In: Aldinhas Ferreira M.I., Fletcher S.R. (eds) The 21st Century Industrial Robot: When Tools Become Collaborators. Intelligent Systems, Control and Automation: Science and Engineering, vol 81. Springer, Cham. https://doi.org/10.1007/978-3-030-78513-0_6

# Trust in industrial human-robot collaboration

George Charalambous and Sarah R. Fletcher

Much has already been written about the importance of 'trust' in new technology over the years. It now seems that the role of 'trust' in ensuring the success of new systems is universally accepted. However, the concept of 'trust' and the particular role it plays in a situation is very rarely examined and understood. Trust reflects a state where one is willingly placing themselves in a vulnerable position on the expectation that the other party will perform a particular action, important to the trustor, regardless of whether their action can be controlled or monitored. This means that trust is not fixed and is likely to be affected by contextual factors. For example, a skydiver's trust in their parachute opening correctly will naturally be formed by technical factors about that situation that are completely different from, say, a parent's trust in the behaviour of their children at school! Equally, the same principles are applicable to a context/setting where humans are interacting seamlessly in close physical proximity to industrial robots. In this industrial robotic setting, a worker's trust in a robot is a specific type of trust made up from very specific attributes of the system / environment. Unfortunately, very little – if any – of the literature on this subject considers the concept of trust in this specific context.

The purpose of this chapter is to:

(a) Introduce the concept of 'trust' as a key human factor to facilitate successful interactions between human operators/users and automated systems – section 1.

(b) Provide a literature review of trust in generic human-automation interactions and then highlight how trust can vary in relation to human-robot interactions – section 2.

(c) Introduce the concept of industrial human-robot collaboration and how the industrial context adds a layer of complexity which only recently has been explored. On this basis, trust is discussed as a fundamental element that can enhance the effectiveness of the collaboration – section 3.

(d) Discuss the outputs of recent empirical works on the topic of trust in industrial HRC carried out at Cranfield University – section 4.

## 1. Introduction to Trust

Trust represents an essential feature of daily human interactions, whether it is with other people or with interfaces and systems. In human-to-human relationships, Rotter (1967) described trust in terms of relying on behaviour, verbal or written statements or promises from others. Mayer, Davis and Schoorman (1995) defined trust as the willingness of "*a party to be vulnerable to the outcomes of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party*" (p.712). This introduces a degree of vulnerability – individuals are willing to put themselves in a vulnerable position by giving the responsibility for actions to another individual (Lee and See, 2004). For

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example, people can trust someone if they are reliable, but lose trust when they experience being let down by them; any redevelopment of trust will then require more successful experiences of not being let down, over time, in order for them to trust again and reach previous trust levels. Similarly, trust in a non-human system is built upon experience of the system not failing, and is diminished when a system is found to be unreliable or unsafe. Trust in a robot depends on how well it is perceived / experienced to be reliable and safe.

Since trust can have a significant impact on performance outcomes, the development of trust between humans and machines cannot be neglected. Hence, extensive research over the years has focused on the development of trust in automated systems (Lee and See, 2004; Madhavan and Wiegmann, 2007). With automated systems becoming highly utilised for a variety of tasks (Murphy and Burker, 2010), trust has been highlighted to be a key human factor that can determine the success of the interaction (Parasuraman and Riley, 1997).

# 2. Trust literature review

## 2.1. Generic human-automation interactions

Trust is a vital component for the successful co-operation within any team, regardless of the entities that form it. In the context of human-automation teaming, trust can influence the willingness of humans to rely on the information provided by an automated system (Freedy, de Visser, Weltman and Coeyman, 2007; Park, Jenkins and Jiang, 2008). If, for instance, a person enters a lift / elevator and pushes the button for the 5$^{th}$ floor but the lift stops at the 7$^{th}$ floor, then the human will, naturally, question the reliability of the lift system and their trust in it will be reduced. When experiences lead to a change in trust levels we see behavioural consequences. For example, studies have demonstrated that a lack of trust in an automated partner will eventually lead the operator/user to intervene and attempt to take control (de Visser, Parasuraman, Freedy, Freedy and Weltman, 2006; Steinfeld, Fong, Kaber, Lewis, Scholtz, Schultz and Goodrich, 2006). However, on the other hand, over-trusting an automated system can result in the user losing situation awareness and/or developing complacency that means they may passively accept all information provided by an automated system and not intervene – which obviously impacts on performance and safety.

