipment installed and attached to cobot's arm. These factors need to be taken into consideration in evaluation as they might exclude heavier tasks such as tire assembly, wind shield placing, and door handling.

Nonetheless, not all tasks are limited to payload capacity. Fastening activities hardly require endurance for carrying heavy loads, but in contrast, they require a certain degree of torque resistance capacity. The technology sample had fairly effective torque generation capacity varying from 9Nm up to 110Nm. Table 12 presents torque capacity requirement by each task in respect to the average values of different categories. Categories 1 and 2 share the same average value of 19Nm and category 3 has an average value of 64Nm. As perceived from the table 12, devices in category 1 and 2, which are the smallest and the weakest devices, could theoretically perform in 48 % of all fastening task in terms of torque capacity. Instead, category 3 on average has the theoretical capacity to operate in 86% of all fastening tasks. The maximum value of an individual device in category 3 reaches up to 110Nm. Tasks with higher requirements are out of the scope of cobotization with current technology. Nonetheless, cobots are quite capable of operating with fastening tasks.

Table 12 Torque specifications in respect to technology capabilities by category



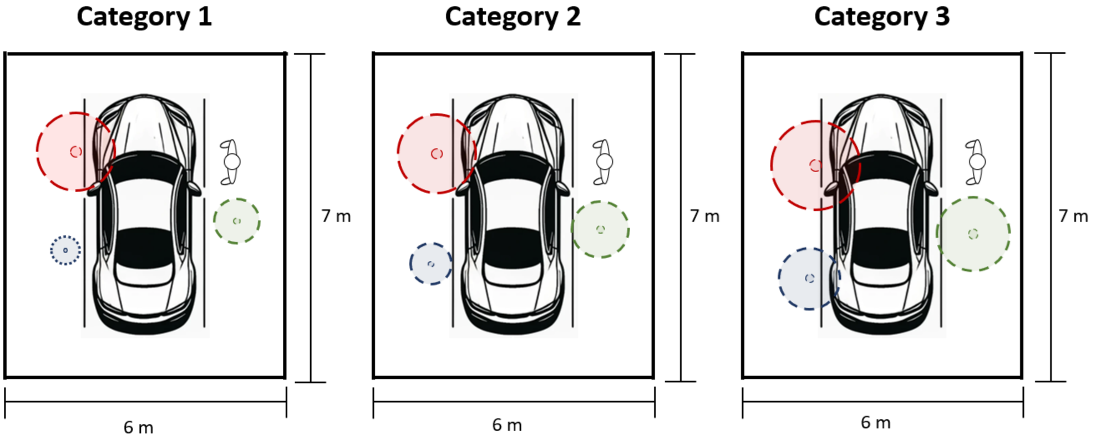
As fastening tasks appear quite feasible for collaborative robots in terms of torque resistance capacity, the challenge comes with the other activities of the fastening operations. Based on the observation in the line and according to the data source material, fastening tasks include steps from picking the screw, placing it to the threat, and fastening it for specified torque. Hence, either human assistance or visual detection is needed for successfully positioning the screw into the threat hole. This could be applied, for instance, as a sequential work where operators place the screws to the threads and a cobot finish the task. Alternatively, the task could be completed as a collaborative work where the operator utilizes the hand guiding feature of the cobot to position the device. (Bauer, W et. al. 2016; Gisginis, A. 2021; Brera, G. 2022) The second issue with fastening tasks, besides the inaccurate positioning, is the screw infeed. Based on the observation on the line, the screws are typically delivered mixed inside containers to the assembly line. It is not currently feasible for cobots to pick individual screws from a container one by one (Brera, G. 2022). Therefore, a screw infeed system should be designed so that cobot can pick them up. A prominent case example is to utilize feeding machine where cobot picks the positioned screw one by one or automatically feeding the screw directly to the robot's tool with a blow-feeding machine as illustrated in picture 1. (Brera, G. 2022; Johnson, P. A, 2023)



Picture 1 Examples of screw feeder systems (Brera, G. 2022)

Quality inspection and checking tasks represent some of the most practical applications for cobots in assembly lines. These tasks typically involve visual inspection but may also include other types of inspections. Replacing human operators with robotic visual inspection not only streamlines the process but also improves the robustness of quality control. (Gisginis, A. 2021) For human operators, the ability to perform visual checks decreases over time with numerous repeated tasks whereas robots maintain consistence performance. (Simundic, A. M. et al. 2009) In tasks such as assembly, fastening, shifting, and moving parts have strict specifications for payload and torque. In contrast, quality activities rarely constrain cobotization, as visual detection and sensor systems are relatively lightweight.

The reach is a significant limiting attribute for cobotizatization as the devices are relatively reduced in size. Especially in the first category where the lowest value of reach is merely 0,5m. Category 3 devices already offer a significant reach capability, ranging from 1.5m to nearly 2m. Nonetheless, evaluating the feasibility of cobots for each individual tasks is challenging due to the lack of relevant information in the source material. However, a general comparison is possible by exposing typical characteristics in each line. According to Omar, M.A (2011), activities in trim line focus on mainly to vehicle interior whereas chassis line activities focus on vehicle exterior. To get an image, picture 2 provides a prominent overview of the reach capabilities on each category. In each section, there are presented a minimum, maximum, and average value of reach in respect to the workstation. Blue colour represents the minimum value, green represents the average value, and red the maximum value. The vehicle is not in correct dimensions but gives good perception on the real-life phenomena. The workstation and the reach sections are, on the other hand, in scale. As interpreted from the picture, devices in each category are struggling to reach inside the vehicle when installed on the side of the workstation. Practically, without extended manufacturing engineering solutions, only category 3 devices with longest reach are capable of operating inside the interior, yet still to a limited degree. Since chassis line activities primarily focus on the vehicle's exterior, chassis line activities can be perceived more inviting for collaborative robots. Also in chassis line, the vehicle is positioned on a hanging conveyor where cobots can also operate beneath the vehicle. Despite these advantages, it is difficult to see applications for small devices in category 1 and 2. However, by investigating individual tasks, a beneficial use case can be found. Nonetheless, category 3 cobots can be seen as feasible for both trim and chassis lines, offering the most applicable reach capabilities among the three categories.



Picture 2 Comparison on cobots in a workstation setting by category

Ultimately, collaborative robots face a fundamental issue that affects their performance in every task. As the system level standard limits the tool point velocity maximum to 0,25m/s, cobots might face difficulties complying with the cycle time and uptime criterion. (Taesi, C. Aggogeri, F. & Pellegrini, N. 2023) As the dataset contained Time Measurement Unit (TMU) for each task, it is possible to assess the feasibility for each task. For this study it is more important to understand that the given TMU indicated the time reserved for each task to be performed. By converting the Time Measurement Unit (TMU) into seconds, the duration of each task could be evaluated in relation to the cobot's tool point velocity of 0.25 m/s. Longer-duration tasks, such as those tasks over 4000 TMU which is approximately 143 seconds, are generally more suitable for cobots. These tasks allow for slower, precise movements that align well with the cobot's tool point velocity limitations. In contrary, shorter tasks especially those with durations around 100-200 TMU which is approximately 3.6- 7.1s cause significant challenges for cobots. These tasks typically require more rapid movements, often within a predefined workspace. This can make it difficult for cobots to meet the cycle time requirements especially under the 0,25m/s limitation. The ability of cobots to perform such rapid, repetitive tasks efficiently would require either a redesign of the task sequence or the use of alternative automation technologies better suited for faster operations.

In conclusion, there can be found numerous possible use case tasks for collaborative robots to operate in automobile assembly domain. As discussed, not all tasks are relevant for cobotization as some of them suits better human operators. Among the tasks feasible for collaborative robots, the majority are heavily focused on fastening. According to the data analysis, cobots are capable of complying with a major share of the torque specifications. Only the heaviest chassis fastenings were beyond the capacity of current technology. Also, quality inspections and checks were identified as prominent applications for cobotization as the critical evaluation factors did not limit these tasks. Ultimatelly, all tasks come together with the reach and tool point velocity. In trim line reach is limiting cobots form operating inside the vehicle almost completely, but in chassis line all devices are seen feasible. After all, if the cycle time requirement is not matched, the feasibility is lost, and no integration is suggested.

4.2 Interviews

This chapter presents the results of the interviews conducted with experts both from internally and externally. These specialists were chosen based on their expertise on the topic and long experience in industry, manufacturing engineering, and robotics. In total five people were interviewed: three internal experts and two external esperts. Two experts internally had long experience within the case company, one with nearly 20 years of experience in automobile assembly production and manufacturing engineering and the other one with nearly 20 years of experience in automation where 10 years of experience in automobile manufacturing automation and advanced engineering technologies. Additionally, the two external experts, both from a major robot supplier, provided more detailed insight on collaborative robots as they had also nearly 20 years of experience in robotics, some of which they recently spent working with the collaborative robots. Ultimately, to provide a more nuanced perspective of the topic, third internal expert was involved. The expert has over 10 years of experience in the automobile industry by acting currently as a production supervisor of the case assembly process. The reason behind the choice was to get deeper insight of the assembly line tasks and to exploit the knowledge of the end user.

All the interviews were held separately from one and other. The interview setting varied between internal and external colleagues. Internally, the interview was held in a meeting room together with participants, but externally it was arranged via video call. The interviews were semi-structured and were carried out as described in chapter 3.1.4 and 3.1.5 by following the structure but not limiting the discussion to predefined questions. This chapter works as a consolidating reference of these three interviews. All of them were recorded to simplify the documentation, avoid bias and subjective interpretation. Ultimately, all of the interviewees were given a change to proofread the notes for minimizing the author's own interpretation.

In previous chapters, the discussion has focused on comparing tasks requirements for collaborative robots' capabilities in automobile an assembly line. Following subchapters will comprehend steps four and five in TTF approach. Chapter 4.2.1 will conduct a technology assessment derived through interviews with experts, which will supplement the analysis with concrete comparison between collaborative robots and conventional robots. Chapter 4.2.2 on the other hand will evaluate the performance impacts through the predefined evaluation criteria and therefore strengthens the understanding for cobot exploitation especially in automobile assembly.

