Paper:

Experienced Challenges When Implementing Collaborative Robot Applications in Assembly Operations

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The industrial collaborative robot (ICR) application is a promising automation technology that combines human abilities with the repeatability and accuracy of an industrial robot. Yet, industrial challenges have prevented ICR applications from being implemented extensively in industry. Therefore, the purpose of the presented work is to deepen the knowledge of the key challenges that manufacturers experience during the implementation of ICR applications. In this study, a case study approach was used with eight companies to identify those challenges. The analysis of the qualitative data was conducted based on thirteen interviews with respondents from the industry to identify their challenges when implementing ICR applications. In this paper, a defined implementation process is presented that is combined with three significant areas of challenges relevant for the implementation of ICR applications, i.e., safety, knowledge, and functionality. Then, these areas are used as a basis to identify the corresponding challenges during the early implementation phases. The findings of the study point to an insufficient understanding of safety assessment and a lack of operator involvement in the pre-study phase that was propagated into the later implementation phases. The application design phase was identified to have several ad-hoc approaches due to a lack of knowledge concerning the application of ICR. In the factory installation phase, the challenges included increasing flexibility and ensuring standardised ways of working. This paper makes three distinct contributions to the research community. First, it provides rich data to the research concerning the implementation of applications of ICR, and it focuses on three areas, i.e., safety, knowledge, and functionality, and the challenges associated with their respective implementations. Second, contributions are made to the literature on implementing new technology, and they are focused on the early phases. Third, the results of this paper suggest that the role of system integrators might change in ICR application implementation projects. This paper contributes to practitioners a list of challenges that they might face during the implementation of ICR.

Keywords: CoBot, assembly, Industry 4.0, industrial robot, case study

1. Introduction

The industrial collaborative robot (ICR) is one of the automation technologies in which manufacturers and researchers have become increasingly interested [1–4]. In industry, the ICR applications are used predominantly in assembly operations and the manipulation of parts because of their fenceless and collaborative nature [3, 5]. The human-intense assembly operations combine typical human abilities, such as problem-solving, cognitive skills and flexibility with the repeatability and accuracy of the ICR [6–8] while reducing or removing unergonomic jobs [9, 10]. Although ICR applications have many benefits, manufacturers have not implemented them at the expected rate [1, 2]. Previous research highlights a proficient implementation process, i.e., pre-study, application design, factory installation, start-up, and production [11] as the keys to increasing the number of ICR applications [12–14]. However, the implementation process encompasses conflicting and complex organisational, resource, and technical issues [12, 15, 16].

Researchers have attempted to clarify the implementation process of ICR application, e.g., [12, 14, 17]. Even so, the current literature on ICR applications does not include explicit studies of the critical activities of the implementation process. Instead, the current literature has highlighted the assumed importance of such activities, but it did so without examining them in detail.

Given this background, the purpose of this research is to deepen the knowledge of the key challenges that manufacturers experience during the implementation of ICR applications. Specifically, this study explores the implementation process and its different phases to identify the challenges that are encountered related to the specific characteristics of the ICR application implementation process.

The rest of this paper is structured as follows. First, the method that was used in the study is presented, and this is followed by a theoretical framework on the implementation of ICR applications. Then, the empirical findings on experienced ICR implementation challenges are pre-
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Table 1. Case descriptions.

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<td>Research centre</td>
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sentenced, and this is followed by a discussion of the main findings. The paper is concluded with a discussion of the conclusions that resulted from the study.

2. Method

2.1. Approach and Case Selection

In order to fulfill the purpose of this research, data were collected from eight cases with ongoing ICR application implementation projects in the manufacturing industry. The collection of real-world data is imperative when the phenomenon being investigated has a clear connection with manufacturers and several interdependent variables [18]. This study involved thirteen interviewees from manufacturers. In addition, one ICR expert who works at an ICR research centre was interviewed. The research centre conducted ICR pre-studies for the eight companies included in this study. The role of the research centre was to develop ICR application concepts for the case companies. Consequently, in this study, data were collected via a multiple-case study that involved eight companies.

The case selection criteria were as follows. First, the cases were limited to the manufacturing industry. Second, the cases had to include manufacturers that were implementing advanced automation technologies into their assembly operations. Also, the cases were limited to manufacturers that followed an internally-defined implementation process. Finally, the cases specifically had to involve ICR applications. As Table 1 indicates, the companies had not reached the operations phase with their ICR applications during the study.

2.2. Data Collection

In this study, the data included documents and interviews that were collected during the Spring of 2020. The respondents were ICR project members, including production engineers, operators, and managers within the assembly operations. Table 1 presents the manufacturer cases, respondents’ related roles, products produced, and which implementation phase they had reached. The interviews ranged from 30 min to 90 min, and they included one or two employees in each of the cases. See Table 1 for the duration of specific interviews. The aim of the interview was to capture the manufacturers’ challenges in their ICR implementation processes. In addition, various documents, such as project descriptions, project reports, and 3D simulations, were collected to enrich the data.