In the domain of human-automation interaction, a trust definition that has been widely cited is by Lee and See (2004) and defines trust as "*the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability*" (Lee and See, 2004, p54). Subsequently, trust becomes a key component in human-automation interactions as the user/operator, must be willing to depend on the actions of another party.

Lee and See identified trust antecedents are based on three factors, namely purpose, process and performance. The purpose factor is related to the level of automation used, the process factor relates to whether the automated system employed is suitable for the specific task while the performance factor relates to the system's reliability, predictability, and capability. In addition, the degree of the system's transparency and observability available to the human partner has been found important for the development of trust in human-automation interaction (Verberne, Ham, and Midden, 2012). Furthermore, task complexity has been suggested to have an impact on the

level to which the human operator relies on the automated system (Parasuraman, Molloy and Singh, 1993; Mazney, Reichenbach, and Onnasch, 2012).

Research has also been directed to investigate people's perceived reliability of automated assistance versus human assistance (Dzindolet, Pierce, Beck, Dawe, and Anderson, 2001b) and machine-like agents versus human-like agents (de Visser, Krueger, McKnight, Scheid, Smith, Chalk and Parasuraman, 2012). Dzindolet and colleagues (2001b) suggested that humans tend to view automation as being more reliable compared to a human aid, despite the same information being provided both by the automation and the human aid. Further on this, Lyons and Stokes (2012) found that as the risk level increased, human reliance on automation support increased when compared to human support. Potentially this can lead to automation misuse or overtrust, which can be detrimental (Parasuraman and Riley, 1997). Therefore, calibrating appropriate levels of trust is vital for the success of the interaction.

## 2.2. Human-robot interactions

Robots and robotic systems, despite having a degree of automation, also have different attributes not possessed by general automated systems. The International Organisation of Standardisation (ISO) defines a robot as an "automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications" (ISO10218-1, p2). As such, robots may include some particular attributes which introduce an additional layer of complexity. For instance, robots can be mobile, have different physical embodiments or various degrees of anthropomorphism, be of varying size depending on the application being used, may include an end-effector, and are often designed to fit a purpose. These attributes have the potential to tease out different human/user responses when interacting with robots than with any other, static, automated system. Subsequently, trust development in human-robot interactions may be affected by different factors.

Over the past 15 years, literature investigating trust development in human-robot teams and the factors that influence it, has expanded significantly. A key publication by Hancock, Billings, Oleson, Chen, De Visser and Parasuraman (2011) involved a meta-analytic review in a bid to provide an initial framework of trust antecedents in human-robot teaming. Their review of 29 empirical studies provided quantification of the effects of the various factors influencing trust in human-robot interactions. Robot-related factors appeared to be a key element, and these were split in two sub-categories: performance-based factors (such as reliability, predictability, behaviour) and attribute-based factors (e.g. size, appearance, and movement). Perhaps unsurprisingly, these were found to be of primary importance in the development of trust.

Robotic attributes, such as the size of the robot, its degree of anthropomorphism and proximity to the human partner, have attracted attention from the research community. For instance, a highly anthropomorphic robot can generate high expectations that it may not be able to satisfy in practice thus resulting in the disappointment of human partner (Bartneck, Croft, Kulic and Zoghbi, 2009). This is suggested to be a result of human establishing an emotional connection and trust with the robot as a result of its human-like appearance and demeanor (Li, Rau and Li, 2010).

