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Trigger Points of Fear and Distrust in Human-Robot Interaction: The Case of Cooperative Manufacturing

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TRIGGER POINTS OF FEAR AND DISTRUST IN HUMAN-ROBOT INTERACTION: THE CASE OF COOPERATIVE MANUFACTURING

Research paper

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Abstract

Digital technology is becoming ubiquitous and embedded as an integrated part of our daily lives, in which the digital and the physical worlds are increasingly interconnected and intertwined. While advanced technology can provide tremendous benefits and opportunities, it can also be very complex and challenging to understand, potentially leading to fear, suspicion, and distrust. This paper investigates a case of human-robot interaction in cooperative manufacturing, focusing on understanding how operators, managers and viewers feel about cooperating with industrial robots using potentially dangerous tools like nail guns. The aim of the study is to identify how human reactions to technology-induced change can be understood. The research question is: how can different trigger points of fear or distrust in technology be understood in the context of human-robot interaction? The findings reveal three key factors in overcoming fear, creating trust and encouraging interaction: knowledge, control, and self-preservation. The main contribution is illustrated through suggested guidelines for aspects that have to be practically considered when building this type of flexible robot cell for interacting with industrial robots in a real setting.

Keywords: Collaboration, Fear, Industrial robot, Trust, Human-Robot Interaction.

1 Introduction

Since the beginning of time, humans have been fascinated and intrigued by new technology but also frightened of its implications. Technology can change how work tasks are performed, how we communicate and our behavior towards each other or a phenomenon. During the last decade, many tasks have transformed from manual to automated and new technology is present in almost everything humans do (Susskind and Susskind, 2015). Today's workplaces are typically characterized by a combination of old, established and new, emerging technologies that are continuously changing and co-exist within and outside the workplace as people interchangeably use digital technologies for work, learning, and entertainment (Fischer and Baskerville, 2022; Vallo Hult et al., 2021). This has been seen in industries over time when the different technological revolutions have changed the work tasks, the work environment, and the knowledge required by the workers to perform a job task or an assignment (Castells, 2010; Susskind and Susskind, 2015). About three million industrial robots, or 126 per 10,000 employees, operate within the manufacturing industry worldwide (IFR, 2021). Completely autonomous robot lines have been used since the 50s, commonly seen in car and vehicle manufacturing, while collaborative robots have been introduced in the last ten years. In contrast to household and social robots, industrial robots create different types of interaction.

Advanced technology can provide tremendous benefits and opportunities, leading to a sense of wonder, but it can also be very complex and challenging to understand and potentially also lead to fear, suspicion, and distrust in new work processes. There is a fine line between helpful, intelligent systems that can foresee and plan new work activities and an intrusive system that knows too much. Digital transformation is rapid and ongoing and calls for fundamental changes in product design, work processes, and practical tasks. The development is changing the nature of work by redefining and reconfiguring professional roles and existing work practices, thus demanding new expertise among the professionals, along with opportunities to develop skills and competence (Islind et al., 2021; Susskind and Susskind, 2015; Vallo Hult, 2021). As the number of manual jobs is decreasing; contrasting feelings of responsibility and loss of control are common when adapting to new conditions in a new work environment; new workplace technology may change traditional practice and thereby lower the autonomy and power of the professions; and new machines could cause physical injury or, with a digital system, lead to security threats, loss of data, or the sense of intrusiveness (Jussupow et al., 2018; Susskind and Susskind, 2015; Zuboff, 2019).

This paper summarizes lessons learned and observations made in an exploratory practical case of a transformation process from manual assembly to a semi-automated system. A simplified industrial robot cell was used as a proof of concept for a flexible human-robot assembly of standard wooden house elements. The study focuses on industrial robots and how humans respond to being asked to interact with active robots using potentially dangerous tools like nail guns. The overall aim of the study is to identify how human reactions to technology-induced change can be understood. The research question posed in this paper is: *how can different trigger points of distrust or fear in technology be understood in the context of human-robot interaction?* Based on observations, we define how to encourage change and development without triggering fear. In particular, we seek to capture what type of fears or distrust the technology induces and what can be done to overcome or reduce these types of feelings within the transformation from manual to semi-automated assembly. The paper contributes practical insights and suggested guidelines for interactive aspects that have to be considered when building this type of flexible robot cell in a real setting.

2 Industrial robots

The basic design of robots in the manufacturing industry has seen minor changes since the first industrial robot, Unimate, was designed in the 1950s and patented in 1961 by Georg Devol (1961). The design and behavior of industrial robots were based on separating humans and robots by fences and gates to meet the industry's safety requirements. Regardless of the brand, model or purpose, the standard industrial robots have followed the 1950s guidelines related to appearance, design and software utilities. Robots are to be programmed to solve a specific task or series of tasks while simultaneously doing this with speed, high precision, and repeatability for long periods. These completely autonomous robot lines have been used typically in mass production industries with large batch sizes, where the characteristic of the industrial robot creates benefits for efficiency, accuracy and labor costs. The idea of interaction between humans and robots did not exist in the industry at all at that point.