4.2.1 Expert derived technology assessment

The technology assessment in this study offers both supporting and opposing arguments for collaborative robots to establish a thorough understanding of which processes are currently considered feasible for cobotization and where to turn for an alternative option (Hartelt, R. Wohlfeil, F.& Terezidis, O 2015). Collaborative robots, like any other technology, has their strengths and weaknesses, and are designed for certain purposes (Matúšová, M. Bučányová, M. & Hrušková, E. 2019). The definition for collaborative robot is not clear and often it is used in cases where human and robot work collaboratively in assembly system (International Federation of Robotics, 2020). The external experts offered their insight on the definition of collaborative robots by clearly separating them from the conventional industrial robots. Based on their statement, cobot is a device designed and manufactured with inherent safety measures which prevent humans from injuring while operating collaboratively without limited access. This means that collaborative robots are devices that has the ISO 10218 defined safety measures internally built and it can be integrated into a process without causing harm to operating people around and does not need additional safety measures to comply with the safety requirements.

When discussing the strength of collaborative robots, according to Matúšová, M. Bučányová, M. & Hrušková, E. (2019), it comes from the flexibility and safety. Both internal and external experts confirm these statements describing cobots to be quick and effortless to integrate due to their small size and absence additional external safety measure installations. Consequently, cobots can be installed without further exertion into different postures while conventional robots always require careful evaluation especially in terms of installation bed. The biggest challenge integrating collaborative robots', according to all experts, arise from the concern of insufficient competence on a comprehensive workstation design. The issue is not directly related to the technology itself, but the experts highlighted that lack of competence on understanding especially the safety requirements which will create conditions that lead to inefficient application of the technology. At this stage, the technology loses its advantage. Furthermore, technological maturity of collaborative robots was identified as a limiting factor, and internal experts raised their concern that cobots are still in the middle of their technological development. They speculated, is it too early to invest for cobots at this stage and believe them to meet the expectations as following quote by one of the internal experts demonstrates:

> *"Cobots were branded and marketed as a miraculous solution with high expectations solving all assembly automation related problems, but the reality was quite different when the safety requirements revealed the true capacity of the technology"*

Even if the cobots have offered this type of image, according to the internal experts, cobots have still already exceeded certain expectation regarding for example the speed of development. They emphasized that cobots will have their place in industry and the amount of cobots will increase progressively in the near future. They saw also that in automobile assembly domains with the current maturity level of cobots the focus remains in processes with lower volumes and slower cycle time requirements.

When comparing conventional industrial robots with collaborative robots, both internal and external experts highlighted the differences on investment costs. Internal experts addressed the cobots as more expensive to invest in. They mentioned that the cost difference can vary from only a few percentages up to three times per device depending on the model and manufacturer. External experts however argued for the collaborative robots would become more cost-efficient option as the complete project and implementation costs will be taken into consideration. They highlighted that planning, ordering, and installing conventional robots' system will eventually come more expensive as the collaborative robots do not require external safety measures and thus consume less shop floor capacity as the conventional counterpart offering also indirect savings.

The first of the four evaluation criteria was the ability to comprehend process requirements. Process requirements consist of several factors, with quality and process capability standing out as the most critical ones. In automobile manufacturing, robust quality assurance is essential for maintaining low costs and product quality. (Monden, Y. & Ohno, T. 2011 p. 6) Experts identified only a few significant differences between collaborative robots and conventional robots in terms of quality yield capability. Both technologies are considerably precise and capable of achieving adequate quality output. As both technologies were considered equal on quality yield, experts were unanimous on cobots trailing on process capability capacity. It is an important performance indicator in automobile assembly to measure the capability of the line (Omar, M.A, 2011). If the technology does not meet the process capability requirements, it cannot align with process capacity and, therefore, is not considered a feasible solution. Then, an alternative solution should be considered. (Suomen Robotiikkayhdistys ry, 2023 p. 78-80) The basic characteristic of a cobot is the ability to operate without external safety measures which the conventional robot is not designed for. Due to those factors, the payload and velocity are reduced which directly reflects on the process capability. When discussing suitable tasks for cobots in terms of process capability in automobile assembly, experts offered operations with light parts and performed in a low pace best fit for collaborative robots. They also perceived the current case study assembly domain, being a low volume line, as a distinguishing platform for cobot integrations in automobile industry.

The second criteria, safety, fits well in this evaluation as collaborative robots are known for being safety intensive devices. (Matúšová, M. Bučányová, M. & Hrušková, E. 2019) To support this argument, both internal and external experts addressed safety as the most significant factor for collaborative robots compared to other similar applications. One of the external experts even explained the fundamental of collaborative robot design is reaching for ultimate safety operating with humans. The expert quoted as followed:

> *"First of all, the cobot is safer in terms of design and structure as it has been designed specifically with a rounded and in some cases with a soft exterior. Also, with the design all pinch points have been eliminated to avoid injuries."*

Also, both robots and cobots are capable of operating in collaborative systems offering an environment with enhanced ergonomics. However, without external safety measures robot systems will remain unprotected and risky for humans. Even with certain degree safety measures, according to experts, there is a possibility for human operators not fully operate simultaneously with the robots in shared workspace. Therefore, as the collaborative robot is inherently safer it has extended opportunity to operate fully with humans in shared workspace simultaneously.

If evaluating green impact of the collaborative robots, external experts wanted to clarify that only lightweight robots should be assessed when conducting the comparison as being even in size and other specifications. Otherwise, the green impact evaluation between cobots and robots might be irrelevant. Internal experts raised the importance of reusability. According to the technology waste is a significant concern, and reusability can mitigate the issue. The remobilization with effortless commissioning through reinstallation and reconfiguration provided evidence for cobots green impact over robots. The internal experts raised a concern with wearing out parts and ageing software. Are collaborative robots updatable or does extra safety features provide additional maintenance requirements?

As a final consideration, the experts pointed out that when assessing the benefits and challenges of a cobot, the opinion on negative and positive effects can be subjective. Selected technology should always serve the automated process and in this case, the optimal solution can vary between several different options. A noteworthy finding is that even within the automobile assembly process, there are several individual subsystems, processes, and tasks so a very precise comparison itself becomes difficult without a concrete context. Therefore, finding an optimal solution requires deep analysis of multiple variables case by case. Generally, collaborative robots have competitive advantage when searching automation for light tasks with moderately high cycle time requirements with minimal amount of external safety measures.

4.2.2 Evaluation on performance impact through predefined criteria

The intention of performance impact is to study the case assembly line and evaluate in which type of processes collaborative robots would provide the biggest positive impact in respect of the evaluation criteria defined, process capabilities, quality, safety and ergonomics, and green impact. This subchapter describes the findings similarly by presenting findings collected from interviews. Same internal and external interviewees were exploited, and interview questions are presented in chapter 3.1.5. Additionally, to these four experts, another internal expert was involved to get deeper insight of the assembly line tasks and to exploit the knowledge of the end user.

When considering the performance impact of collaborative robots, especially in automobile assembly, all experts addressed the similar question: what added value is achieved by automating the processes with collaborative robots? Performance impact evaluation was reviewed through the concept of added value into the process. The evaluation was carried out through four criteria. It was interesting to see divergence in answers when discussed biggest impact compared to assessment in the last chapter.

As discussing on process capabilities, internal engineering experts considered that the cobots do not improve the process capability significantly or at all. They argued that the volume and the cycle time is too low as the benefit is there lost. The real benefits on the other hand could be found in a high-volume process. They then considered the performance impact advantage coming from other attributes. In contrast, the production supervisor emphasized that if the same output is reached with less human resources, the process capability increases. The external experts searched for different angles on this topic. They emphasized the significance of finding the right tasks for the right technology and highlighted that in terms of process capability, it might not be feasible to fully automate processes but rather allocate correct tasks for correct resource. By then benefits of resource utilization are maximized and process capability to be improved. Unfortunately, experts could not provide real life examples on which tasks could directly improve the process capabilities but offered the concept where process capabilities could be improved.

From the perspective of quality capacity, the experts gave direct examples of tasks where the technology is seen feasible and have a significant impact on performance. According to experts, cobots are capable of maintaining quality both directly and indirectly. The internal experts raise up tasks where an operator has difficulties producing a standardized procedure directly impact the quality. Tasks such as adhesive insertion, windshield or glass installations, or similar tasks where certain parameters need to remain stable are prominent case examples. In adhesive insertion the precision and stability of the movement was key according to the internal experts. Therefore, cobots could maintain this process stable better than human operator. The windshield or glass installations require stable force generation. According to the internal experts, if applied manually, actual forces applied cannot be traced. Indirect quality impact considers all checks and measurement activities that requires documentation. These types of tasks are visual checks, different measurements, and fastening activities. Experts aligned with the statement that although a human is capable of executing these types of tasks, over time human lose consistency and precision whereas cobot does not. In terms of traceability, all activities executed by cobot can be documented and therefore traced back to its origin if needed. This was considered as a great impact based on the answers by the internal experts.

The experts offered various examples where cobots could have a great impact on safety and ergonomics of shop floor operators. Cobots could improve both factors by assisting in various tasks where operators have a difficult assembly posture especially with heavy or relevantly large instruments and parts. or repetitive task routine. A monotonous process with repetitive task routine was recognized by the experts as the biggest threat to cognitive ergonomics. It was seen beneficial that by eliminating the stressful tasks for body and also for mind, sick leaves could be prevented. Especially activities inside the car body stressful significantly stressful for the physical ergonomics perspective. According to the interviewed production supervisor, there are very few tasks which by replacing could positively affect cognitive ergonomics as the low volume line offers variative tasks. Then operators obtain a balanced working environment with proper level of cognitively challenging tasks. As internal experts were keen to discuss the ergonomic impact of the cobots, only external experts were able to identify value-adding features in terms of safety. According to the externals, if considering a human centric assembly process as a system level, each individual is a variable. Despite guidelines, instructions, rules, and legislation humans have individual behaviour and this random behaviour can derive into a safety risk. External experts saw this as a possibility to enhance safety by stabilizing the environment where tasks are performed always in a standardized manner which reduces the number of unexcepted variables and increases the ability for predicating the environmental risks on safety.