In this study, the research centre focused on one type of ICR in the pre-study phase, i.e., a two-armed, lightweight ICR. The research centre developed a concept that included the delivery of hardware, software, and a simulated version of the ICR applications. Then, the manufacturer conducted an internal pre-study based on the concept developed by the ICR research centre. Some manufacturers had experience they had gained from ongoing ICR projects, and they provided the experiences they had in these ICR projects.

2.3. Data Analysis

The respondents were shown the standard implementation process at the start of the interviews to confirm that they could relate to each of the implementation phases. Then, the implementation processes allowed matching the challenges to the respective implementation phases. The transcriptions were read iteratively to validate which challenge was associated with which implementation phase in order to ensure consistency.

The analysis involved transcribing the interviews and coding them using NVivo software. In qualitative data analysis, coding refers to labelling words, sentences, or sections of text. The codes are created from, for instance, a theoretical framework that indicates what codes to use through the data analysis [19].

To ensure that the results were thorough and inclusive, the data analysis consisted of the following steps: (1) the code challenge was used to identify the challenges that the manufacturers incurred during their implementation.
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effort. (2) The second coding round used various codes, such as pre-study, application design, and others to place the challenges in their respective implementation phases. (3) A literature review was done to identify significant areas of challenges for the implementation of the ICR application, resulting in three areas, i.e., safety, knowledge, and functionality. (4) The three areas were used in the third coding round to identify the challenges the manufacturers had experienced within these areas through their efforts to implement the ICR application.

3. Theoretical Framework

This paper defines an implementation process that serves as a basis for assigning challenges to appropriate phases. In addition, this paper focuses on managing new technology and the related ecosystems and on simultaneously connecting these to the specific literature that addresses the application of ICR.

3.1. Defining the ICR Application Implementation Process

The research on how to implement ICR applications in assembly operations is related to implementing advanced manufacturing technologies that have been studied for several years [11, 20]. Recently, research on the ICR application implementation process has presented a wide range of detailed levels of the phases involved [12, 14, 17]. According to Kopp et al. [12], the ICR implementation process contains three phases, i.e., the decision phase, the implementation phase, and the operation phase. These phases could benefit from a more detailed structure to visualise the intermediate actions within the implementation phase. According to Malik et al. [17], the early phases of the implementation process contain several critical ICR application aspects, and their processes are based on a product design structure, yet they do not provide details on the start-up and operations phases. To capture these phases, i.e., the start-up and operations phases and the subsequent actions conducted by the manufacturer during the implementation of ICR, an abstraction level of five process phases is deemed sufficient [11].

Thus, it has been suggested that the ICR application implementation process should include the following phases, i.e., (1) pre-study, (2) application design, (3) factory installation, (4) start-up, and (5) operations [11, 12, 17]. The pre-study phase concerns the generation of ideas and concepts while balancing the business and assembly process requirements [11, 17]. In this phase, the companies investigate the feasibility of the application of ICR [12] and select a suitable ICR. Also, companies explore the essential safety and task planning aspects [17]. In the application design phase, the manufacturer continues to develop the ICR application concept by designing applicable grippers, feeders, and safety measures while including the operator in the design [17]. The companies root the design details, and they develop an ICR application that represents the daily operations [12]. Commonly, the companies test the ICR application internally or at an integrator’s facilities before installing the application in their assembly lines [11], and this leads to the factory installation phase.

In the factory installation phase, the manufacturers run the ICR application within their assembly operations, but they do so with limitations on product variants and simplified operations [11, 12]. The aim of this phase is to test the equipment in the assembly operations with the complexity increasing continuously.

In the start-up phase, complexity is increased as more product variants are incorporated into the applications. Here, the manufacturer aims to increase the cell’s production rate [11]. Last, in the operations phase, the responsibilities of the cell are handed over entirely to the manufacturer, and the cell is producing at its full capacity [11, 12]. This definition of the implementation process and its phases is used in the rest of this paper.

3.2. Factors When Implementing ICR Applications

The implementation of ICR applications includes three decisive areas, i.e., safety, knowledge, and functionality. The safety area is indeed a hot topic in the ICR application literature, and it is focused mainly on how to ensure that operators are safe in an open environment that could involve contact between the robot and operator, but it also is focused on interpreting the safety standards, e.g., [1, 21]. The knowledge area concerns the manufacturer’s existing knowledge and what knowledge about ICR applications the manufacturer should adopt. The manufacturer’s existing automation knowledge can be a prerequisite to mitigate the implementation [22]. In addition, the manufacturer must pay attention to ICR application knowledge concerns, such as training the workforce, collaborating with and exchanging knowledge with integrators, and the organisation of the work [2, 15, 16]. In addition, since this technology is often new to the manufacturer, uncertainties can occur during the early implementation phases [23]. Finally, the functionality area means the specific ICR application functionalities that affect the implementation effort, such as the characteristics of the ICR, its speed, integrated software, hardware, and what application equipment is suitable in a fenceless application (e.g., vision system, grippers, feeders, scanners, and fixtures) [17].