Robot size is another type of physical attribute that has received attention in relation to human trust. Tsui, Desai and Yanco (2010) found that robot size can influence human level of trust when

a robot and a human bystander cross paths in a narrow corridor scenario. In particular their study suggested that participants appeared to trust a small mechanoid robot more than a larger one.

Similarly, robot performance characteristics (e.g. reliability, predictability) represent the second key category for trust development. When a human operator cannot predict what the robot is about to do, trust decreases (Ogreten, Lackey and Nicholson, 2010) whilst similar decreases in human trust can be expected when a robotic system demonstrates poor reliable (Dzindolet, Peterson, Pomranky, Pierce and Beck, 2003).

Although these studies enhance our understanding as to how trust may be fostered and developed in human-robot interactions, the bulk of the work involved robots in a social and healthcare settings, whilst work has also been directed to explore trust development in a military context (Yagoda and Gillan, 2012). Little research, however, had been directed in understanding how trust develops in an industrial context, where industrial robots may work seamlessly with human operators to complete a manufacturing task. In an industrial environment, where robots are seen as tools to enable the completion of a task, grasping how human trust develops when collaborating seamlessly in close proximity with an industrial robot can be key for a successful interaction.

# 3. Industrial human-robot collaboration

A significant amount of assembly tasks in various manufacturing processes still require the flexibility and adaptability of the human operator (Ding and Hon, 2013). For example, humans react very well in response to external influences and variabilities and are superior in physical dexterity and cognitive reasoning, such as engineering tolerances or process variations. At the same time, however, industrial robots can handle high payloads with greater speed, accuracy and repeatability, do not suffer from fatigue whilst the risk of operating in challenging workspaces (e.g. confined spaces or unhealthy environments) is minimised. In such processes, it is neither feasible nor cost-effective to introduce full automation. A hybrid solution where human operators collaborate seamlessly alongside industrial robots offers an optimum solution as the weaknesses of the robot can be complemented by the strengths of humans and vice versa. This type of industrial human-robot collaboration (HRC) gained momentum in manufacturing industries [2–5].

Aerospace manufacturing have also shown greater interest in the prospect of having more closer, and eventually seamless, collaboration between human operators and industrial robots. Work by OC Robotics and Airbus has seen the development of ‘snake-arm’ robots to assist the assembly tasks within aircraft wing boxes (Buckingham et al., 2007). Currently, when the aircraft wing is closed-out in a box, aircraft fitters need to enter the wing box through small access panels while carrying power tools to perform a variety of tasks. The narrow access opening does not allow sufficient room for manual work to be carried out efficiently. This problem is particularly emphasised in wing sections where the wing is too small for a person to enter inside. At the same time, health and safety issues are raised when working within a confined space for a prolonged period of time. In such situations conventional off-the-shelf automation is impractical. A potential solution explored was the development of ‘snake-arm’ robots (Buckingham et al., 2007). A standard single arm industrial robot is used which employs a snake-arm and represents a long slender ‘proboscis’. In this way, the slender snake-arm section can advance into the wing box or any restricted section where human operators cannot reach. The snake-arm robot can follow a

route into the section under investigation either by joystick control or from a pre-determined of path. In addition, the system has been designed to allow automatic operation without the operator being present, semi-automatic where the operator is initiating a program and supervises the robot and manual tele-operation where the robot is controlled via a robot control system (Buckingham et al., 2007).

Apart from the snake-arm robot, the concept of industrial HRC has also been considered to optimise the equipping of aircraft with internal services such as attachment of aerodynamic surfaces with the use of industrial robots. To date, this area of aircraft manufacture remains exclusively manual (Walton, Webb and Poad, 2011). The typically lengthy assembly methods and tight tolerances utilised in aerospace manufacturing of +/−0.25mm or less, have historically made the application of off-the-shelf automation almost impossible (Devlieg, 2010). Walton, Webb and Poad (2011), however, suggested that a potential solution to overcome these challenges would be a metrology assisted human-robot collaborative system. The aim of this system is to optimise the assembly process by utilising an industrial robot to position the parts whilst the human operator performs the attachment process which requires high level of dexterity. A metrology assisted demonstrator cell was developed at Cranfield University where a typical equipping process is performed using realistic parts (**Error! Reference source not found.**).