The performance impact on moving towards more sustainable ways to work can be referred to in this chapter as green impacts of the collaborative robots. External experts provided insight into their product development process and how they have taken sustainability and green impact into account. The first step is to provide extended information to the customers of the life cycle assessment of the devices. Thus, the customer can make more transparent analysis on the products. The manufacturers have started to focus on energy consumption and production material reduction. Notable is that these does not only consider cobots but all the robots provided by the organization. Internal experts did not see any direct impact on the cobot integration. They were aligned with the argument that a major part of the green impact is on the product life cycle management.

Lastly, it is valuable to discuss separately one individual task type which was raised in almost every criterion and thus it needs to be considered as a separate point. Experts were all aligned with that by automating fastening tasks. According to them, the carefully considered and high-quality automation design of fastening tasks could have large impact on the ability of the process capabilities, produce better quality, and enable improved ergonomics. To maximize the benefit, the expert perceived the fastening task to be conducted in conjunction between cobot and the human operator.

4.3 Thematic analysis to establish utilization evaluation

Thematic analysis is founded around the formulative themes derived from the interests of the research or data. Inductive thematic analysis search patterned themes from the source material and formulate a comprehensive analysis based on only acquired data within the research. Deductive thematic analysis establishes the themes beforehand to bind the analysis within that framework. The identification of patterns and themes is referred to as coding and it is a key characteristic of thematic analysis. (Braun, V. & Clarke, V. 2006) As this research is a deductive study, the coding should be carried out before the analysis. To reach the goal of utilization evaluation for understanding of overall benefits and challenges for cobot deployment, the codes should comprehend with the study objectives (Hartelt, R. Wohlfeil, F.& Terezidis, O. 2015). Therefore, the keywords of the study can be effectively utilized as the codes of the analysis. The analysis will be carried out through the keywords by firstly defining and understanding the main characteristics of the researched system. Only after defining the system, analysis will delve deeper into human robot collaboration and factors which enable collaborative robots to thrive in the discussed assembly domain. Thereafter, a proper conclusion can be made. Main principle is not to repeat and summarize once discussed topics but establish a holistic image of possibilities and challenges of collaborative robotics in automobile assembly domain.

Human centric assembly line

Collaboration in industrial domain is built around human centricity as collaborative actions require a human for either acting with humans or with machines in this case. The manufacturing processes can be perceived as fully automated without any human activities. After placing a human in the center of a process, it immediately changes the domain by extending the focus from considering not only process and quality capabilities to but to think both safety and ergonomics too. (Lachvajderova, L et. al. 2023) It is essential to distinguish prerequisites of human centricity when beginning a collaborative process concept design. In a system level, humans should be seen as a valuable resource and value adding components in the process, despite the belief for being a less value adding component in industry. Although it requires additional effort on design level, an effective human centric system level design might lead to reducing head count in certain processes, by optimizing task allocation, proper process engineering, and cost-benefit analysis. However, after proper analysis, some processes might still appear more feasible for humans to operate, and the most efficient option is to allocate resources to the execute the process. In the end, through a poor process design, some automated processes will lose their efficiency as well. Consequently, a human centric assembly line is an effective system providing value by balancing the quality and capacity. This system can be a human intensive system or highly automated system, but ultimately it needs to be designed so that exploiting human labour is as efficient as possible.

Automobile manufacturing

Automobile manufacturing aims to assemble a complete vehicle from different individual parts as efficiently and as high quality as possible. The three-part manufacturing system varies from shop to shop based on their basic characteristics. (Omar, A. 2011) Assembly line is the most diverse process with numerous individual tasks performed in a high paced environment where tasks are focused on assembling and installing different parts and components. Also, screwing and fastening is widely utilized method to install the parts to the car frame. Automobile manufacturing is phasing the increased degree of mass customization which has led to complex products and processes. These types of processes require a high-level human centricity. Western OEM's has pursuit to improve human efficiency by involving the in decision making, improving their ergonomic conditions, and working environment.

The automobile manufacturing industry is known for the high competition. To gain competitive advantage within that industry, a high level of efficiency, and quality capacity should be achieved. The improved efficiency is searched in every process and especially through human robot collaboration from the assembly line in terms of automation as other shops are less human intensive and highly automated. The current assembly process is limited with opportunities in regards of automation as the mass customization has led to a high product and process complexity, which remain as the limiting factors for automation. Also, demanding cycle time, safety requirements, and reduced shopfloor capacity prevents full process automation in assembly domain. The automobile assembly process together with subassemblies contains almost 2000 individual tasks only for a single product. Among these 2000 tasks at least 400 of them are to some degree suitable for robotization. By robotizing all tasks 400 tasks is not possible as not all tasks within a workstation or assembly phase share similar characteristics. For successful workstation automation, collaboration between human and robot needs to be hen considered as humans cannot be removed out of the scope. This requires human robot collaboration to successfully fulfil the challenges depending on the cycle time, safety, and shop floor capacity.

Human robot collaboration

Automobile assembly systems, with their human centric characteristics, are difficult domains for increasing automation. As stated, limited shop floor capacity, unsuitable tasks, and strict safety regulations are very demanding towards process and manufacturing engineers. Human robot collaboration can be considered as a catalyst for change in this regard (Bauer, W et. al. 2016). HRCS taxonomy offers variative different platforms where humans and robots can work collaboratively which serves both issues the human centricity and process capabilities.

In automobile assembly domain, the pool of tasks is enormous and thus, there are numerous possibilities for collaborative applications. Ultimately it depends on the cumulative effect on the task allocation and technology utilization. Therefore, a human robot collaboration as its best can yield beneficial results in various terms. Human robot collaboration taxonomy offers possibility for applying different collaborative forms based on the considered task and technology.

As for the automobile assembly system, the product and process design establish the framework for task requirements. Ultimately, the technological capabilities of the applied devices should comprehend with these requirements. Nonetheless, the designed and implemented system must be first of all safe, yet efficient. Safety in automobile assembly workstation is an essential factor as human operators perform tasks there continuously. As in human centric assembly systems, the tasks of human operators are prioritized and after other possibilities could be investigated. Lightweight robots can be seen as prominent applications for executing tasks within the assembly line together with operator due to their size. Nevertheless, robots always require external safety measures to comprehend safety regulations and standards. This puts pressure on limited shopfloor capacity and limits the possibility for humans operating simultaneously in the workstation with the robot. Collaborative robots have the potential to thrive in this type of environment as promoting safety and ergonomics with inherently designed features.

Collaborative robots

The integration of collaborative robots (cobots) into automobile manufacturing processes has created new opportunities by offering a versatile and efficient solution to automate various tasks that was not possible previously to be automated. Collaborative robots entail internal safety measures and thus can directly comply with the safety standards and embrace safety with additional safety features related for example to the exterior design. Also, offering a possibility for mobilization together with the absence of heavy safety measures, collaborative robots can appear inviting for implementation when workstations can remain open for operators to complete their tasks simultaneously with cobots. Simultaneously shop floor capacity can be preserved. The determination of cobot feasibility for specific tasks necessitated a comprehensive examination of both task requirements and technological capabilities.

According to the findings of this study, despite its reduced capabilities, collaborative robot as a technology has turned out as a prominent attributor for executing different tasks in a human robot collaborative system (HRCS). Cobots have vast opportunities to operate in automobile assembly as significant contributors claiming responsibility for light, simple, and mostly repetitive tasks that require maintaining a stable process. Fastening, quality inspections, and moving and placing the parts can be perceived as he most prominent applications for cobots. These activities allow them to leverage their strengths. Common factors for these tasks were the lightweight parts, exploited tools, repetitive and monotonous characteristics, and documentation requirement. In addition, most of the fastening or inspections tasks were either dual or multi-level tasks. By automating the one step in dual or multi-level tasks, human resources can be freed for other activities or assigned workstation activities can be executed with fewer resources. Freeing humans from monotonous and repetitive tasks has a big impact on especially from the perspective of physical and cognitive ergonomics.

Through literature review, task-technology comparison, and interviews a holistic understanding of collaborative robots' opportunities and challenges was possible to be established. To bring all the knowledge together in summarized and illustrative format, SWOT (strengths, weaknesses, opportunities, and threats) analysis was conducted. In a SWOT analysis, a four-quadrant grid is utilized based on the word: strengths, weaknesses, opportunities, and threats. These quadrants are further split into internal factors (strengths and weaknesses) and external factors (opportunities and threats). (Inyang, E. 2017 p. 38 & 128)

Strengths	**Weaknesses**
Opportunities	**Threats**

Figure 8 Illustration of SWOT analysis matrix (Inyang, E. 2017 p. 38 & 128)

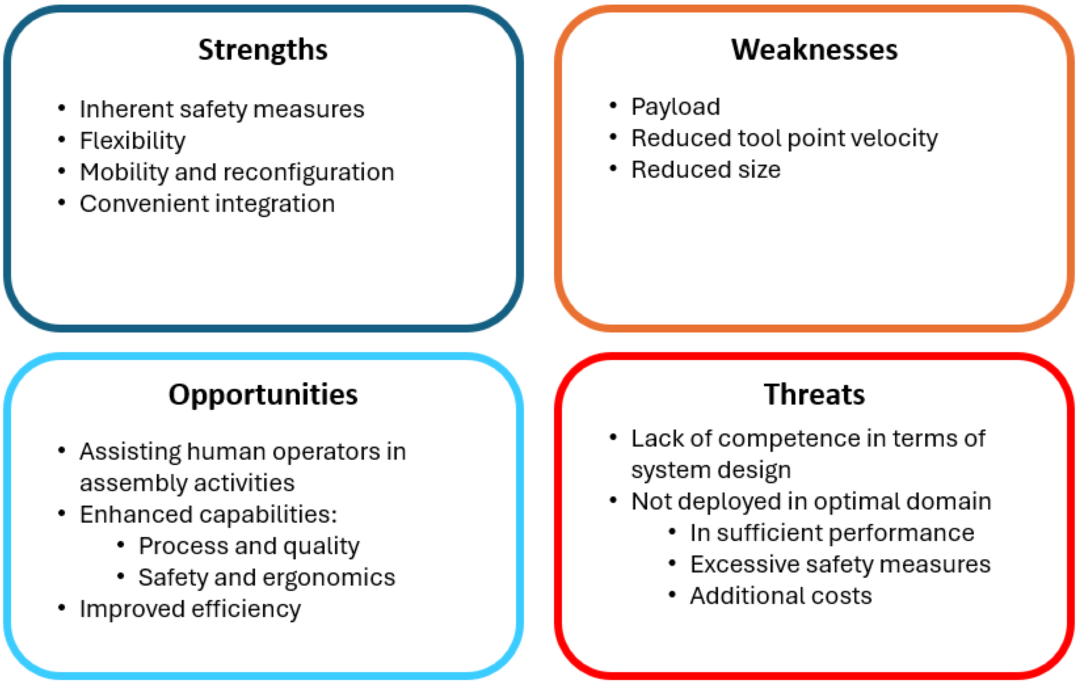
One of the key strengths of cobots is the flexibility which. Flexibility comes to the capability for feasible reconfiguration which means that cobots can be easily relocated or adjusted to new tasks conveniently. They are also very convenient for integration into existing systems and processes. In addition, inherent safety measures enable cobots to work alongside human operators without extended safety measures. These strengths collectively make cobots a valuable asset in automobile manufacturing.