3.2.1. Safety

An essential aspect of the safety of ICR applications concerns what level of collaboration should be allowed; this is a subject that has resulted in several different viewpoints throughout the research community (e.g., [2, 24, 25]). Out of these viewpoints, this study uses the distinct levels, i.e., cell, coexistence, synchronised, cooperation, and collaborations [2]. Specifically, the term cell refers to a fenced robot that is completely separated from the operator, and coexistence is a non-shared, yet fenceless application, in which the robot and the operator conduct their
tasks separately. At the synchronised level, the robot and operator share the same workplace, but they do not enter it at the same time. In the cooperation and collaboration levels, the operator and robot both work simultaneously in the workspace, yet in cooperation, they work on separate components whereas collaboration permits simultaneous work on components.

Safety has become increasingly challenging partly because the levels of collaboration are, in and of themselves, unique in ICR applications since previous traditional cell applications have separated the operators from the robots [3]. Now, manufacturers must learn how operators can stay safe while placing the ICR applications in an open, fenceless environment [1]. However, in industry, manufacturers mainly have implemented coexisting ICR applications because it is a simple way of testing and learning this new technology while sidestepping the complex task of ensuring safety for higher levels of collaboration [2]. In their survey of German manufacturers’ expectations concerning the implementation of ICR applications, Kopp et al. [12] identified that safety ranked as highly important and that manufacturers were expecting to evaluate such aspects in the implementation phase.

In their conversations, manufacturers should assess safety in the early phases of the implementation in order to ensure that they meet the safety standards and the design is not harmful to the operators, e.g., there are no sharp objects, safe grippers and other safety equipment [21].

The system integrators have conducted these safety assessments previously when they designed the robot cell. However, the introduction of ICR applications poses a question of who is responsible for changes in the application after implementation [2]. By taking a change management perspective and focusing on the human factors, Charalambous et al. [15] identified that safety also involves the human factors that the operators need to feel safe and understand the ICR application is safe in addition to the official safety requirements. Moreover, by involving operators in the early phases of the implementation of ICR applications, the manufacturers can ensure that the operators feel safe and understand the safety of ICR applications [15, 16]. The manufacturers are aware that the early phases indeed should involve employees’ trust and confidence in the ICR [12]. In fact, trusting the ICR was ranked as an imperative factor for successful implementation in their study.

### 3.2.2. Knowledge

Knowledge is an important area when implementing ICR applications because the technology is often new to the manufacturer since the managers and operators have no relevant knowledge or limited knowledge [2, 16]. However, the manufacturers could mitigate their implementation challenges of new technologies if they possess relevant knowledge [22]. The ICR literature has identified such relevant knowledge to encompass technology knowledge, such as ICR programming, application equipment, and application design [2, 16]. Other factors are related to the organisation, such as justifying economic benefits and the organisation of work [15]. In addition, understanding the division of tasks between people and the ICR is a significant challenge because it affects the capacity and collaboration level of the cell [26, 27].

Knowledge also encompasses challenges that stem from a lack of operator involvement. The managers might lack an understanding of how the manual process works since it can be challenging to describe the complexity of the operator’s work [28]. Even so, [15] identified that the operator’s knowledge of assembly tasks and the ability to transfer that knowledge to system integrators is imperative when implementing ICR applications. The authors also found that manufacturers can work closely with integrators to manage this lack of knowledge, and the training of both management and operators on ICR applications increases knowledge.

Moreover, external actors (in an ecosystem) are essential since Industry 4.0 production technologies require multiple knowledgeable people working together [29]. These people, for example, system integrators (also referred to as technology suppliers), the technology provider (also called original equipment manufacturer), research centres [16, 30], and governmental agencies [16, 30, 31]. The recent ecosystem literature suggests that the manufacturers will intensify their collaboration with these actors as the technology and the manufacturers mature [30].

Manufacturers expect that prior knowledge in traditional robots and robot programming is success factors in the early implementation phases [12]. By involving operators in the early phases of the implementation, they can support the development, layout, and design of the ICR application [15], and training the operators can mitigate the ICR’s resistance that may occur because operators may think that the ICR might replace them [2, 16]. Manufacturers expect that the implementation phase will involve managing the operator’s fear of being replaced by the ICR [12].