The concept of the first collaborative robot, Cobots, was introduced between 1995 to 1999 and was intended for interaction with human workers handling shared payloads. Peshkin and Colgate (1999) describe the Cobot as separate from regular industrial robots, which must be fenced and isolated from humans and are distinctively different from teleoperators, machines controlled remotely by a human operator. However, it took more than ten years for the industry to start looking at the concept of collaborative robots and their possibilities and implications. First, in 2011 the safety standards (International Organization for Standardization [ISO] 2011a; ISO 2011b) took the first steps towards some interaction with standard industrial robots allowing semi-automated robots and production systems to be used. The change could be seen in new types of industrial robots with integrated sensors and additional software that could detect collision and external touch in a different way than standard robots (Kock et al., 2006; KUKA Robotics, 2014).

In 2016 the standard was updated again (ISO/TS 2016), and this new type of interaction was allowed on an industrial scale. This allowed new solutions for humans and robots to solve work tasks in parallel or together. This change initiated the design of a new genre of robots, sensors and different tools. The new segment is called collaborative robots and includes smaller robots intended for interaction and co-production along an assembly line. These robots have a distinctive design with more human-like arms or grippers, reduced speed, limited payload capability, and improved sensor technology compared to traditional industrial robots (ABB, 2014; Guizzo and Ackerman, 2012). Some of them come with a screen where a human-like face can be displayed for communication purposes, and most come with an interface for programming by showing the robot how to perform a move.

Industry 4.0 describes the fourth industrial revolution and refers to a vision of a digital transformation where the digital and the physical worlds are fully interconnected and intertwined. With this trend or revolution, the usage of industrial robots is no longer limited to large companies with extensive mass production lines. Also, smaller and middle-sized companies must turn to more automated solutions. Although, with short time horizons, high product variation, large turnovers, the manual skills required, and the wish for locally produced products. This creates new demands for the robot lines, forcing them to be more flexible in production, support smaller production volumes, and deliver a faster payback. To be able to meet these new demands from the market, the industry needs to start looking at implementing flexible and more innovative ways of production, which requires new solutions for interaction between robots and humans in a joint effort to produce products together (Grønsund and Aanestad, 2020). There is now a suggestion of progress toward Industry 5.0, in which technological and social systems work harmoniously to deliver personalized mass customization of products and services (Bednar and Welch, 2020; Lee et al., 2015)

2.1 Interacting with an industrial robot

In most industrial processes, it is impossible to stop the robots or change behavior in an ongoing task or process to acknowledge the detection of a human in the same way that is done for domestic and service robots. This limitation is based on various aspects of the production industry. Two of the most common are meeting set-process-time for specific tasks while following the overall production-cycle-time set for the plant and not interrupting a critical process that can affect or change the quality of the produced parts. These limitations and the difficulty of relaying important information in real-time to create a safe environment affect the human-robot interaction, crippling the natural flow of the interaction (Mirnig et al., 2012; Scheutz et al., 2011; Thomaz and Chao, 2011). It also affects the design and programming of industrial robots and solutions for how information is to be transferred back to the human if the robot cannot acknowledge as we are currently getting used to technologies in our daily lives.

Interactive co-production in a flexible robot cell can make use of both the human's and the robot's beneficial characteristics. The standardized robot is built for speed, accuracy, strength, and repetition, while the human can accomplish tasks where intelligence or human perception or deduction is needed. A collaborative robot can interact between those two competencies. Combined, their individual skills can be used to solve complex tasks, a highly esteemed feature in small batches, one-off production, or when constructing extraordinarily complex structures. To do this is a matter of both economical and sustainable usage of resources, as buying a fully developed collaborative robot is much more expensive than using a standard component as a regular industrial robot. If the company already has industrial robots, they can be re-programmed and reused. The company might also want to shift the work tasks for the robot to function both as a collaborative and as a standard robot to get the benefits of its strength and speed, which are often limited in the fully collaborative robot types.

3 Distrust and fear as driving forces of interaction

Already in the 1980s, Chao and Kozlowski (1986) studied human reactions to the introduction of fully automated lines in the mass-production industry. They investigated how employees handled the introduction of robots into their work environment and their responses, hence their willingness to change the work process on the factory floor. This study is more than 30 years old, but their insights are still relevant, and the same psychological resistance is seen in the industry today. With the added complexity of technology like ubiquitous and embedded systems, AI, smart sensors, and big data, it becomes even more important to handle ethical aspects and fear of technology (Zuboff, 2019). Research suggests that studies of technology-induced change and its effects on work and learning need to move beyond techno-centric views and traditional standalone systems with attention to new work practices where people work together with digital technologies (Baptista et al., 2020; Vallo Hult and Byström, 2021).