Despite their many strengths, cobots, like every technology, has their weaknesses. The biggest weakness is the reduced operating capability in terms of payload and velocity.

Compared to conventional robots, cobots are designed to handle lighter parts, which directly prevents them executing certain tasks and limits the number of applications it can be exploited. Especially in automobile assembly where parts can be relatively heavy, it is a huge limitation. Another weakness is their reduced velocity. Cobots needs to operate at slower speed when working alongside human operators. This reduced speed leads to the situation where cobots can compromise the process capability. One particular attribute that has not been discussed properly is the reach. Especially when working in a car interior reach becomes crucial attribute. Considering current technology discussed, in categories 1 and 2 have relevantly short reach and it is hard to see the devices with lowest range of reach operate with interior tasks.

Cobots have significant opportunities for enhancing efficiency, productivity, and ergonomics. Working alongside humans in collaborative environment remains the biggest opportunity of technology discussed. Cobots are considered to execute tasks independently but also with humans assisting executing main tasks within the assembly line. By handling subtasks in a dual level task, cobots can release resources enabling reallocation of operators to execute assembly tasks where they are essentially needed. In conclusion, a well implemented cobot improves process efficiency and quality together with ergonomics. Typically, this will be achieved when they operate alongside with humans. The cobot could carry the bigger ergonomic load of the tasks and provide enhanced quality and efficiency by maintaining stable process.

Lastly, like any technology, cobots also present potential threats. A significant threat for successful cobot exploitation is the lack of competence in system design. Without understanding all the requirements and capabilities of cobots, the risk of deploying a cobot insufficiently can lead to using the technology in a suboptimal domain. If cobots are deployed in settings that do not match with their capabilities, the competence of the technology is compromised and misused. This misalignment can lead to insufficient performance and integration of unwanted additional safety measures. The threats take on greater significance as conventional lightweight robots compete with them. As collaborative robots become more expensive as an individual device, if implemented incorrectly and system level enhancements, such as external safety measures are needed, collaborative robots lose their advantage. This type of lack of competence might lead to repelling the technology and not being able to harness the full potential of the it in a system level. If cobots are integrated and utilized properly, the biggest threats can be avoided.



Strengths

- Inherent safety measures
- Flexibility
- Mobility and reconfiguration
- Convenient integration

Weaknesses

- Payload
- Reduced tool point velocity
- Reduced size

Opportunities

- Assisting human operators in assembly activities
- Enhanced capabilities:
  - Process and quality
  - Safety and ergonomics
- Improved efficiency

Threats

- Lack of competence in terms of system design
- Not deployed in optimal domain
  - In sufficient performance
  - Excessive safety measures
  - Additional costs

Figure 9 SWOT analysis for collaborative robots in automobile assembly

5 Conclusion

This concluding chapter provides a comprehensive wrap-up of the thesis by presenting a summary, addressing the research questions, and outlining opportunities for future research. Firstly, the summary briefly revisits the key objectives, methodologies, and findings of the study, offering a prominent overview of the complete thesis. The conclusion then evaluates the results in the context of the research questions by utilizing main insights from the analysis. Finally, the future research section proposes areas for further investigation, highlighting potential topics and directions that could benefit both academic research and industrial applications within the case company.

5.1 Summary

The main objective and the research question of the study was to discover opportunities and challenges of collaborative robots in a human centric automobile assembly domain by investigating contemporary cobot technology and assessing their capabilities in a holistic perspective. In order to answer the research question, the study came up with the following three main objectives:

1. To identify contemporary collaborative robot technologies suitable for an automobile assembly line.
2. To identify key factors, criteria and challenges that influence collaborative robot integration to a human-centric assembly.
3. To discover the benefits that collaborative robots can provide for the automobile assembly process.

As a summary, chapter 2 provided a literature review for establishing solid foundation for empirical study to understand a human centric automobile assembly system, human robot collaboration, and basic principles of collaborative robots. This chapter gave general understanding of how automobile assembly systems operate, what are the main components of the system and what are the characteristics for automobile assembly tasks. It focused also on explaining the basic principles of human robot collaboration and describing different forms of it in terms of taxonomical categories. This review opened up the correlation between the requirements of human centric assembly system and human robot collaboration. Lastly in literature review the collaborative robots were investigated by trying to understand cobots, their capabilities, benefits and challenges through existing research. Also, workstation cobotization was reviewed for initializing the discussion in empirical study.

Chapter 3 presented the research methods for the empirical part of the study. The study obtained a deductive approach by utilizing a theoretical framework of task technology fit (TTF). The main tested hyphothesis of the deductive study was that integrating collaborative robots will derive improvements in productivity and quality together with safety and ergonomics within automobile assembly domain. To test this, a six-step approach was applied to compare the technological capabilities of cobots to automobile task requirements, assess the technology to a prominent alternative option, and conducting a utilization evaluation. Lastly, the validity and reliability of the study was discussed first by defining the validity and reliability in research and then reflecting them to the study's targets and methods.

Chapter 4 presented the results and analysis of the empirical findings. The main structure of the chapter follows the principle of TTF. The first part of the chapter represented the first two steps of TTF approach providing the results on technological and task attributes and comparing them together. The main target was to discover contemporary cobot technology capabilities, assess suitable tasks for cobotization, and conduct feasibility assessment by comparing the task and technology attributes together. The second part of the chapter represented the steps of 3, 4, and 5 by setting the evaluation criteria, conducting technological assessment, and evaluation performance impact through these criteria. This was conducted through interviews with experts internally and externally. The interviews gave a profound understanding of the strengths and weaknesses of collaborative robots and where they can be utilized with biggest impact in terms of improved process capabilities, safety and ergonomics, quality, and green impact. The last part of the chapter brought empirical findings alongside the literature review providing the targeted holistic review on the topic. It was carried through with thematic analysis by using keywords as the theme codes, supported by SWOT analysis to summarize the strengths, weaknesses, opportunities, and threats.

5.2 Findings

The study set three clear research objectives to get the answer for one main research question. The key goal was to find opportunities and challenges of collaborative robots in a human-centric automobile assembly line and by getting there, study required to identify contemporary available technology, suitable for automobile assembly tasks. Then come up with key factors, criteria, and challenges for cobot integration into human centric assembly system. Lastly, to understand the benefits for collaborative robots.

The task technology fit (TTF) was a prominent tool for establishing firstly identify the contemporary technological attributes, and secondly test the feasibility of the technology in a human centric automobile assembly domain. Despite TTF sitting well for holistic approach, it appeared a moderately difficult apply especially with large and scattered dataset. As the data set was incomplete and partly classified, the importance of interviews grew to get valid and reliable study results. While the study successfully addressed the research question and achieved its objectives, certain challenges such as the incomplete and classified nature of the dataset and highlight areas where further work is needed to ensure greater robustness.

The study identified and presented contemporary collaborative robot technologies and tested their feasibility in automobile assembly system. As a result, all categories were seen feasible for integrating to automobile assembly line, but from a holistic perspective only category 3 devices were comprehend fulfil all established criteria for the technology. The second objective was to identify these criteria, factors, and challenges which will affect the integration decision. The criteria were set by the TTF methodology and key factors and challenges were identified within the SWOT analysis. The biggest challenge is the reduced capabilities in terms of payload, speed, and reach. Lastly, the benefits of collaborative robots were to be discovered. The study detected the benefits through literature review and empirical study by generally understand the benefits and then narrow the scope to the automobile assembly line within the case company. The benefits are found from the inherent safety features and light and flexible deployment.

Even though the targets were achieved, the study's external validity in terms of generality can be considered challenging. A strongly limited and case specific research considered only a single product low volume assembly line within a one particular case company. Also, purposefully only qualitative methods were exploited as it aligned well with the holistic framework. As the result, the topic should be further investigated with quantitative methods and expand to different externally within the industry and internally within the case company because the external validity will remain low even though interviews, especially with the external experts, attempted to enhanced it.

In conclusion, collaborative robots are flexible devices with inherent safety features. They are much effortless to deploy compared to conventional robots. The most feasible tasks for cobots are the repeatable, monotonous, precision intense, and ergonomically challenging tasks which can be performed with moderately low payload and speed capabilities. In automobile assembly systems, these task types are typically fastening, quality inspection, placing and sifting. The biggest challenges of cobots comes from their reduced size and capabilities as a compromise for the inherent safety features. Cobots are not capable of handling heavier parts and also are sensitive to external disturbances which have a direct impact on the assembly process capability in terms of uptime. In respect to conventional lightweight industrial robots, cobots lose their competitive advantage if external safety measures need to be applied. Therefore, an optimal domain for cobots to operate in a human-centric automobile assembly are together with humans without heavy external safety measures, performing tasks independently or together with the human operator.

5.3 Future research

This section outlines potential areas for future research based on the findings and limitations of this study. While the results offer valuable insights, they also reveal gaps and opportunities for further investigation and research. This chapter addresses these areas from the author's perception which could be beneficial to be investigated and applied in academia and in industry.

Future research within the case company should take lessons learned from this study and advance to a case-level investigation. The primary goal could be to enhance the understanding of human-robot collaboration system design and the effective deployment of cobots. It is recommended that the company focuses on identifying specific processes for deeper analysis. By leveraging the knowledge gained in this study, the company can then work on integration projects within the assembly domain, aiming to conduct thorough workstation evaluations and assess the potential for efficient utilization of cobots.