### 3.2.3. Functionality

In the area of functionality, the ICR application literature shows that it can be flexible, collaborative, and utilise minimal floor space [3, 25]. Manufacturers strive to implement ICR applications in their crowded and variable assembly operations because their functionality is highly suitable for such tasks [5]. Moreover, the ICR needs application equipment suitable for flexibility and an open environment that includes grippers, feeders, and fixtures [14, 17]. Another essential function is the ICR’s speed because it is slow compared to traditional robots, which can be challenging for the manufacturer when striving for increasingly cost-effective applications [12, 16]. However, when manufacturers implement ICR applications, they use a coexisting application (utilising minimal floor space) and focus on repetitive tasks [2].

As is evident in the literature, manufacturers scarcely use ICR applications in their assembly operations, and the
implementation process for this new technology is still under investigation. The remainder of this paper deals with the challenges the manufacturers experienced when implementing ICR applications, followed by a discussion.

4. Challenges Faced by Manufacturers Implementing Industrial Collaborative Robot Application

This section presents the challenges experienced by manufacturers when implementing ICR applications. The section is divided as follows, i.e., pre-study, application design, and factory installation.

4.1. Pre-Study

It is a challenge that safety, a significant part of ICR application implementation, is not assessed in the early phases of the implementation process. First, this challenge arises because all of the manufacturers and research centres conduct their pre-studies in a lab environment. Second, the manufacturers do not assess the interaction between the ICR application and the operators in this phase. The unassessed safety in the pre-study propagates into later stages of the implementation. Thus, the manufacturer must adapt the ICR application in later stages to ensure safety, and this impacts the design of the application. This challenge is exemplified by the associate project manager from Case D who said:

“It’s challenging because of the products we assemble. They have sharp edges, so even if the cobot itself is collaborative, it’s not safe with the product in its hands because there are risks of lacerations.”

Because the pre-study does not include an operator working within the application, the manufacturers could not assess safety aspects extensionally during this phase.

Because of the low ICR knowledge, the demands on cycle times were unpecific and uncertain to the extent that the manufacturers could not specify their takt time expectations. This challenge was overreaching for the manufacturers because they could not consider the current manual assembly tasks and figure out how an ICR could perform those tasks.

In this early stage of the implementation process, the manufacturers have limited capability to understand where the ICR application would be useful in their assembly operations. All manufacturers possess limited ICR knowledge in this phase; consequently, it is challenging for the manufacturers to know what demands to evaluate. This concerns the evaluation of ICR cycle times and the capabilities of the ICR application. The following comments from the project manager of Case F exemplify these challenges in the pre-study phase:

“it was difficult to do a correct specification, partly because we don’t have this kind of automation in our production. This project was something new. Our specifications only said what product to produce. […] It was difficult to know what they [ICR] could and could not do. […] that was a limitation for us. It was not easy to do the specification the right way. We were not able to present our demands to the integrator in our pre-study.”

One manufacturer (Case D) found that an extensive internal investigation was needed based on the results from the external pre-study. They realised that the conceptual ICR application would have significant implications for their assembly operations, which meant that the pre-study needed prolonged efforts. The associate project manager in Case D elaborated on the challenges:

“You can say that the assembly flow does not fit this robot [ICR] cell. It poses too many challenges and would have required that you redo the assembly stations. Partly because of the limits of this robot [ICR] and the limitation that our product has. It is about the geometry of our products. It only worked on one of our product variants.”

Even manufacturers with experience with traditional robots lacked the knowledge to specify ICR application cycle times in the pre-study phase (Cases C, E, and F). Case C, who was experienced with traditional robots, found that the ICR requirements were increasingly challenging to describe. A predominant requirement for them was to ensure that the ICR application can meet the assembly cycle times. The technical operator at Case C explained the challenges that were encountered during the pre-study:

“[…] tighten four screws and apply a sticker. That was what he [ICR] was supposed to do. But in the pre-study, it turned out that we could not achieve the whole assembly scope.”

All of the manufacturers experienced the need to scope the application to a few assembly operations and select only one specific component or simplify the assembly operations extensionally. These facts were somewhat unexpected by the manufacturers as the ICR often is portrayed as capable of flexibility (i.e., handling multiple product variations) and portability. The mismatch of the manufacturer’s ICR expectations and its functionality is a challenge also related to transferring the manual assembly skills to an automated solution. Also, the challenges are dependent on the manufacturers’ context, as seen in this statement by the project manager in Case D:

“The general challenge was the prerequisites in our assembly. You can say that it [manual assembly] requires a lot of craftsmanship. In this case, it’s about taking the craftsmanship to an automation [ICR application]. Here, we have a major challenge to identify the undocumented craftsmanship.”
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In terms of functionality, manufacturers experience a challenge concerning the use of vision systems. Seen as a beneficial function, several manufacturers (Cases A, C, D, and H) integrate vision jobs into their ICR application tasks. When implementing a vision system, the manufacturer must overcome challenges with the colours of various components and overall factory lighting. This statement by the project leader in Case D encapsulates challenges concerning the vision system:

“[…] and it can be quite difficult that our products are unpainted, kind of rusty and has shifting colours which cause issues. We’ve seen that the vision system is very important in this type of application [ICR application] and that some ICR brands don’t have a very good vision system.”