When new technology is introduced, it will usually mean a transformation of processes and work tasks. This type of change could be challenging for the individual or even perceived as a threat (Jussupow et al., 2018). Many employees associate robots with losing one's jobs, which can create initial distrust and worries. The employee could also experience a loss of control when adapting to new conditions and new routines. Their work tasks are changing and might require new capabilities and knowledge, which might be challenging for the employee. If the employee is unfamiliar with the new technology and routines, it can also create uncertainty and worries about making mistakes. A mistake could mean a substantial cost if the robot or machine interacts wrongly with an expensive workpiece. Change can create anxiety and irritation in the work environment, possibly leading to conflicts, unwanted staff turnover and sick leave due to increased stress. Therefore, irrational protests and emotional behavior are common first reactions. The bigger the change, the bigger the reaction. One of the most severe cases of irrational behavior led to sabotage, where the workers attempted to prove the downside of the new technology or machines in the factory by intentionally making them break down (Hobsbawm 1952; Sullivan 1982). The organization must be able to handle both the technical challenges and the socio-cultural aspects that arise between workers, management, and the new technology.

Industrial robots are big, fast and noisy, and they work with large tools without considering their surroundings. Compared to the fields of humanoid, domestic, and service robotics, these robots can trigger a relaxed response since they are usually boxed inside a fenced area and therefore seen as safe because they cannot reach outside their box. They are also predictable since they often repeat specified tasks or a cycle of tasks. However, their speed and ability to lift and move heavy objects rather quickly pose a physical threat to humans if they are expected to collaborate inside the robot cell or in its proximity. There are no visual cues for intention, and the consequences are very severe if the operator is at the wrong place at the wrong time. A report published by Statistics Sweden showed that industrial robot operators had the second highest risk of being killed at work in Sweden compared to other work branches (SCB, 2014). Self-preservation and fear of getting hurt could trigger feelings of distrust or at least a great deal of respect toward the robot. Suppose the robot is expected to act based on the human's activities. In that case, it could also trigger feelings of lack of control due to communication and interpretation problems – the human is not sure when the robot is doing something or why. Industrial robots are perceived as immensely powerful and sometimes even intimidating, even when operating slowly. This creates a problem when a flexible robot cell is built for production, where the human operator or worker is expected to go into the cell and collaborate with the robot. The cell then must be redesigned to support the new collaborative environment.

3.1 Distrust and fear from a psychological and cognitive point of view

The appearance and the first impression in an encounter with a robot are considered essential and play an important role when forming an initial feeling or hunch of that robot (Goetz et al., 2003). Some robots can be seen as cute, cuddly, and harmless based on their size and visual appearance (Han et al., 2010), whereas some robots can also trigger opposite feelings, such as fear, respect, and repudiation (Bethel and Murphy, 2006). Some reactions are based on images from media, movies and TV series where the robots become self-aware and stop responding to human orders, eventually becoming violent and evil. This feeling can be challenging to grasp and describe to others. It can also be very difficult to change the initial or previous feelings towards robots or technology in general.

This type of reaction to change and new technology depends on the environment, how change is managed by the organization and on individual personality. Human behavior and reactions can then be explained from a psychological viewpoint and theories of motivation, where humans react depending on if they are extrinsic or intrinsic (Oudeyer and Kaplan, 2007). Intrinsic motivation means that the person can identify benefits with an activity for its own sake and spontaneously engage and explore out of curiosity. They will engage in new work tasks and activities if they think it will be exciting, fascinating, challenging or rewarding. Such a person will find working with a robot interesting just because of what the robot itself can contribute with. In contrast, an extrinsic person needs to be motivated by external factors like a better salary or reduced workload. Extrinsic persons will engage in behavior not because they enjoy it or find it satisfying but because they expect to get something in return or avoid something unpleasant.

The advantage of having intrinsic motivation is that there is an association with a decreased level of stress in an uncertain situation (Hancock, 2013). Moreover, having the option to either continue or suspend the situation, i.e., the circumstances of the vigil will lead to a lower level of stress (Karasek and Theorell, 1990). The person will embrace the new challenges with a different attitude than an extrinsic person. The extrinsic persons' distrust can also be anchored within cognitive appraisal models and coping mechanisms. A well-known theoretical assumption is that perceived controllability is a critical component in the appraisal of stressful events (Folkman, 1984; Lefcourt, 1992). Understanding a process can make it easier to conquer new challenges and adapt to changes in work situations. Safety issues are essential not only to create a feeling of security but also to create a safe system. Trust and coping can be increased if there are clear goals and the outcome or rewards are explained and discussed. The main feelings that are important with respect to a positive interaction are curiosity and interest in the system – how it works, what it can do and how it can be beneficially used. It is, therefore, important to create an understanding of the robot and its system as well as pinpoint its essential benefits.