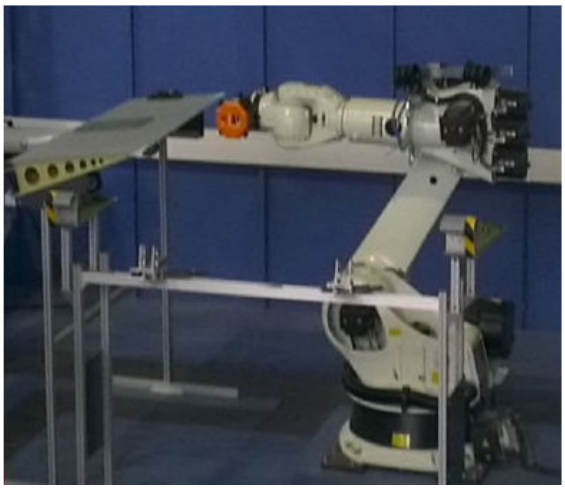

Figure 1: A metrology assisted demonstrator cell using a high payload industrial robot

This initiation demonstrated that a HRC system can be the solution into labour intensive aircraft equipping processes. The robotic partner will execute the “non-value adding” process of accurately positioning the surface while human operators will be utilised to perform the highly dexterous task of attaching the component.

In light of these technological advancement in metrology systems and industrial robotics, health and safety regulations have been updated to reflect that in some circumstances it is safe and viable for humans to work more closely with industrial robots (ISO 10218:1: 2011). Integrating humans and robots within the same workspace is bound to raise human factors challenges. As discussed in sections 2 and 3, one key human factors element that can determine the success of such a system is the degree of trust of the human operator in the robotic teammate (Chen and Barnes, 2014). With the concept of industrial HRC being embraced further, trust needs to be

explored in depth in order to achieve successful acceptance and use of industrial robotic teammates. Furthermore, given that industrial robots come in various shapes, sizes and degrees of anthropomorphism depending on the application being used, understanding how trust develops in this setting is crucial.

# 4. Measuring trust in industrial human-robot collaboration

To understand how trust develops between human workers and industrial robots, it is important to be in a position to measure it. Existing measures of trust have been heavily focused on automation, such as automated teller machines (Singh, Molloy and Parasuraman, 1993) and automated process control systems (Muir and Moray, 1996; Jian, Bisantz, Drury, 2000; Master, Gramopadhye, Melloy, Bingham and Jiang, 2000). Additionally, trust measures have been developed for human interactions with military robotic systems (Yagoda and Gillan, 2012), and Schaefer (2013) developed a trust scale to evaluate changes in trust between an individual and a robot in general. However, the context of these previous works has been different from that of an industrial HRC setting. In military human-robot teaming, the functions and goals of both agents are obviously very different from those in an industrial scenario, and even the characteristics of industrial robots can be quite different to those possessed by military robots. Whilst the development of other measures provided a springboard to understanding trust, trust development between human operators and industrial robots will be influenced by context-specific factors that are quite different from generic or other context human-automation interactions so a trust scale that has been created from generic or alternative context scenarios is unlikely to be suitable. The difference in robotic attributes discussed in section 3 mean that alternative factors can be at play influencing human trust development in the industrial environment and, therefore, an effective scale needs to measure these particular contextual attributes. After extensive searching of previous research work, to our knowledge no measure has been developed specifically to evaluate trust in industrial HRC. With significantly increasing deployment of robotics in industry, this presents a major gap in design capability so there is a need to develop a measurement tool for this purpose. The following section describes the work carried out by the authors to develop a psychometric scale for evaluating trust in industrial HRC.