These manufacturers identified that some ICR brands have inadequate vision systems leading to a challenge where ICR executes the vision task very slowly. In turn, the pre-study becomes challenging because the ICR cannot uphold the required cycle times. The speed of the ICR is a challenge for all of the manufacturers as the slower speeds required for safe applications make it challenging to justify a sound business case. Case A, who was experienced with multiple ICR applications, identified the cycle time as the major challenge when evaluating ICR applications. Another example was stated by the project leader in Case C:

“It’s all about time-savings. The cost of implementing a traditional robot is no different from a Cobot because, from a robot, you get a lot higher speed so you can produce at higher volumes. Because of its safety, the Cobot needs to reduce the speed so slow that you don’t get any gains. […] That is probably the major lesson from all of this. If we’re going to make money on this, we need to achieve high speeds.”

The pre-study challenges have ramifications in the later stages of the implementation process as the pre-study phase’s scope often is quite limited. Thus, challenges in application design emerge as the manufacturers continue to the next phase. One of the challenges that manufacturers face is transitioning from a conceptual ICR application to industrialising the concept. Although the ICR application concept proved that the assembly operation was indeed possible, the manufacturers found that it is still a significant challenge to develop the concept, thereby initiating the application design phase.

4.2. Application Design

In this phase, the uncertainties from the pre-study phases commonly become incommodiously apparent. These uncertainties concern, e.g., cost, safety, feeding the ICR, flexibility, speed, and knowledge.

Indeed, safety is an imperative aspect when implementing ICR applications at manufacturers. The manufacturers need to adhere to standards and have an internal safety evaluation as well as meeting union demands. Specifically, the manufacturers need to adhere to safety standard restrictions, such as no risk of head contact. Significantly, there is a challenge that safety is not evaluated in the pre-study, which propagates into the application design phase. The manufacturers in this study designed applications that were coexisting rather than collaborative (Cases B, C, E, F, and H).

The manufacturers approach safety in different ways, and they are highly dependent on the application. Thus, all manufacturers have identified safety as one of the significant challenges when implementing ICR applications. The manufacturer needs to design a safe application while gaining the benefits of utilizing less floor space, and two main approaches have been identified to achieve this goal. First, using scanners, so the ICR slows down when operators approach (Case C), or ICR speeds are limited to ensure that the risk of injury is minimal (Cases B, E, F, and H). These safety challenges involve, first and foremost, the safety of the operator. As expressed by the technical operators in Case C:

“[…] it [ICR] works at face-level, and there is a risk that it hits you in the face. If you follow the safety standards strictly, that’s not allowed from a Cobot safety perspective. It will probably end up with us using external scanners. We don’t want to put a fence up, even though it is a simpler solution.”

The manufacturers’ safety challenge envelope consists of sharp components, tools, grippers, and even unintentionally unsafe programming, threatening operator safety, albeit the operator and ICR do not work directly on the same product. The project manager in Case H explains:

“[…] we need to assess if there will be any sharp products and so forth. […] what type of gripper design is allowed so the operator can work without risk. There are risks even with the programming, as you can program it to be dangerous. That was a discussion with our machine safety group. How do we need to think about the risk analysis surrounding this? One major question was about protecting the eyes.”

Manufacturers also experience that the internal safety documents and evaluations must be updated continuously because of the ICR application requirement. The manufacturers’ current safety evaluation lacks human-robot interaction aspects that every manufacturer needs to learn and evaluate. These safety skills are ICR-specific because even companies with prior robot knowledge found the ICR application safety to be challenging (Cases C, E, and F). A project manager, experienced with traditional robots, in Case C explains:

“the robot [ICR] implementation is simple stuff, but the difficulty is the safety assessment. And we’re not all through that. […] It is a major difference between what the robot [ICR] suppliers would do and what the manufacturer would do.”
promise and what it [safety standards] says. So, ninety-five per cent is not about the robot [ICR] itself but the risk assessment surrounding it [the application].”

Manufacturers frequently face issues with handling materials, and they need to investigate the needs associated with doing so they can feed the ICR properly. The feeding requires unique feeders that are expensive and adapted to the products within the specific application. Second, there is a challenge that the operator needs to re-fill the feeders during the operation of the ICR application. The manufacturers need to consider both correct feeding and operator safety.

In the design phase, manufacturers focus on achieving accuracy and repeatability in the application, which is known as one of the benefits of ICR applications. The challenge here is that the manufacturer often needs to spend a considerable amount of time to achieve accuracy and repeatability because of the complexity of ICR programming. To simplify their scope, the manufacturers limit the design phase to a few component variations to ease the programming (Cases B, C, E, F, and H).