The scope of this study was limited to a low-volume assembly line with relatively low takt time requirements, which may not fully reflect the challenges in high-volume automobile assembly environment. Therefore, future research could extend the analysis to high-volume lines with stricter requirements on takt time and uptime. It also requires much more rosources for a one station. In high-volume line, the task characteristics can also come up with different opportunities and constraints for cobot integration. In addition, finishing line activities were excluded from this study as they were part of the mixed-model line. From the finishing line there could rise prominent use cases for deeper understanding of the assembly as a whole. According to the author's perception based on this study and observation within the case company, the main impact on process attributes and task requirements appears to be more significant than the differences between single-model and mixed-model lines. Although mixed-model lines were outside the study's scope, they were observed to have minimal process variation compared to single-model lines, with differences primarily arising from individual processes.

Consequently, at a holistic level, the broader impact of mixed-model production is limited, suggesting that future research should focus instead on specific process attributes and task requirements.

Lastly this study did not consider task characteristics from a product and part design aspects of automobile manufacturing. Designing a part or product has significant impact on the manufacturability of the part which could the play a crucial role in HRCS domain. If the investigation is started the from product design table instead of manufacturing engineering design table, assembly tasks could be adjusted to suit better collaborative actions, potentially improving efficiency and integration outcomes. Although part design was not explored in this research, it is an intriguing area for future investigation.

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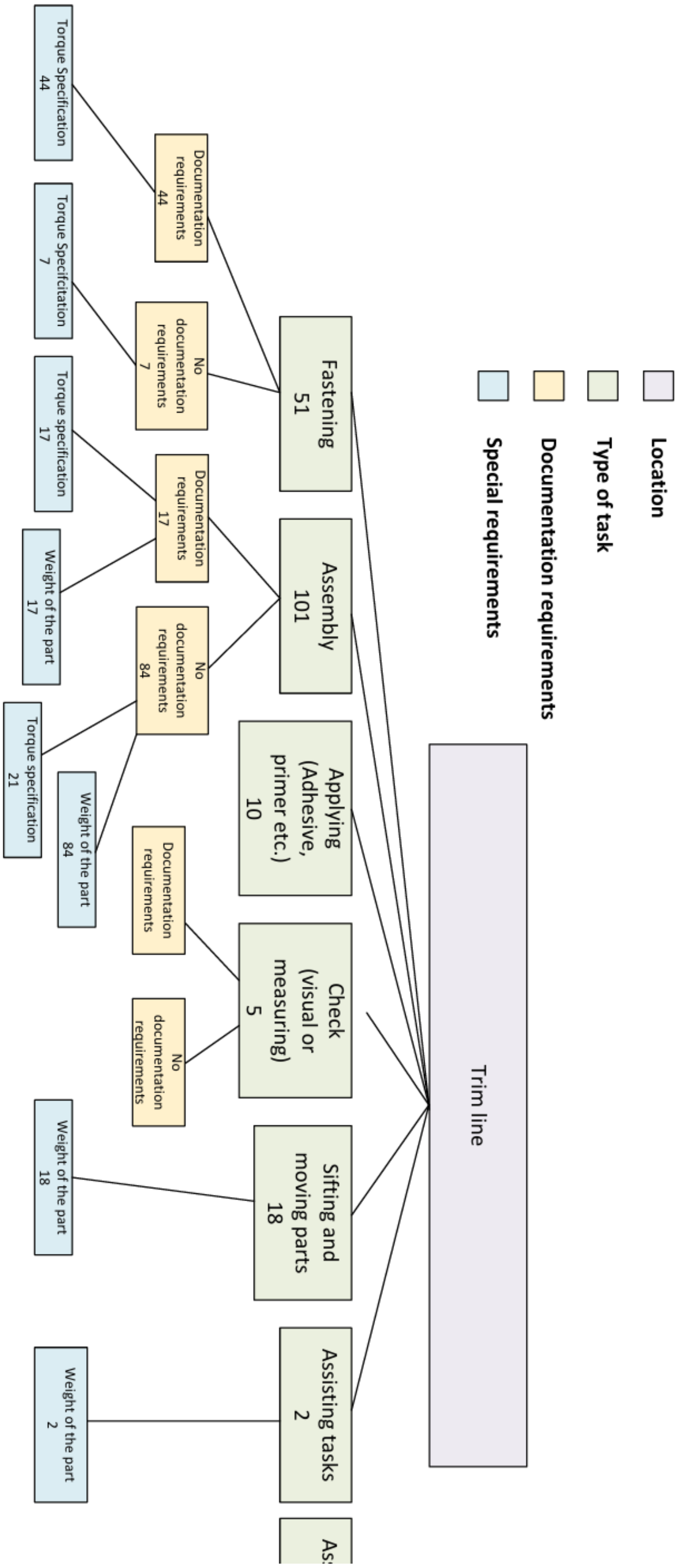
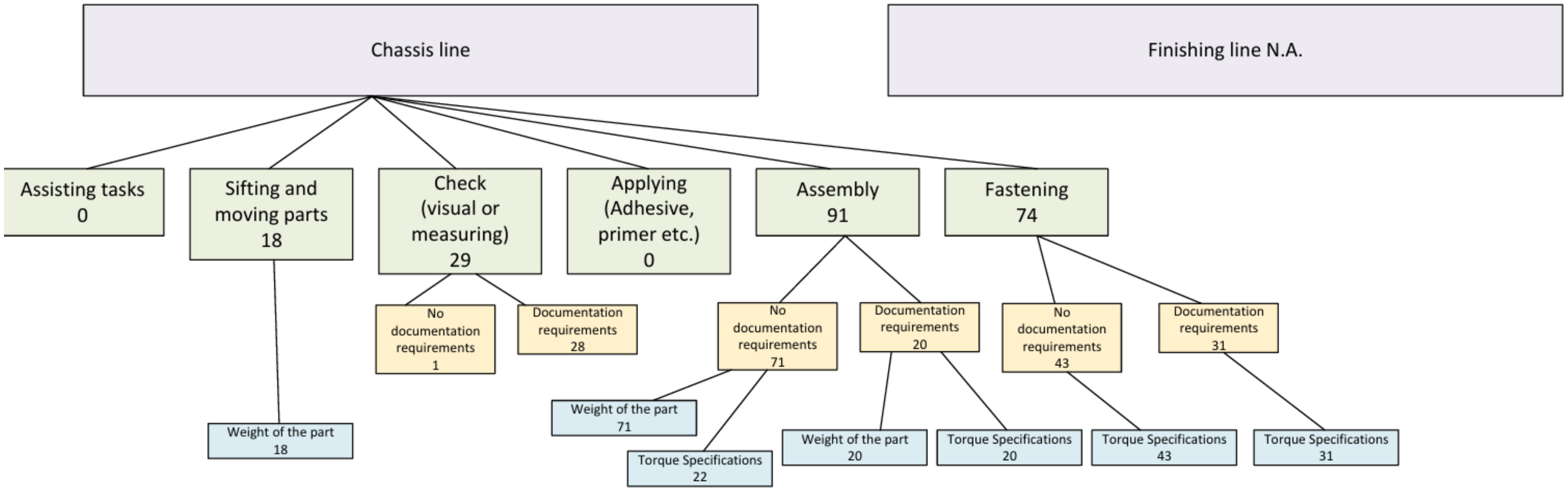
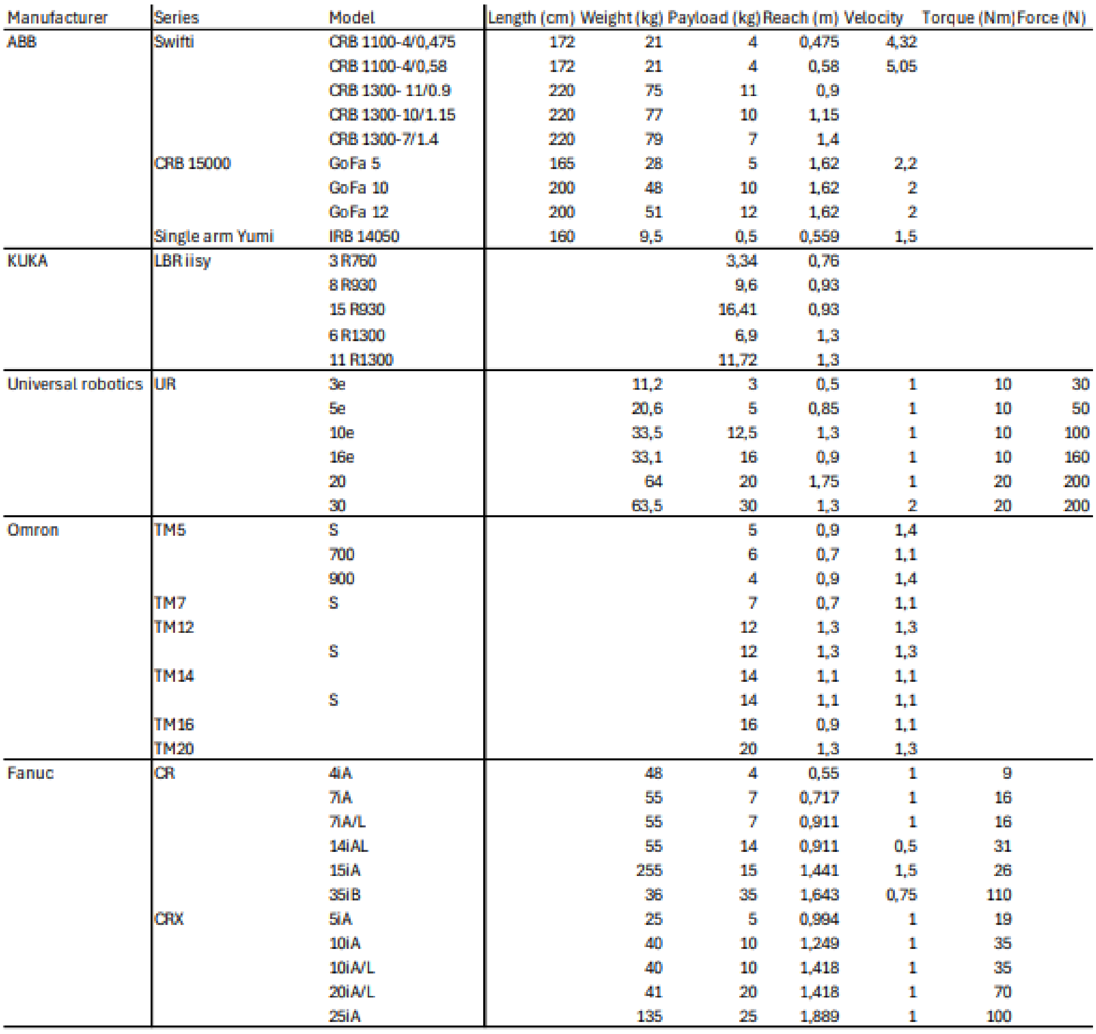
Appendices