Human fear can be connected to the lack of knowledge or the inability to affect the situation; in the same way, a person can fear water based on their inability to swim. By studying humans in everyday life, we can see several areas where the behavior is triggered by fear, which drives the person to a variety of choices and behaviors. If the fear is very severe, the human begins acting illogically, making irrational decisions. A pedestrian does not step out in the middle of the street if they see cars approaching. This is triggered by the fear of getting hit by the vehicle. But what would the behavior of the pedestrian look like if the cars had always stopped for them? In countries where the pedestrians know that the vehicle must stop, different behavior can be observed than in the opposite case. Human interaction is highly affected by fear and the ability or inability to control and understand the surroundings. While studying the interaction with robots, fear can be seen as an equally strong or even stronger force compared to curiosity. The desire to reduce or eliminate the feeling of fear can produce innovative ideas and be considered "out of the box" from the normal assorted solutions based on knowledge and logical thinking concerning interest and curiosity.

4 Methodology

This paper builds on observations from a testbed demonstration, reflective interviews, and a small questionnaire consisting of quantitative measurements and open-ended questions based on scenarios focusing on participants' feelings and willingness to interact with an industrial robot. First, the testbed demonstrations were performed, and participants could watch how two technicians interacted with the robots. The participants' reactions were observed, and they were asked to describe their thoughts about the demonstration. The observations were done on the participants as a group. To get a deeper understanding of our observations and the factors that hinder or encourage a person to step into the robot cell, a handful of participants were asked to elaborate further on what they had seen in an open-ended discussion. The discussion was based on the scenarios and the demonstration they had seen.

After the demonstration, the participants were asked to complete a small questionnaire and reflect on what they had watched. The questionnaire intended to catch their individual viewpoints and reactions. To get a within-perspective, we ended the session with a small interview with the two technicians. We asked them to reflect on how they feel about interacting with the robots inside the fence, how they perceive the safety inside the cell and if they trust the system. This to further elaborates our understanding of the experiences and feelings a collaborative situation could render when working inside a robot cell. All results were analyzed from a qualitative perspective to gain understanding. No statistical analysis was used on the questionnaire, the numbers were only summarized, and group correlations were made based on the participants' role in the company. Our results were discussed by a fellow researcher in psychology to better understand what we had observed.

4.1 Study setup and demonstration

This study uses a simplified industrial robot cell to demonstrate cooperative wood element construction at a research center. The testbed used for the demonstration is a flexible robot cell with two industrial robots and an assembly table in between (see Figure 1).

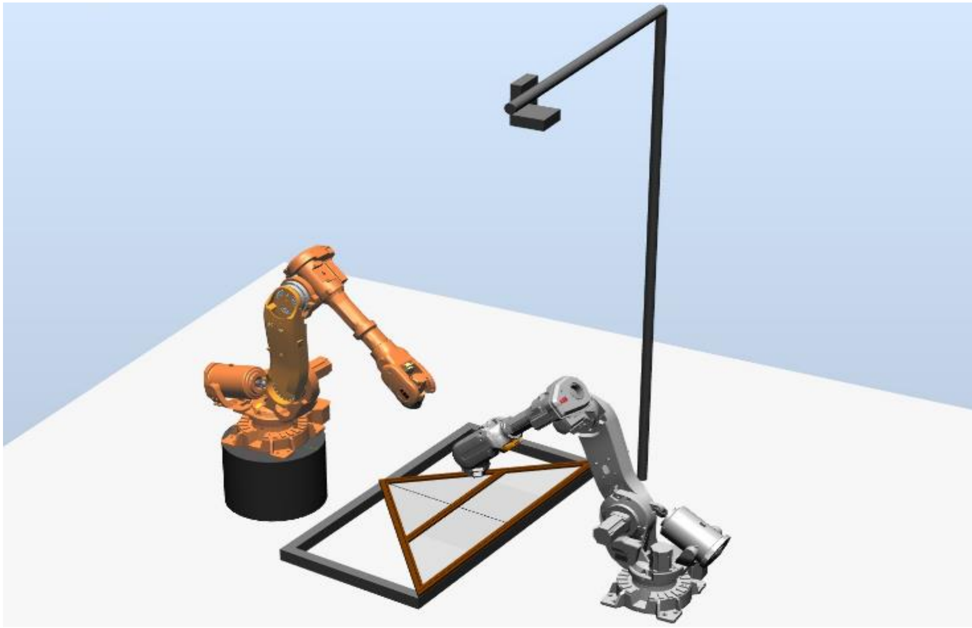

Figure 1. Layout of robot cell in test case setup (authors' illustration).