Manufacturers with automation experience recognised that the ICR is a traditional robot without a fence, meaning that introducing multiple product variants leads to numerous hours of programming (Cases C, E, and F). Programming is challenging when striving to achieve flexibility. The development engineer in Case E explains his challenge:

“I would say that the takt time is a challenge. To trim it [ICR] so that it’s faster and more efficient than in the pre-study. The pre-study was done on two products, and it will be a challenge to get this concept to work on everything we want to include. […] So, it is a challenge to industrialise it [ICR] on the rest of the products.”

4.3. Factory Installation

One manufacturer (Case F) working with a system integrator experienced that the integrators also had limited knowledge about ICR applications in the factory installation phase. The limited knowledge materialises in a prolonged implementation partly because both the system integrator and the manufacturer are involved in the learning process. The learning processes require extended collaboration both during the design phase and after installation. Significantly, this challenge is evident in this phase as it typically involves a complete solution hand-over from the system integrator to the manufacturer. Thus, the system integrator needs to spend extended time at the manufacturer after installation, ensuring fault management, programming, and joint learning. The manufacturer identified numerous test issues at the system integrator, leading to a challenge in which they had to work intensely with continuous improvements after factory installation, requiring extended collaboration with the integrator. The project manager in Case F explains:

“We saw that we could go further if we install the cell here and make continuous improvements. It was not that we did the test, and then the cell worked. We still need a lot of support from the system integrator. We have still not done the factory test because we always get new issues that the system integrator is responsible for.”

The end-effect of this challenge is that the time for implementation increases compared to other automation implementation efforts.

In the installation phase, the manufacturers aim at an ICR application that can manage daily operations (Cases B, C, E, F, and H). The daily operations can include picking-and-placing operations with the ICR. Even for experienced robot programmers, these operations can be challenging because of ICR ergonomics (Case C). When using a seven-axle ICR, the robot ergonomics can be exceedingly delicate as the axles need to be adjusted to support each other, especially when manipulating relatively substantial loads. ICR ergonomic is a novel and challenging aspect which is explained by the skilled technician in Case C:

“[…] cobot ergonomics was probably one of the greatest challenges during installation […] we had to move him [ICR] back and forth. Still today, one screw is tough for him [ICR]. We need an extensive reorientation of axle seven so that he [ICR] can be strong on the way down.”

Another programming challenge is the limited skills of ICR project members, which leads to suboptimal ICR programs. Thus, the manufacturers need to spend more time programming the ICR for multiple products, which is a time-consuming and challenging task for manufacturers (Cases C, E, F, and H). The technical operator in Case F exemplifies this challenge:

“The challenge is that it [ICR application] does not look the same as the initial concept, and to change all those positions requires a lot of programming. Then we must redo some parts [application equipment] with 3D printing. So that became a challenge and an extra step that we did not know when we did the pre-study.”

At this stage of implementation, manufacturers (Cases C, E, F, and H) introduced increasing complexity in the ICR application via, e.g., increasing various component variants or changes in component design, namely increasing flexibility. Introducing flexibility poses a challenge because the manufacturer needs to program the ICR for each variant. This challenge leads to extended time for implementation because of the slow process required to develop flexible ICR applications.

In this phase, the manufacturers also continue their work to improve repetitiveness, accuracy, and a robust ICR application (Cases C, E, F, and H). However, these three factors are considered significant challenges through
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In the installation phase, the manufacturers test daily operations, which results in safety challenges. The challenges identified by the manufacturers are mainly sharp parts and heavy components (Cases C, E, F, and H). But even small parts can be considered risky. The small parts could be thrown through the air and cause eye or tissue damage (Case F). It is a challenge to identify all possible risks, and the manufacturers spend a significant amount of time ensuring a safe work environment (Cases C, E, F, and H). In turn, this leads to a prolonged implementation process. The project manager in Case H explains his challenge:

“The safety assessment was heavy. It was exhausting. We had experienced guys, but one can make the world’s most simple and quite a harmless machine [ICR] become very messy. […] one can really twist and turn things. The question is: what is dangerous and not dangerous and what assessments are required?”

Another challenge related to safety is the overall speed of the ICR. Because the manufacturers experience that the ICR needs to work slowly to be safe, which leads to an issue where the application output is limited, the manufacturers might find a significant challenge to motivate the ICR as a replacement for operators.