Appendix 1 Nested categorization




Chassis line
Finishing line N.A.
Assisting tasks
0
Sifting and moving parts
18
Check (visual or measuring)
29
Applying (Adhesive, primer etc.)
0
Assembly
91
Fastening
74
Weight of the part
18
No documentation requirements
1
Documentation requirements
28
No documentation requirements
71
Documentation requirements
20
No documentation requirements
43
Documentation requirements
31
Weight of the part
71
Torque Specifications
22
Weight of the part
20
Torque Specifications
20
Torque Specifications
43
Torque Specifications
31

Appendix 2 Collaborative robot attribute data



Manufacturer	Series	Model	Length (cm)	Weight (kg)	Payload (kg)	Reach (m)	Velocity	Torque (Nm)	Force (N)
ABB	Swifti	CRB 1100-4/0,475	172	21	4	0,475	4,32		
		CRB 1100-4/0,58	172	21	4	0,58	5,05		
		CRB 1300- 11/0.9	220	75	11	0,9			
		CRB 1300-10/1.15	220	77	10	1,15			
		CRB 1300-7/1.4	220	79	7	1,4			
	CRB 15000	GoFa 5	165	28	5	1,62	2,2		
		GoFa 10	200	48	10	1,62	2		
		GoFa 12	200	51	12	1,62	2		
	Single arm Yumi	IRB 14050	160	9,5	0,5	0,559	1,5		
KUKA	LBR iisy	3 R760			3,34	0,76			
		8 R930			9,6	0,93			
		15 R930			16,41	0,93			
		6 R1300			6,9	1,3			
		11 R1300			11,72	1,3			
Universal robotics	UR	3e		11,2	3	0,5	1	10	30
		5e		20,6	5	0,85	1	10	50
		10e		33,5	12,5	1,3	1	10	100
		16e		33,1	16	0,9	1	10	160
		20		64	20	1,75	1	20	200
		30		63,5	30	1,3	2	20	200
Omron	TM5	S			5	0,9	1,4		
		700			6	0,7	1,1		
		900			4	0,9	1,4		
	TM7	S			7	0,7	1,1		
	TM12				12	1,3	1,3		
		S			12	1,3	1,3		
	TM14				14	1,1	1,1		
		S			14	1,1	1,1		
	TM16				16	0,9	1,1		
	TM20				20	1,3	1,3		
Fanuc	CR	4iA		48	4	0,55	1	9	
		7iA		55	7	0,717	1	16	
		7iA/L		55	7	0,911	1	16	
		14iAL		55	14	0,911	0,5	31	
		15iA		255	15	1,441	1,5	26	
		35iB		36	35	1,643	0,75	110	
	CRX	5iA		25	5	0,994	1	19	
		10iA		40	10	1,249	1	35	
		10iA/L		40	10	1,418	1	35	
		20iA/L		41	20	1,418	1	70	
		25iA		135	25	1,889	1	100	

Appendix 3 Interview notes

Haastattelu 14.5.2024

XX.XX Production Supervisor

Otto Runola haastattelija

Haastattelu toteutettiin tuotannon esihenkilön kanssa. yhteistyörobottien implementoinnin vaikutuksia teoreettisessa kontekstissa. Tarkoituksena oli pohtia missä kohtaa prosessia, mitä työtehtäviä suorittaessaan ja millä perustein yhteistyörobotilla on suurin vaikutus perustuen tutkimuksen kriteeristöön: (process capability, quality, safety and ergonomics, and greenimpact). Haastattelu oli semi-strukturoitu ja se rakentui alla olevin kysymysten ympärille, mutta keskustelu oli vapaamuotoista

1. Jos yhteistyörobotti implementoidaan tapauksen kokoonpanolinjalle, mitkä ovat ne prosessin vaiheet ja työtehtävät, joilla on suurin vaikutus alla oleviin kriteereihin:
    a. Prosessin kyvykkyyteen
    b. Laatuun
    c. Turvallisuuteen ja ergonomiaan
    d. Green impact

Yhteenveto haastattelusta:

1. Haastattelija esitteli työn aiheen, taustan sekä tutkimusmenetelmät, jonka jälkeen hän kävi läpi haastattelun kulun ja tavoitteet.
2. Haastattelua ei nauhoitettu, mutta dokumentoitiin muistiinpanoin
3. Yhteenveto:

    Prosessin kyvykkyyksien kannalta on merkityksellistä ymmärtää mitä automatisoinnilla saavutetaan. Lähtökohtaisesti tahtiaika määrittää linjan tavoitteellisen suorituskyvyn. Tällöin mitä vähemmän pystytään käyttämää ihmisten tekemää työtä autoa kohden samalla päästen tahtiaikaan sitä tuottavampi ja kyvykkäämpi prosessi on. Siksi asiantuntija nostaa esille tehtävät, jotka ovat ihmiskeskeisiä, mutta mahdollisesti suoritettavissa cobotilla. Näitä ovat muun muassa marriage point sekä lasisolu.

    Asiantuntijan oli vaikea arvioida laaduntuottokykyä edistäviä tekijöitä tuotantolinjalla, mutta hän nosti esiin prosessin, jossa on tärkeää, että voimantuottokyky pysyy vakiona koko työn ajan. Ihmisen tuottama epätasainen voima prosessin ajan johtaa laatuvirheisiin ja sitä kautta kasvaneeseen korjaustarpeeseen.

    Turvallisuutta ja ergonomiaa käsiteltäessä suurin painoarvo nähtiin fyysisessä ergonomiassa. Pienvolyymi linjalla kognitiivisen ergonomian taso on hyvä johtuen vaihtelevasta työstä useiden eri tuotevarianttien ansiosta. Siksi kyseiseltä linjalla suoritetut tehtävät eivät kuormita kognitiivisesti yhtä paljon kuin linjalla, jossa volyymit ovat korkeita. Fyysisesti taas tehtävät joissa siirretään, käsitellään, nostetaan tai asennetaan painavia osia tai huonossa asennossa ovat fyysisesti kuormittavia. Näiden cobotisoinnista kokonaan tai osittain olisi iso hyöty asiantuntijan mukaan linjan ergonomiselle kehitykselle.

    Green impact kohdalla asiantuntija ei nähnyt coboteilla suoraa vaikutusta.

Haastattelu 20.5.2024

XX.XX Lead Project Engineer, Advanced Engineering

XX.XX ME Lead Project Engineer, General Assembly

Otto Runola haastattelija

Haastattelu toteutettiin kahdessa osassa. Ensimmäisessä osassa tarkasteltiin kriittisesti yhteistyörobottien mahdollisuuksia neljän kriteerin kautta (process capability, quality, safety and ergonomics, and greenimpact). Haastattelu toteutettiin semi-strukturoituna, jolloin keskustelu oli vapaamuotoista, mutta rakentui alla olevin kysymysten ympärille:

1. Mitkä ovat yhteistyörobottien yleisimmät hyödyt ja haitat autoteollisuuden kokoonpanotuotannon näkökulmasta?
2. Vertailtaessa yhteistyörobotteja (cobotteja) teollisuusrobotteihin, missä tilanteissa yhteistyörobotit näyttäytyvät edukseen ja milloin teollisuusrobotti on kannattavampi vaihtiehto tarkasteltaessa asiaa seuraavien kriteerien kautta:
    a. Prosessin kyvykkyyteen
    b. Laatuun
    c. Turvallisuuteen ja ergonomiaan
    d. Green impact

Haastattelun toisessa osassa suoritettiin yhteistyörobottien implementoinnin vaikutusarviointi teoreettisessa kontekstissa. Tämäkin osuus toteutettiin semi-struktuurisena haastatteluna, jonka runkona toimi seuraavat kysymykset:

1. Ottaen huomioon edellisessä kohdassa tehdyt huomiot, minkälaisiin tehtäviin yhteistyörobotit soveltuvat parhaiten ja kuinka suuri vaikutus sillä on alla oleviin kriteereihin:
    a. Prosessin kyvykkyyteen
    b. Laatuun
    c. Turvallisuuteen ja ergonomiaan
    d. Green impact

Yhteenveto haastattelusta:

1. Haastattelija esitteli työn aiheen, taustan sekä tutkimusmenetelmät, jonka jälkeen hän kävi läpi haastattelun kulun ja tavoitteet.
2. Haastattelu nauhoitettiin
3. Ensimmäinen osa:

    Negatiivisiksi ominaisuuksiksi lausuttiin nopeus sekä voima. Lisäksi cobottien hinta nähtiin vaikuttavan negatiivisesti. Asiantuntijoiden mukaan hinnat vaihtelevat eri mallien välillä valmistajista riippuen marginaalisista eroista aina kolmin kertaiseen hintaan robotteihin verrattuna. Positiivisiksi ominaisuuksiksi lausuttiin laitteen siro ulkomuoto ja mahdollisuus työskennellä ihmisen kanssa linjalla ilman isompia turvajärjestelyjä. Ongelmana asiantuntijat näkivät kuitenkin sen, että merkityksellistä ei ole se onko cobotti itsessään turvallinen vaan kokonaisuus ratkaisee, esimerkiksi cobottiin kiinni tulevan työkalu turvallinen ihmiselle, joka toimii toimia samassa tilassa cobotin kanssa. Yhteistyörobottia pidettiin myös joustavana sillä se on liikuteltavissa ja se pystytään asentamaan useaan eri asentoon kuten ilman, että asento on ennakolta tarkoin määritely.