The two industrial robots have a height of two meters, a payload capacity of around 200–250 kg, and a maximum speed of approximately seven meters per second. One of the industrial robots (KUKA Robotics, 2014) is used for lifting wooden boards and equipment onto a fixture table. The other robot (ABB, 2014) is used for fastening the parts and is equipped with three tools: a screwdriver, a nailing gun, and a nailing press tool. An assembly table or fixture table is placed between the robots, where the wooden elements are picked and placed. A 3D-based camera system (Pilz GmbH & Co. KG, 2014) is mounted above the robots and is connected to a Safety PLC, a programmable control system. A big screen is attached to the wall behind the robots showing the camera view. A regular computer projector is mounted to project building information onto the assembly table with the camera. A human (one of the technicians) is present within the cell to align parts, check building instructions, and do quality control while the parts are being placed and assembled. The other technician is placed outside the cell by the robot cabinet where he can reach an emergency stop if something goes wrong and can perform seatrain tasks guiding the robot. The two technicians switched places during the demonstration day. There are stationary gates on three sides of the robot cell, and a laser guard is used on the fourth side when the cell is used for normal operations.

4.1.1 The scenarios of the demonstration

Three different scenarios were tested during the demonstrations. In the first scenario, the robot cell runs in fully automated mode. The two robots assemble a house wall element without human assistance. The robot to the left in Figure 2 is fastening the planks and boards using the screwdriver tool and the nailing gun. The robot on the right in Figure 2 fetches and places the different materials onto the fixture or assembly table. In this setup, the robots are running at almost full speed. This shows how two robots can collaborate and demonstrates possible cycle times for the process.

Figure 2. Picture of interaction between robot and human (authors' photo).

In the second scenario, one robot (the one on the left in Figure 2) and one human (one of the technicians) assemble the wall element in cooperation. The human place and align the materials onto the assembly table and then control the details of the assembly. Meanwhile, the robot fastens the different materials in the wall segment. The human can jog the second robot manually to lift the heavier boards if wanted. The robot runs at a reduced speed to meet safety requirements in this scenario. The human is equipped with a remote control for the fastening robot. The remote has two settings, one that can temporarily cut the power to make the robot pause and one to stop it entirely by an emergency break. This enables the human to instantly stop the robot if there is a need for it or to be able to pause the robot to make adjustments to the materials on the wall segment.

The third and final scenario is used to demonstrate the technical performance of the fastening robot and the different fastening tools used. First, the robot shows fastening by using the nailing gun tool at different speeds. Then the same procedure is done with the screwdriver tool, and finally with the nailing press tool. The demonstration ends with a procedure where all three tools are used in a sequence to show tolls shifting speed.

4.2 Participants

Thirteen different companies from the construction industry attended the demonstrations to see and discuss different possibilities for automation in wood house building and how the cooperative work could be solved. Over 30 visitors participated in the demonstration, and each company was represented by two to three men aged 25 to 60. Their occupations within the company were managers, operators, carpenters, and production technicians. 24 out of 30 had no previous experience of working directly with robots in automation, while six had.

They were asked to reflect on how they would feel about going into the cell and cooperating with two active robots. The demonstrations were carried out for a whole day, and around five to ten representatives (or two-three companies) participated in each demonstration. Six separate demonstrations were conducted in the study resulting in a population of about 30 valid respondents. Half of the respondents have an age distribution between 30 and 50, while six are younger than 30 and nine are older than 50.

4.3 The questionnaire

The questionnaire was developed with a focus on the participants' reactions and feelings toward cooperation with active robots. The questionnaire had questions like; Would they enter the robot cell to cooperate? How important is a visible safety system for encouraging the viewer to enter the cell? Does the ability of the robot programmer affect the viewers' judgment of the cell?

The questionnaire intends to try to capture what kind of feelings the participants individually would say they have for interacting with an industrial robot or robot system in action. The questionnaire also contained questions about trust in the safety system and trust or confidence in the developer or programmer of the robot cell.

In the first set of questions, the participants were asked to react to the cell in front of them and the demonstrations they had just watched. In the second part of the questionnaire, they were asked to respond to three theoretical scenarios introducing tasks where they would engage with the robots in different ways. The scenarios refer to the cell in front of them (see Table 1).

Scenario	**Description**
Scenario 1	*Two robots are co-producing a product at full speed. As a spectator, you stand outside the cell, but there are no protecting gates between you and the robot. How would you feel about this setup?*
Scenario 2	*As a spectator, you stand outside a robot cell, and there are no protecting gates between you and the robots. The robots are working at full speed. You are then asked to enter the cell to fetch a tool from the worktable. How would you react to this request?*
Scenario 3	*As a spectator, you stand outside a robot cell, and there are no protecting gates between you and the robot. The robot is working at full speed. The operator demonstrates the function of the camera-based safety system and different safety zones. A screen on the wall also shows the different zones and how humans are detected. After the demonstration, you are asked to test the system and enter the cell to fetch a tool from the worktable with the active robots still running. How would you react to this setup and request?*

Table 1. Scenarios developed and used in the study.