The manufacturers (Cases C, E, F, and H) designed the ICR application to replace workers in boring, repetitive, or unergonomic assembly stations. The manufacturers justify the payback by advocating replacing one or more operators with the ICR application. Moreover, the manufacturers focus on implementing the ICR in a station with manual assembly tasks. This approach, commonly expressed as one of the benefits of ICR applications, is challenging because having an ICR performing manual tasks might not be applicable, and the manufacturer might need to make extensive changes to the assembly station to accompany the ICR application. The technical operator in Case F exemplifies this challenge:

“Implementing these components and this way of working has been one of the major challenges that we’re still trying to solve. All the operators do this differently, and all the component variants are different.”

The operators working with the ICR need to manage daily stops, such as restarting the ICR, managing minor errors, and re-orienting an arm that would crash. The manufacturers experience a challenge in educating the operators to manage these aspects of the ICR. Because of a lack of education, the ICR might suffer periods of prolonged disturbances, and the operators do not have the confidence to handle the situation (Cases F and H). The operator involved in the ICR project in Case H explains his experience:

“It still happens that we get stops because the operators do not have confidence in themselves.”

It is a challenge that the operators interact with the ICR, which they do not do with a traditional robot. The operators are expected to enter the ICR working space and re-set or start the robot in case of failure, which some operators are afraid to do. Consequently, it is a challenge to train the operators so that they understand the importance of working closely together and correctly with the ICR. Lack of operator training is an issue leading to incorrect feeding and ICR failure causing interruptions in the assembly process. Increasing the knowledge of the ICR project team and the assembly staff is a significant challenge in the implementation process (Cases C, E, F, and H). The project manager in Case H talked about one significant challenge during installation:

“The challenge is the whole knowledge thing. Both for us in the project team and increasing knowledge in the working group [assembly team].”

5. Discussion

This section provides a summary of the results, accompanied by discussion. A comprehensive list of the challenges experienced by the case manufacturers is presented in Table 2.

In the pre-study phase, the case manufacturers have focused their efforts on increasing their ICR application knowledge and understanding its functionalities and what it can do in the manufacturer’s assembly operations. Literature on new product development has suggested that the manufacturers should decrease technical uncertainty in the early phases of its implementation, specifically via a pre-study [23]. However, this study showed that one case manufacturer’s predominant challenges for ICR applications were to produce a good enough list of requirements encompassing the ICR application’s functions and scoping the pre-study towards assembly operations. However, the use of an external expert, i.e., a research centre, provided conceptual designs that the case manufacturers could evaluate to determine whether or not to proceed with the implementation project. The ecosystem literature points out that collaborating with external actors, specifically research centres, is highly useful when technology is new to the manufacturer and in its infancy, which is the case for the ICR applications [30].

Moreover, the implementation of the ICR application processes has been suggested to assess the safety design parameters in the pre-study phase [14, 17], also involving
The aim of this study was to identify the challenges in the ICR implementation process. Table 2 presents the challenges that have been identified in the first three implementation phases correlated to three areas identified in the literature. We base these findings on empirical ev-

<table>
<thead>
<tr>
<th>Implementation phase</th>
<th>Area</th>
<th>Challenges</th>
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<tbody>
<tr>
<td>Pre-study</td>
<td>Safety</td>
<td>Safety not assessed – for example, safe grippers and tools</td>
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<tr>
<td></td>
<td></td>
<td>Operators not participating – leads to an inability to evaluate operator safety aspects</td>
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<tr>
<td></td>
<td></td>
<td>Lack of knowledge regarding ICR application equipment such as cameras, grippers, and feeders</td>
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<td></td>
<td></td>
<td>Lack of knowledge concerning how to perform previous manual tasks with the ICR</td>
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<td></td>
<td>Knowledge</td>
<td>Justifying the cost of ICR application difficult due to slow cycle times</td>
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<tr>
<td></td>
<td></td>
<td>Unclear how ICR applications can be useful in assembly</td>
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<tr>
<td></td>
<td></td>
<td>Unclear how to industrialise the ICR applications concept</td>
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<tr>
<td></td>
<td></td>
<td>Pre-study scope limited to one product variant leads to uncertainty when scaling up to multiple variants in later implementation phases</td>
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<tr>
<td></td>
<td>Functionality</td>
<td>ICR speed slow compared to manual assembly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integrated vision system imperative but challenging to utilise due to parts characteristics</td>
</tr>
<tr>
<td>Application design</td>
<td>Safety</td>
<td>Lack of knowledge about ICR application safety – leads to extensive application design limitations focused on coexisting level of collaboration</td>
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<tr>
<td></td>
<td></td>
<td>The lack of safety knowledge involves design parameters such as ICR programming, the manipulated parts, the grippers, and other application equipment</td>
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<td></td>
<td></td>
<td>Operators feeding the ICR application also subjected to safety risks</td>
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<td></td>
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<td>No internal safety assessment for ICR applications – leads to an ad-hoc approach</td>
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<tr>
<td></td>
<td>Knowledge</td>
<td>Lack of skills in ICR programming leads to an extensive learning curve and, a challenge to develop ICR task planning</td>
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<tr>
<td></td>
<td></td>
<td>A trade-off between higher speeds and a slower coexisting application</td>
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<tr>
<td></td>
<td>Functionality</td>
<td>Complex ICR programming leads to limitations on how many product variants can be programmed; thus, flexibility is not thoroughly evaluated</td>
</tr>
<tr>
<td>Factory installation</td>
<td>Safety</td>
<td>Ensuring safety for operators – even those who only need to feed the ICR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increasingly difficult to identify final safety aspects, such as sharp edges, risk of laceration etc. Integrators lack ICR knowledge – leads to increased time for installation with ad-hoc problem-solving</td>
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<tr>
<td></td>
<td></td>
<td>Lack of ICR application knowledge in assembly and project team leads to ad-hoc application installation</td>
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<tr>
<td></td>
<td>Knowledge</td>
<td>Lack of skills in ICR programming hinders flexibility</td>
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<td></td>
<td></td>
<td>Operators can lack the confidence to solve ICR stops and cannot feed the ICR correctly</td>
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<td></td>
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<td>Way of working difficult to standardise because no overarching strategy exist</td>
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<td>The 7-axis ICR need an ergonomic approach</td>
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<td></td>
<td>Functionality</td>
<td>Extensive assembly station adoptions needed to implement ICR applications</td>
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<td></td>
<td></td>
<td>Difficult to reach ICR application repetitiveness and robustness while increasing flexibility</td>
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the operators [12]. Therefore, it is a surprising and critical finding that the case manufacturers in this study only sparingly evaluated safety in the pre-study and that the operators were seldom involved in this phase.