## 4.1. Development of the trust scale

### Exploratory study

Due to little understanding regarding the influence of trust in an industrial context, the authors started out their objective to create a new context-specific measurement tool for the industrial context by carrying out an exploratory study to gather participants' opinions in a qualitative fashion. This approach led to the generation of trust related themes relevant to the industrial robot context. Specification of the procedures, methods and data analyses that were employed in this initial exploratory work are available in Charalambous, Fletcher and Webb (2016). The output results revealed a number of trust-related themes which were grouped in three high level elements, namely: robot, human and external. Figure 2 below shows these themes and the frequency of occurrence in participants' responses.

| Element | Trust-related themes | Lower level theme | Frequency |
|---|---|---|---|
| Robot | Performance | Motion of the robot | 21 |
| | | Robot and gripping mechanism reliability | 20 |
| | Physical attributes | Robot's size | 18 |
| | | Robot's appearance | 15 |
| Human | Safety | Personal safety | 17 |
| | | Robot's safety features | 11 |
| | | Safe programming of the robot | 6 |
| | Experience | Priorexperiences with robots | 14 |
| | | Mental models of robots | 9 |
| External | Task | Task complexity | 15 |

Figure 2: Trust-related themes that emerged from the exploratory study

In line with previous research, the robots' performance was one the most highly discussed themes among participants. Specifically, the motion of the robots was found to be a key trust-relate topic not least the way the robots moved and the speed at which they grasped the components. Participants views elaborated extensively that the robots employed a smooth and fluid motion when moving which was found to be comforting. Also, participants highlighted that the speed at which it grasped the components allowed sufficient time to react and predict what it was intending to do.

Another prevailing attitude among participants was the perceived reliability of the robots and the gripping mechanisms. Participants discussed that they could trust the robots because they completed the respective tasks accurately. Also, participants paid attention to the gripping mechanism of each of the robots. Participants felt they could trust the robot because the gripping mechanism did not drop the components during the collaboration.

Physical attributes received attention by the participants. The majority of participants elaborated that the robots' size had an influence on their perceived trust in the robot upon first encounter. Most of the participants felt intimidated by the size of the medium-scale robot prior to the interaction. The dominant view is that upon encountering the robot, participants felt intimidated by its size and appeared to be worried about interacting with it. Some participants discussed that the robots' general appearance can influence their trust. Participants found that a robot with a simple design is preferred to interact with as it is perceived less like a robotic machine which increases trust.

Safety was among the most frequently discussed themes. 17 participants mentioned that trust in the robots was influenced by their feeling of personal safety during interaction. Participants' comments suggested the main safety concern was to avoid being hit by the robot. Also, six

participants elaborated they had faith that the robot had been programmed correctly by its operator. In addition, prior experiences with robots received attention by participants. 14 participants suggested that any prior experiences interacting with industrial robots would have influenced their trust. Specifically, participants elaborated that having prior exposure to similar robots would have reduced their initial anxiety. In addition, nine participants commented their trust in the robot was affected by their mental models. It appeared that participants had pre-conceived notions of robots, mainly through mainstream movies, and these had an initial influence in their level of trust as some expressed a general belief the industrial robots are fast, jerky and quite intimidating.

Task complexity was the only external related trust theme emerging through the interviews. 15 participants discussed that the complexity of the task had an influence on their trust towards the robot. Participants commented that the interactive task was not significantly challenging and this aided them to have greater trust in the robot.

As a result of these trust-related themes generated by the exploratory study, a questionnaire was developed with twenty-four items relevant to each low-level theme. Reverse-phrased items were introduced to minimise participant response bias, whilst the items were randomly placed in the questionnaire.

The next step towards the development of the trust scale was to carry out a series of industrial HRC tasks whilst using the questionnaire to gather participants' level of trust. The data would then be subjected to a factor analysis to determine the factors affecting trust in industrial HRC and to produce the trust scale. This is described in section 5.1.3.