5 Findings

During the observations, the reactions were mostly positive, and the participants seemed intrigued by what they were watching. A lively discussion was going on between the participants about what they saw and how this could be used. The focus of the discussions was on technical details and solutions, therefore the third part of the demonstration was mostly discussed. Cycle times, speed and efficiency were discussed as well as the difference between the nailing gun and the nailing press tool when it comes to noise. The nailing press tool is much more silent, and the participants reacted to how that would change the work environment in their workshops, where nailing guns are used.

We could observe that the factor of the live demonstration influenced the groups' thoughts about interaction with the robot. Since they had seen someone, in this case, the technician, perform work tasks together with the robot live, they were more willing to believe in the possibility of this type of interaction. The reactions we saw during the demonstrations could also be found in the individual answers to the questionnaire. Half of the participants responded that they found the robots fascinating and intriguing. A few also expressed happiness and joy that this automated system could reduce work efforts and make their home workshop more effective. One respondent even described the feeling as love for the robot. However, a rather large group also find robots intimidating and have a great deal of respect for them, especially the six participants with previous experience of working with robots. They also show lower confidence in the safety systems and the camera-based system. One participant reflected on that matter in the observations and stated that he would not go in if he had not programmed the cell himself. This group needs more persuasion and motivation than just the knowledge that their work could be easier if automated in the interactive human-robot cell environment.

Also, in the reflective discussions, different feelings about how safe interacting with an industrial robot is, were brought up. Their reactions seemed connected to their previous knowledge of robot systems and personal encounters with robots and how well they could see benefits with such a system within their own workshop. Some participants discussed from a very personal point of view while, for example, managers had a more holistic or company-based perspective. These observations also match quite well with the response to the first scenario (see Table 1), where the majority answered that they feel safe with the setup. They trust the safety system, but quite a few would feel more relaxed or comfortable if there was a gate in-between. Also, the questionnaire response shows that those with previous experience of actively working with robots were more reluctant to go into the cell. When asked to judge the three additional scenarios, they all answered that they found the situation unpleasant. They would wait for more information or proper assurance that the setup is safe before engaging in any type of interaction.

In Figure 3, the data from the questionnaire is grouped by participants with and without robot experience. It illustrates that those with robot experience are much more reluctant to go into the cell than visitors without this practical experience. However, the exact numbers are of less importance in such a small population but rather their line of reasoning when it comes to safety and trust. The participants with previous experience had examples of how things can go wrong and how easy it is to make mistakes when coding. They also discussed the cases of malfunctioning software or sensors within the cell and what kind of consequences that could have. The participants with planning and management perspectives were more open to ideas from a work perspective and how new ways of automated systems could change their processes. They discussed optimization and how the technology could be best utilized. They based their arguments on that safety is more of a technical problem to solve than a management problem. They related to the cell in front of them and stated, if it was safe and possible for the technician at hand in front of them it should be possible to solve in their own workshop.

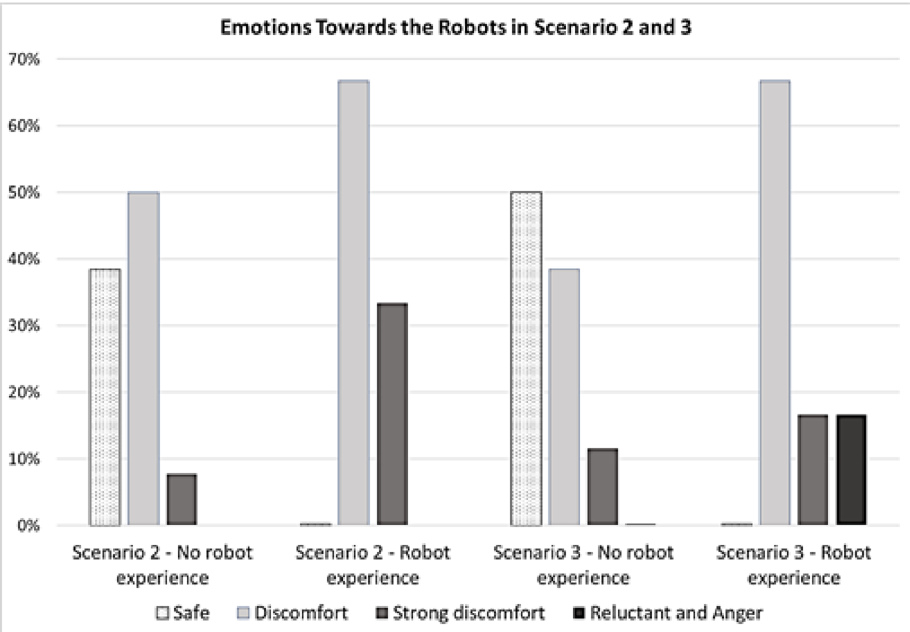

Figure 3. Different emotions in the two scenarios 2 and 3.