The literature shows that operator involvement is increasingly vital in ICR application implementation concerning safety, knowledge, and functionality [2, 15, 16]. In this study, there were challenges in each area because of a lack of operator involvement. Since operator involvement is essential, it is suggested in this paper that case manufacturers should include them from the pre-study phase to support the ICR application implementation, specifically to identify safety aspects and transfer their knowledge of complex assembly tasks to the team.

One key finding in this study is that the case manufacturers experienced that the flexibility function was increasingly challenging to achieve. As the case manufacturers did not extensively evaluate flexibility in the application design phase, they needed to spend significant time incorporating their product variants during the factory installation phase. In fact, none of the case manufacturers in this study had fully achieved what they thought was a good enough level of flexibility. However, the ICR literature has indicated that the ICR is easy to program and that flexibility is one of its benefits [3, 25]. The results from this study are more in line with the identified approach to start with a simple application and evolving the complexity of the application as the manufacturer gains knowledge and experience [2]. Moreover, having skills in the traditional programming of robots can mitigate the implementation of the ICR application [2, 12].

The literature has identified that the complexity of Industry 4.0 technologies will require an increase in collaboration with external actors as it requires numerous experts [29]. Also, it is anticipated that the collaboration with these actors will increase as the maturity of the manufacturers’ technologies increases [30]. Interestingly, only one manufacturer (Case F) used a system integrator in its ICR application implementation project, which showed that even the system integrator was inexperienced with this technology. This suggests that the role of system integrators might change when ICR applications are implemented.

6. Conclusions

The aim of this study was to identify the challenges in the ICR implementation process. Table 2 presents the challenges that have been identified in the first three implementation phases correlated to three areas identified in the literature. We base these findings on empirical ev-
Experienced Challenges When Implementing Collaborative Robot Applications in Assembly Operations

Experienced Challenges When Implementing

Collaborative Robot Applications in Assembly Operations

dence from eight cases by presenting their experienced ICR implementation challenges. Thus, this study provides a table of challenges that practitioners can use as support in their effort to implement ICR applications.

This paper makes three distinct contributions to the research community. First, the paper provides extensive data related to the implementation of the ICR application, which is currently still in its infancy. Specifically, the study contributes to three areas, i.e., safety, knowledge, and functionality, and their respective implementation challenges. Second, this study contributes to implementing new technology, mainly in the early phase, while maintaining an ICR application perspective. Finally, as suggested in this paper, the role of the system integrator might be changing as manufacturers use various ICR applications, which contributes to the current body of knowledge on the ecosystem and on research related to the management of new technologies.

The results from this study apply widely to ICR implementations in assembly operations based on two critical factors. First, the study involved a wide range of manufacturers and products, ensuring that the findings can be generalized. Second, the analysis of the qualitative data in this study involves both rigour and an iterative process, ensuring that the findings are representative across the dataset.

This study could have benefited from a complementary survey to quantify the findings, and we recommend this approach for future research. A study on ICR implementation enablers also should be undertaken to investigate the potential approaches that could be used to implement ICR applications successfully. Finally, we suggest a follow-up study to investigate how these challenges affected the operations phase.

Acknowledgements

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References:


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