### Scale development

Three human-robot trials in laboratory conditions were carried out using three different types of robots. Tasks represented potential industrial scenarios where humans and robots would collaborate. Three independent groups of participants were recruited. Upon completing the task, participants completed the survey developed from the exploratory study. Although the purpose is not to replicate the working methods already reported in detail in Charalambous, Fletcher and Webb (2016), it is deemed appropriate to provide a high-level description of the work carried out to provide the necessary context.

Trial 1 consisted of 60 participants (15 female, 45 male; M=30.6, SD=9) from Cranfield University. 19 participants reported having some experience with robots and automation while 41 reported having no prior experience with robots and automation. Trial 2 included 50 participants took part (13 female, 37 male; M=30.9, SD=9.6) from Loughborough University. 20 participants reported having some experience with robots and automation while 30 reported having no prior experience with robots and automation. Finally trial 3 consisted of 45 participants (19 female, 26 male; M=30.7, SD=10.3) from Cranfield University. 17 participants reported having some experience with robots and automation while 28 reported having no prior experience with robots and automation.

All three studies were an independent design at laboratory conditions. In trial 1, participants interacted with a single arm industrial robot to complete an assembly task. In trial 2, participants

interacted with a twin arm industrial robot to complete an identical task to study 1. In trial 3, participants interacted with a single arm industrial robot to complete a pin insertion task.

For each trial a different industrial robot was used with varying payload capability. The tasks employed were of comparable level of complexity and represented a simplified form of typical assembly tasks found in manufacturing settings. For instance, in Trials 1 and 2 participants collaborated in close proximity with industrial robots (45kg payload robot for trial 1 and 20kg payload robot for trial 2) to complete a simple fitting assembly – the robot would pick up and present two sets of drain pipes (reflecting the non-value adding part of the task) whilst the user fitted the plastic fittings provided (reflecting the value-added part of the task). In trial 3, the robot (200kg payload capability) lifted a representative aerospace sub-assembly, placed it into position and the user then applied two metallic pins to secure into the bearings. The reason for choosing different types of robots and, somewhat, different tasks (trial 1 and 2 vs trial 3) was to gather trust data using the questionnaire developed in realistic scenarios (so far as is reasonably practicable) of industrial human-robot collaboration likely to be encountered in manufacturing settings. Figure 3, **Error! Reference source not found.** and **Error! Reference source not found.** below show the industrial robots and materials used in these trials.

Figure 3: Trial 1 material and equipment used: Single arm industrial robot (left); laser scanner (centre); assembly task materials (right)