Haastateltavien mukaan cobottien kehitys on vielä kesken, ja käytännön ratkaisut kokoonpanotoiminnassa ovat tällä hetkellä hyvin rajattuja. Cobotteja on lähivuosina markkinoitu ankarasti, mutta käytännössä ne eivät ole yltäneet kyvykkyyksiltään asiantuntijoiden mielestä vaadittavalle tasolle. He sanovatkin cobotin teknologiana olevan innovaatiokäyrän pohjalla, mutta odotettavissa on, että teknologian kehittyessä se löytää paikkansa paremmin kokoonpanotuotannossa. Vaikka cobotti on hitaampi kuin normaali robotti, pienvolyymisella linjalla sen ei pitäisi olla este vaan etu, sillä turvalaitteiden tai aitojen rakennuttaminen syö lattiapinta-alaa ja vähentää linjan joustavuutta.

Prosessin kyvykkyyden kannalta merkittävä tekijä on cobotin kantokyky. Autoteollisuudessa osat ovat suhteellisen painavia ja suurin prosessia rajoittava tekijäksi muodostuu cobotin kyvykkyys kannatella osia, työkaluja tai niiden yhdistelmiä. Siksi cobotit kannattaa sijoittaa suorittamaan kevyitä tehtäviä, erityisesti toistotarkkuutta vaativissa toimenpiteissä. Toistotarkkuus ei ole kuitenkaan yksistään cobotin ominaisuus vaan myös normaali robotti on erittäin toistotarkka. Laaduntuottokyvyssä robotti ja cobotti eivät eroa toistotarkkuudeltaan ja suorituskyvyiltään, jos työasema on suunniteltu huolellisesti ja laadukkaasti. Cobotti voi kuitenkin toimia tiloissa, jossa teollisuusrobotin on vaikea toimia ilman erillistä turvallistamista tai suoja-aitoja.

Turvallisuuden näkökulmasta cobotit ovat lähtökohtaisesti turvallisempia kuin tavalliset teollisuusrobotit. On kuitenkin huomattava, että teollisuus robotteja pystytään nykyään turvallistamaan ulkoisilla menetelmillä, kuten skannereilla, joka mahdollistaa myös kollaboratiivisen järjestelmän perustamisen ilman cobottia. Tässä tapauksessa ihmisen ja robotin on asiantuntijoiden mukaan työskenneltävä eri aikaan asemalla. Huomioitavaa on myös se, että osalla coboteista saattaa olla asennettuna pehmustetut käsivarret, joiden tarkoituksena on suojata ihmistä kolhuilta. Ergonomian kannalta ei cobottien tai teollisuus robottien välillä ole asiantuntijoiden mielestä suuria eroja.

Green impact osalta nousi esiin vain kriteerejä joita olisi hyvä tarkastella vertailtaessa cobotteja ja teollisuus robotteja keskenään. Ensimmäinen oli uudelleenkäytettävyys; onko laite uudelleenkäytävä vai ei ja jos on niin kuinka helposti se on uudelleen konfiguroitavissa eri käyttötarkoitusta varten. Cobottien puolesta puhui sen helppo uudelleenasentaminen, mobilisointi sekä uudelleen konfigurointi perinteiseen verrattuna. Isoina riskeinä uudelleenkäytettävyydelle nähtiin ohjelmistojen vanhentumisen tai osien kulumisen osalta. Tämän lisäksi esiin nostettiin energiatehokkuus. Myös rakennusmateriaalit tulisi ottaa huomioon.

4. Toinen osa:

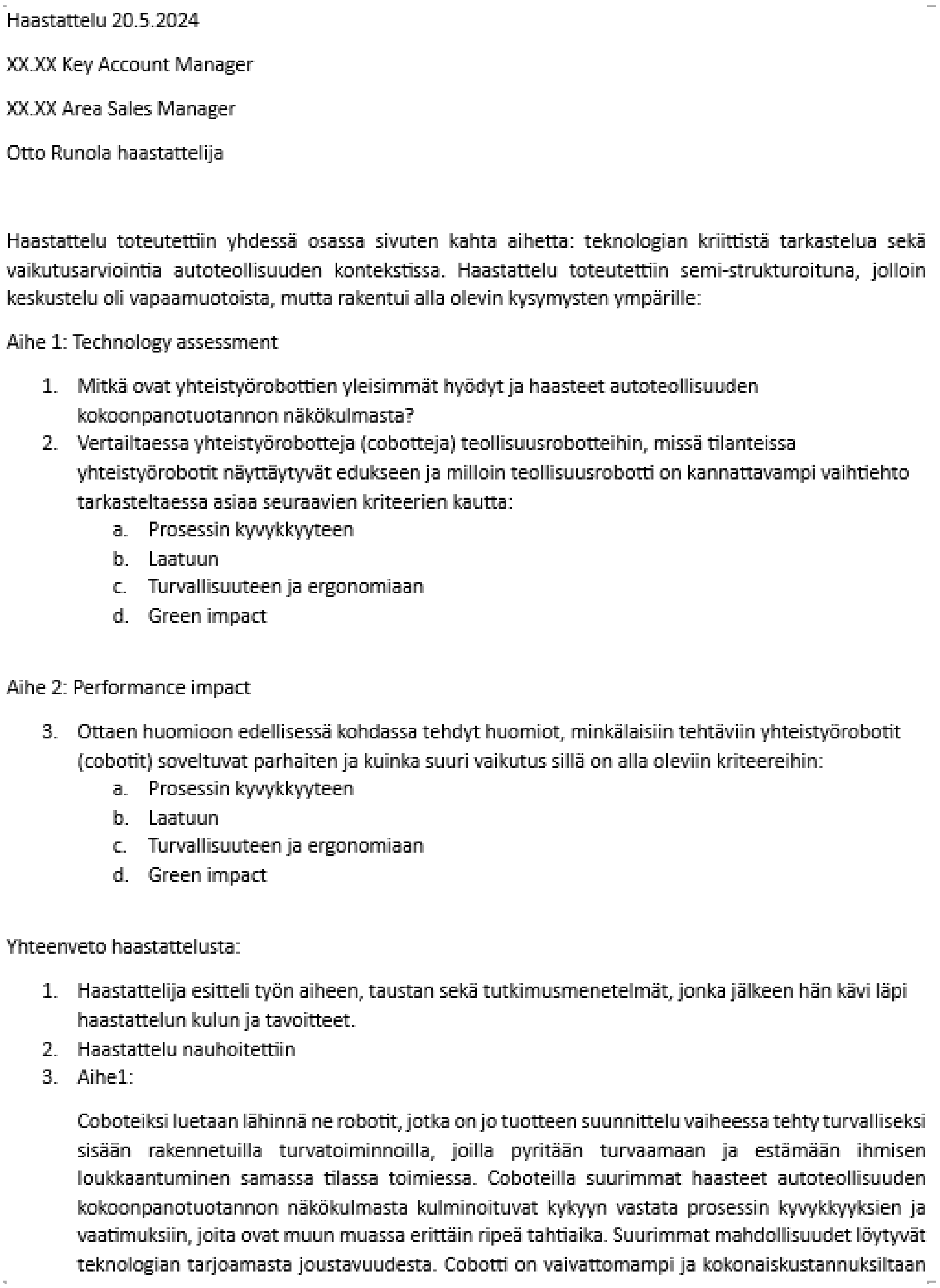
Asiantuntijoiden mielestä lähtökohtana oli se, että pienvolyymi linjalla on mahdollista käyttöönottaa cobotteja, mutta useat tehtävät ovat prosessin kyvykkyyksien parantamisen kannalta kuitenkin merkityksettömiä. Heidän mukaan vasta volyymien kasvaessa saavutetaan piste, jossa robotisoinnista saattaa olla hyötyä. Kun isommilla volyymeilla operoivan linjan tahtiaika kiristyy, cobotin rajoitettu nopeus ei enää kykene vastaamaan prosessin vaateisiin. Asiantuntijat näkevät siis vahvuudet muualla kuin prosessin kyvykkyyksien parantamisessa. Kuitenkin esikokoonpanotoiminnassa on tehtäviä, joissa kokoonpanodynamiikka on erilainen ja siten siellä on mahdollista kehittää prosessin kyvykkyyttä coboteille allokoiduilla tehtävillä.

Asiantuntijat nostavat laaduntuottokyvyn kasvattamisen merkittäväksi tekijäksi cobottien implementoinnille. Paljon painoarvoa saavat ne tehtävät, joista laatu kasvaa suoraan tai välillisesti. Tehtävät joissa ihmisellä on vaikeus tuottaa standardisoitua toimenpidettä voisivat suoraan parantaa tuotteen laatua. Näitä ovat muun muassa liimausprosessit tai voimantuottoa vaativat prosessit, kuten tuulilasin tai muun ikkunan asennus. Lisäksi suoraan vaikuttavia ovat myös laaduntarkastukset, joihin luetaan muun muassa dokumentoitavat visuaaliset tarkastukset. Välillisesti vaikuttavat tehtävät eivät suoraan paranna laatua, mutta sijaan merkittävästi parantavat koko prosessin laaduntuottokykyyn. Esimerkiksi jäljitettävyys kiristystoimenpiteistä koettiin merkittävänä tekijänä, jos on mahdollisuus tietää aina kiristysjärjestys.

Turvallisuuden ja ergonomian kannalta asiantuntijat esittivät, että fyysisen ergonomian hyötyjen saavuttaminen cobotilla olevan merkittävämpi tekijä kuin kognitiivisen tai turvallisuuden näkökulmasta. Fyysistä ergonomiaa voidaan parantaa muun muassa auttamalla operaattoria käsittelemään ja siirtämään tavaroita isoja painavia osia kuten ovia, asentamaan ergonomisesti hankaliin paikkoihin osia tai avustaa tehtävissä, jotka kerta toisensa jälkeen toistettuna saattavat aiheuttaa sairaspoissaoloja. Asiantuntijat painottivat erityisesti auton sisällä tehtävien töiden olevan erittäin haasteellisia ergonomian kannalta.