When talking to the two engineers that performed the interaction inside the demonstrator, they also expressed respect, nervousness or "being on edge" the first times they ran a new robot operation. When they had tested it a number of times, they could be more relaxed in the cell but never completely relaxed. They must have vigilance (Karasek and Theorell, 1990) since something can always go wrong, and the robot must be stopped. One of the engineers elaborates on the feeling by an example: "at one of the demonstrations, a tube became loose from one of the sensors. If I hadn't immediately stopped the operation, the nail gun would have continued through the plasterboard and the worktable". This example shows that even though the operation had been tested several times and the equipment was examined before the demonstration was initiated, something went wrong, and the engineer had to take action. Lack of control is also a factor the engineers put forward as a parameter that affects their experiences of the robot cell: "there are so many aspects and so many parameters to keep track of in this type of setup, and they can all go wrong at some point." This creates concerns about whether something has been overlooked or missed while setting up and initiating a demonstration session, which creates both fear of something physically dangerous and worry of ruining the demonstration. The engineers also express that they feel safer writing the code used in the cell. The lack of information and knowledge about the code can lead to cautiousness or fear.

6 Discussion and analysis

In this paper, we aim to understand the relationship between fear or distrust and curiosity, with a focus on identifying different trigger points for emotional reactions in the context of human-robot interaction. Based on the work from Chao and Kozlowski (1986) and our discussions with a researcher within psychology, our initial assumptions were to look for three main factors: lack of control, lack of knowledge or understanding, and basic self-preservation of injury or instinct. We also looked for intrinsic and extrinsic behavior.

Many participants expressed respect for the industrial robots used in the demonstration but could also see the benefits from a workplace perspective. We could identify the importance of visually seeing the robots in action to understand what they can do and their benefits to create a larger acceptance and trust in an interactive robot system. It seems very important to explain what a robot could contribute with, in the current context, if it is aimed at saving time, reducing workload, or perhaps expanding business opportunities. This could connect to the first parameter, lack of control, mentioned in Chao and Kozlowski (1986). This parameter could also be strengthened by involving the workforce when designing the robot cell and how different work tasks can be carried out in the new cell. The managers have to work on competence development and letting the staff get familiar with the new technology. From an interaction perspective, humans will be more interested in working in a flexible cell with a robot if they see a benefit for them as individuals. This indicates that unpleasant activities like heavy lifting or monotonous, repetitive operations should be the ones that are prioritized to automate first. That will also correspond well with extrinsic staff that needs extra encouragement to engage.

From the dialogs with the participants and the technicians and the answers about the third scenario, we assume that progress and task order must be thoroughly communicated. It needs to be clear what the robot is doing when it is okay to enter the cell and how the safety systems work to increase the trust in entering the cell. If humans are expected to collaborate with a robot, they need to know what the robot is doing and what tasks are expected next. Clear communication and information will increase the ability to understand how to interact with the robots. To create more trust in the existing safety systems, it seems important first to understand the safety system, what it does and how the robot will respond if they were to enter the cell. The more they know about the robot cell environment, the more they need to be reassured that the safety system has been tested and working correctly. The more knowledge they have about the interaction and its occurrence, the safer they will hopefully feel about the robot. Another factor we could observe, pointed out by participants and the technicians, was *physical safety* and basic instincts of self-preservation. The participants describe reluctance to put themselves in a situation where harm could potentially come to the individual. This factor is especially important in the more reluctant or worried group to accept robot collaboration. However, there seems to be a reversed connection between how well a person understands the operations of the robot and the feeling of safety, hence the need for control. The more the person knows about how to program and set the activities of the robot, the more respect they seem to have, and the more control they would like to have. They know how things can go wrong due to mistakes and earlier experiences.

To sum up, findings from this study suggest that the ability to feel in control of the process, foresee the next step and be able to stop the robot if necessary to create a feeling of control are factors that contribute to trust in a system. We also found that fear, based on previous experience from accidents or injuries or fear based on logical reasoning that the robot can be exceptionally large and lift very heavy objects, leads to a more cautious approach. The latter response is quite reasonable since if a human gets in the way of the robot, they will most likely sustain extensive injury. Therefore, comprehensive safety measures are crucial in accepting a collaborative scenario. The more knowledge a person has about a situation, the more control they usually feel. The inexperienced viewers do not worry about what could happen as much as the participants with previous robot experience. A reason for this may be that they do not foresee the potential danger. They seem not to understand that they should ask for more control, while the participants with previous robot experience are more skeptical. The safety systems play a more critical role and their ability to program and control the robot to earn their trust. To practically implement a flexible robot cell, we would have to overcome or make sure that these factors have been considered; otherwise, the robot cell will not be used.

6.1 Outcome

To summarize the lessons learned from our observations, reflections, interviews and discussions, we conclude with a set of recommendations that try to meet the different trigger points of distrust or uncomfortable situations. Our recommendations or guidelines could be used for interactive aspects in a collaborative robot cell. We sorted our recommendations into three categories based on what trigger point they handle; i) overcome lack of knowledge; ii) overcome lack of control and iii) calm self-preservation.