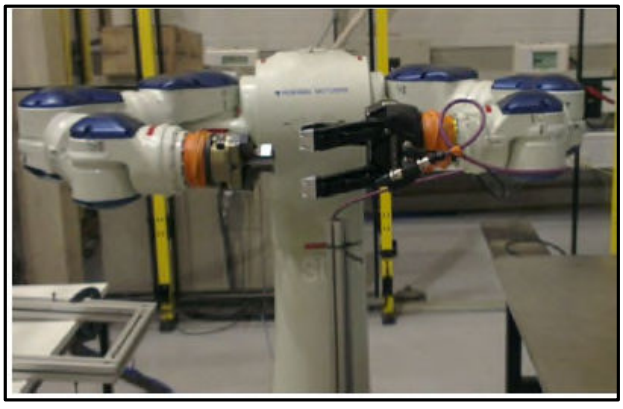

Figure 4: Twin arm industrial robot used for Trial 2

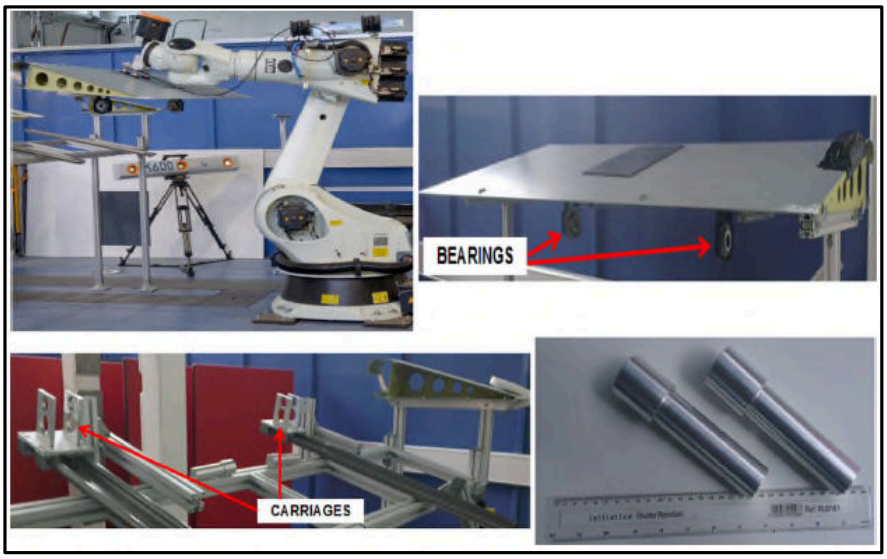


Figure 5: Trial 3 material and equipment: Industrial robot (top left); aerospace sub-assembly (top right and low left); metallic pins for securing the sub-assembly (low right)

Due to employing different types of robots and having some variability in the tasks for each trial (albeit of comparable complexity), an exploratory data analysis was carried out to identify whether participant responses to the questionnaire differed significantly between the three trials. The findings suggested that whilst participants in trial 1 experienced somewhat higher trust in the robotic teammate ($M = 96.75$, $SE = 1.160$), when compared to the participants in study 2 ($M = 93.88$, $SE = 1.359$) and study 3 ($M = 95.51$, $SE = 1.527$); this difference was not statistically significant $F(2) = 1.228$, $p > 0.05$. On this basis, the data from the three trials were merged into a single dataset, providing 155 cases. This new dataset was subjected, initially to a Preliminary Reliability Analysis, to eliminate questionnaire items which did not contribute to the overall reliability. A total of eleven items were removed and the remaining thirteen were subjected to an iterative Principal Components Analysis (PCA); this revealed the emergence of three components:

- Component 1 was labelled ‘Safe co-operation’, it consisted of four items and had a Cronbach’s alpha of 0.802.
- Component 2 was labelled ‘Robot and gripper reliability’, it consisted of four items and had an alpha value of 0.712.
- Component 3 was labelled ‘Robot’s motion and pick-up speed’, it consisted of two items and resulted in a Cronbach’s alpha of 0.612.

The developed scale and the three major components are shown below:

| Scale item | Major components |
|---|---|
| The way the robot moved made me uncomfortable | Robot's motion and pick-up speed |
| The speed at which the gripper picked up and released the components made me uneasy | |
| I trusted that the robot was safe to cooperate with | Safe Co-operation |
| I was comfortable the robot would not hurt me | |
| The size of the robot did not intimidate me | |
| I felt safe interacting with the robot | |
| I knew the gripper would not drop the components | Robot and gripper reliability |
| The robot gripper did not look reliable | |
| The gripper seemed like it could be trusted | |
| I felt I could rely on the robot to do what it was supposed to do | |

Figure 6: The developed trust scale with the three major factors affecting trust in industrial HRC

One of the major components identified through the analysis was safety during the co-operation between the human and the industrial robot. This finding is consistent with earlier work, suggesting that a positive level of perceived safety can be a key element for the successful introduction of robots in human environments (Bartneck, Kulic and Croft, 2009). This is no surprise, as interacting in close proximity with industrial robots of high payload capability can be intimidating whilst Health & Safety of the employees working in a seamless collaboration scenario is paramount. This finding is in line with previous research which highlighted that if a robot is to be successfully integrated within the human environment, it must be first perceived as safe by the human partner (Shiomi, Zanlungo, Havashi and Kanda, 2009).