Green impact vaikutuksen kerrottiin olevan hyvin pieni, jos cobotti implementoidaan tuotantolinjalle. Oleellisempaa on tarkastella sen vaikutusta muihin vastaaviin tuotteisiin aina materiaalin, energiakulutuksen tai valmistusmenetelmien puolesta.

Kiristystyöt nousivat erityisenä luokkana esiin haastattelussa. Asiantuntijoiden mielestä kiristystoimenpiteiden huolellisella ja laadukkaalla automatisoinnilla olisi suuri vaikutus laaja-alaisesti niin prosessin kyvykkyyteen, laaduntuottokykyyn sekä mahdollisesti kohteesta riippuen fyysiseen ergonomiaan. Prosessin kyvykkyyteen kiristystöiden automatisointi vaikuttaisi pääasiassa ihmisen työn korvaamisella cobotilla, jolloin pystyttäisiin tuottamaan vähemmällä resursseilla sama määrä. Kiristystöiden automatisointi mahdollistaisi paremman jäljitettävyyden, jolla pystytään muun muassa lyhentämään korjausaikaa sekä suorittamaan dokumentoitavia laaduntarkastuksia ihmistä varmemmin. Kiristystöissä kannattavinta on kuitenkin toimia yhteistyössä ihmisen kanssa, jossa työvaiheissa ihminen suorittaa näppäryyttä vaativat tehtävät ja cobotti suorittaa manuaalisen ja laadunvarmistusta vaativan työn.



Haastattelu 20.5.2024

XX.XX Key Account Manager

XX.XX Area Sales Manager

Otto Runola haastattelija

Haastattelu toteutettiin yhdessä osassa sivuten kahta aihetta: teknologian kriittistä tarkastelua sekä vaikutusarviointia autoteollisuuden kontekstissa. Haastattelu toteutettiin semi-strukturoituna, jolloin keskustelu oli vapaamuotoista, mutta rakentui alla olevin kysymysten ympärille:

Aihe 1: Technology assessment

1. Mitkä ovat yhteistyörobottien yleisimmät hyödyt ja haasteet autoteollisuuden kokoonpanotuotannon näkökulmasta?
2. Vertailtaessa yhteistyörobotteja (cobotteja) teollisuusrobotteihin, missä tilanteissa yhteistyörobotit näyttäytyvät edukseen ja milloin teollisuusrobotti on kannattavampi vaihtiehto tarkasteltaessa asiaa seuraavien kriteerien kautta:
    a. Prosessin kyvykkyyteen
    b. Laatuun
    c. Turvallisuuteen ja ergonomiaan
    d. Green impact

Aihe 2: Performance impact

3. Ottaen huomioon edellisessä kohdassa tehdyt huomiot, minkälaisiin tehtäviin yhteistyörobotit (cobotit) soveltuvat parhaiten ja kuinka suuri vaikutus sillä on alla oleviin kriteereihin:
    a. Prosessin kyvykkyyteen
    b. Laatuun
    c. Turvallisuuteen ja ergonomiaan
    d. Green impact

Yhteenveto haastattelusta:

1. Haastattelija esitteli työn aiheen, taustan sekä tutkimusmenetelmät, jonka jälkeen hän kävi läpi haastattelun kulun ja tavoitteet.
2. Haastattelu nauhoitettiin
3. Aihe1:

    Coboteiksi luetaan lähinnä ne robotit, jotka on jo tuotteen suunnittelu vaiheessa tehty turvalliseksi sisään rakennetuilla turvatoiminnoilla, joilla pyritään turvaamaan ja estämään ihmisen loukkaantuminen samassa tilassa toimiessa. Coboteilla suurimmat haasteet autoteollisuuden kokoonpanotuotannon näkökulmasta kulminoituvat kykyyn vastata prosessin kyvykkyyksien ja vaatimuksiin, joita ovat muun muassa erittäin ripeä tahtiaika. Suurimmat mahdollisuudet löytyvät teknologian tarjoamasta joustavuudesta. Cobotti on vaivattomampi ja kokonaiskustannuksiltaan halvempi käyttöönottaa kuin perinteinen robotti, sillä perinteisen robotin implementoinnin järjestelemän turvallistaminen tuo lisäkustannuksia. Asiantuntijat mainitsevat myös yhtenä suurena haasteena puutteellisen tai riittämättömän osaamisen järjestelmätason turvallisuussuunnittelussa, jonka takia voidaan ajautua tilanteeseen, missä optimaalista teknologiaa ei voida hyödyntää. Silloin myös cobotin ympäristöä voidaan joutua turvallistamaan tai pahimmassa tapauksessa aitaamaan, jolloin sen hyödyt katoavat. Huomattavaa on se, että mitä avoimempaa tuotanto on, sitä enemmän se vaatii suunnitteluosaamista.

Asiantuntijoiden mukaan yhteistoiminnallista valmistamista voidaan harjoittaa niin teollisuusroboteilla kuin coboteillakin. Teollisuusrobottien kohdalla turvallisuus saatetaan vaadittavalle tasolle ulkoisilla turvallistamistoimilla, kun taas cobottien kohdalla turvallisuus on luotu sisään rakennetuilla turvatoiminnoilla. Sisään rakennetuista turvatoimista hyvä esimerkki on cobotin muotoilu, joka on selkeästi normaalia robottia pyöreämpi ja mahdollisesti pehmeämpi. Lisäksi cobotin rakenne on suunniteltu siten, että on pyrittään minimoimaan (pinch points).

Kun arvioidaan cobotin hyötyjä ja haittoja, asiantuntija huomauttaa, että näkemykset negatiivisista ja positiivisista vaikutuksista ovat subjektiivisia käsitteitä ja automatisoitavalle kohteelle tulisi löytää aina sopiva ratkaisu. Tällöin optimaalinen ratkaisu voi vaihdella usean eri vaihtoehdon välillä aina cobotista, robottiin tai muihin teknologiohin. Huomion arvoista on myös se, että jopa autoteollisuuden kokoonpanoprosessissa on useita yksittäisiä, toisistaan poikkeavia kokonaisuuksia, joilla on merkitystä prosessin kyvykkyyksien, ergonomian, ja laaduntuottokyvyn kannalta. Siksi vertailu itsessään on hankalaa ilman konkreettista kontekstia sillä optimaalisen ratkaisun löytäminen vaatii useamman muuttujan analyysia.

Aihe 2:

Asiantuntijoiden mukaan suunnittelun lähtökohtana tulisi olla kysymys, mitä lisäarvoa yhteistoiminnallisen prosessin automatisoinnilla saavutetaan. Tällöin voidaan löytää suurimmat suoritumiseen vaikuttavat tekijät. Asiantuntijoiden mielestä yhteistyötoiminta ei nojaa puhtaasti siihen, että olisi kannattavaa täysin automatisoida prosesseja vaan on mietittävä mitkä työt on hyvä allokoida ihmiselle ja mitkä coboteille. Ihmiselle sopii erityisesti tarkkuutta (dexterity) ja ongelman ratkaisua vaativat tehtävät, jolloin cobotti pääsee keskittyä prosessiltaan monotonisiin ja toistuviin töihin.

Kokoonpanoprosessin kyvykkyyksien kannalta huomioonotettavaa on useiden tehtävien tarve ulottuville laitteille. Autoteollisuuden kokoonpanoprosessissa ulottuvuus korostuu, sillä harvoin asennustoimintaa suoritetaan aivan auton kyljessä. Lisäksi cobotin on hyvä pystyä käsittelemään painavampia osia, sillä auton osat ovat suhteellisen raskaita. Yhteistoiminnallisessa prosessissa cobottien turvanopeus, joka myös rajoittaa niiden prosessin kyvykkyyttä. Cobottien kohdalla prosessin kyvykkyyksien sijaan olisi takaisinmaksun laskennassa hyvä tarkastella myös muita vaihtoehtoja.

Kun keskustellaan kyvykkyyksistä, laaduntuottokyky on parannettavissa cobottien avulla. Asiantuntijat näkivät cobottien tuovan laadullisesti hyötyä muun muassa jäljitettävyyden ja tarkastustoiminnan osa-alueilla. Toistuvat prosessit haastavat ihmisen havainnointikykyä muun muassa visuaalisissa tarkastuksissa. Cobotti suorittaa tehtävän aina samalla tavalla, jolloin laatu on aina sama.

Asiantuntijat näkivät cobottien edistävän turvallisuutta ja ergonomiaa, mutta vain oikein implementoituna. Kuluttavimmat työt, kuten kiristystoimenpiteet olisi hyvä automatisoida, sillä ne kuormittavat ihmisen fyysistä ergonomiaa ajan kuluessa ja näin voidaan välttää useat sairaspoissaolot. Samalla kun itseään toistavia yksinkertaisia tehtäviä allokoidaan cobotille, voidaan olettaa ergonomian parantuvan sillä se on yksi merkittävä tekijä osaltaan edistämään parempaa kognitiivista ergonomiaa. Turvallisuuden näkökulmasta on tärkeää mieltää, että yhteistyörobotti suorittaa työtehtävät aina samalla tavalla. Asiantuntijoiden mukaan, kun ympäristö vakioituu, stabiilissa ympäristössä olevien arvaamattomien muuttujien määrä vähenee, joka on omiaan lisäämään teollisuus ympäristön turvallisuutta.

Green impact osalta asiantuntijat eivät löydä suurta vaikutusta yksittäisten laitteiden kohdalta. Asiantuntijat kertovat toimittajien enenevissä määrin alkaa tuottaa tarkempaa dataa asiakkaille saataville. Tämä life cycle assessment data kertoo muun muassa valmistuksen hiilijalanjäljestä sekä elinkaaren aikaisesta arvioidusta kulutuksesta. Cobottien osalta asiantuntijat osasivat kertoa muun muassa sen, että nykyisellään cobotit talteen ottavat jarrutus/pysäytysenergiansa, jota ei ole aikaisemmin tehty. Lisäksi asiantuntijat vakuuttavat, että cobottien valmistamiseen kuluu vähemmän energiaa ja materiaalia, kuin ennen. Huomioitavaa on kuitenkin se, että vertailtaessa Green impact vaikutuksia, koko on suurempi määrittelevä tekijä. Siksi pienet teollisuusrobotit ovat vertailussa rinnastettavissa cobottien kanssa.