To overcome lack of knowledge

1. ***Visualization of robot tasks.*** List or graphically display what the robot is doing and in what order. Illustrate the robot motions to indicate where the robot is moving next. Indicate natural breakpoints where it is more effective to "disturb" the robot by entering the cell. Display if a delicate process is ongoing where the robot cannot be interrupted because that will affect the quality of the product or, in the worst case, completely destroy it.
2. ***Visualization of the intended human task.*** List or graphically display human work tasks if the human is supposed to perform something specific in the robot cell. Provide guidance for performing a task and key points in that task. The full sequence should be illustrated if the task is part of a more extensive sequence.
3. ***Visualization of safety.*** Display information about what safety system is being used and how to interact with it. Indicate where it is okay to move without interrupting the robot; safe zones. Indicate that the robot has detected the human and will obey if the human enters an area in a dangerous zone. Display how the robot will move and where it will retract if interrupted. There should also be information about who the programmer is and what type of testing has been performed to ensure the robot programming and the cell's general system functionality. Provide information about or warning signs if there are specific safety risks due to the equipment the robot is using.

To overcome lack of control

1. ***Ability to determine, affect, and stop robot motions.*** The human should have the possibility to impact, influence or change the tasks. There must be compliance between the perceived operation, the displayed movements, and the actual robot motions. The robot motions should also be distinct and predictable to ease decision-making and foresee tasks (Bortot et al., 2013). Provide remote controls that can stop or pause the robot.
2. ***Training and simulations.*** Provide the ability to see an instructor demonstrate the interactive human-robot activities before entering the cell and then provide the ability to practice work tasks with the robot step by step before using it in production.

To calm self-preservation

1. ***Overcome basic instincts.*** Try to identify movements with the robot that trigger stress and feelings of discomfort and avoid those (Bortot et al., 2013). Analyze color schemes of robots and try to use a robot color that will trigger intended emotions.
2. ***Risk assessment and risk visualization.*** Perform risk analysis and inform the human about potential risks and how to overcome them or prevent them before entering to avoid accidents or sudden surprises. Make sure to warn about risk hazards and suggest the correct protective gear.

A starting point for implementing these guidelines would naturally be to study social robots and interactive industrial robots (e.g., Guizzo and Ackerman, 2012; Shibata et al., 2012). Some use a screen to show facial expressions and voice control to communicate, while cameras can represent eyes and motions as a type of body language that can give visual cues to communicate information to the human. Neither of these solutions is obvious or easy to implement for industrial robots in an industrial setting.

Screens and cameras cannot be easily attached to the big robots, and the work environment does not always support this type of equipment. Voice control also has problems since it can be challenging to use this type of system in a noisy factory environment. Nevertheless, a screen could be attached outside the cell or on the cell wall to give information and even show facial expressions if wanted. However, facial emotions would probably not provide the same effect as when the screen is mounted on the robot as a head. Using motions as visual cues could be possible depending on what the robot is doing and how much equipment it has attached. Still, it could affect the quality of the process, and it could also be difficult to make the motions big enough to be detectable. Therefore it would probably be quite difficult to perceive the cues, and they could easily be misunderstood.

Turning to solutions in the industry, signal lights, Andon lights, flashing beacons and light bars are used to show information, status and warnings in the cell. This could also show conformation and acknowledgment of human interruption in the cell in this setting. Instead of verbal communication, the industry uses different sounds to transfer status, motions, and tasks—for example, a beeping sound used for reversing forklifts and AGVs. Other types of bell and ringing signals signal that a machine has finished an operation. These types of sound cues can continuously be used for information transfer in a flexible, interactive cell. Projected pictures and blueprints as an overlay are other possible approaches to providing humans with process information. However, how to practically solve the information transfer and the communication patterns is at this point to be solved case by case. Due to the wide range of tasks, processes and needs for human interaction as a result of the new technology and changes in the safety standardizations in the industry, it is problematic to suggest one single solution for the flexible cell.

7 Conclusion

This study examines a case of human-robot interaction in cooperative manufacturing, focusing on understanding how operators, managers and other participants feel about cooperating with active industrial robots. Three factors were identified to significantly influence overcoming fear, creating trust and encouraging interaction with the robot: knowledge, control, and self-preservation. Based on this, we contribute with a set of guidelines for aspects that have to be practically considered when building this type of flexible robot cell for interacting with industrial robots in a real setting. Findings from this study highlight the importance of focusing on how to earn trust and understanding when introducing technology into a work environment instead of fear and worry. We also identify a need to compare solutions between different areas of expertise when introducing new digital technology. Many organizations have a long experience with automation and robotization, and by sharing information and experiences, we could try to define more generic models based on our guidelines and practical experiences

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