The performance aspects of the robotic system and specifically, the reliability of the robot and the end-effector (i.e. gripping mechanism) was the second trust related component. Robot reliability is in line with previous and more recent literature (van den Brule, Dotsch, Bijlstra, Wigboldus, Haselager, 2014). As discussed earlier the meta-analysis by Hancock and colleagues (2011) suggested that robot performance-based factors (e.g. reliability) had the highest impact on trust. Furthermore, van der Brule and colleagues (2014) reconfirmed that a robot's task performance influences human trust. The findings of this study highlight once again the criticality of a reliable robot system. An unreliable robot will eventually decrease operator's trust which in turn will be detrimental for accepting and using the robot. Also, considering that humans are far more sensitive to automation errors which can lead to a significant drop in trust (Jian, Bisantz Drury, 2002) robot reliability becomes a very important aspect.

Interestingly, the reliability of the end-effector (in this instance the gripping mechanism) appeared to have an impact on trust. To our knowledge, this context-specific element has not appeared in previous literature. This is of particular relevance to industrial HRC, since the gripping mechanism is a vital component of an industrial robot. The gripping mechanism is the mean with which the robot will manipulate components and interact with the human partner in a collaborative task. As industrial robots come in a variety of gripping mechanisms depending on the task being utilised for, findings suggest that the reliability of the gripping mechanism is an important determinant for trust development. When the reliability of the gripping mechanism decreases, human trust in the robotic partner decreases.

The third trust component was relevant to the robot's motion and the component pick-up speed. It appears that the motion of the robot is an important factor for the development of trust. This is in line with previous research indicating that robot's movement can assist the human partner to predict and anticipate robot's intentions (Mayer, Kuz, and Schlick 2013). A fluent, non-disruptive robot movement can put the human partner at ease and foster trust. This is particularly important for an industrial environment where the robot is likely to be collaborating in close proximity with a human operator. Furthermore, industrial settings can be cluttered with people, machinery, tools and other equipment therefore it is important for other operators to predict the robot's movement. Also, the final component suggested that the speed at which the gripping mechanism picks-up components has an impact on the development of trust. Similar with the previous component (robot and gripper reliability) the robot's gripping mechanism appears to have an important role in the development of trust.

Somewhat surprisingly, the analysis did not suggest that the appearance of the robot was a contributing component to trust development. Previous literature in the domain of social robotics provides contradicting results in terms of the effects of robot appearance on user preferences; some suggest robots should not be too human-like in appearance whereas others indicate that more human-like appearance can engage people more (Bartneck, Kanda, Mubin, and Al-Mahmud, 2009). Prakash and Rogers (2014) found that human perception of a robot tends to vary based on the robot's human-likeness. According to their findings, humans tend to over-generalise the capabilities of a very human-like robot. At the same time however, earlier literature stressed that anthropomorphic appearance should be treated with care in order to match the appearance of the robot with its abilities without generating unrealistic expectations to the human user [Bartneck, Kulic, Croft, 2009). This finding may further strengthen the view that people perceive industrial robots as tools used to complete a task. It is acknowledged however that our understanding on this is still growing and further work should be geared to explore the effects or industrial robot appearance on human trust.

## Summary of the scale development

The outputs of this work provide an initial platform to enable the quantification of trust in a unique and largely unexplored context such as industrial-human robot collaboration. Furthermore, they highlight the key factors that determine trust development in this specific context. As discussed at the beginning of this chapter it is important to remember that trust is a state influenced by contextual factors and there is a need for such a measurement tool for the context of industrial HRC design. Having the ability to distill the factors that foster trust in an industrial human-robot collaboration context enables system designers and organisations to focus on the system characteristics that can affect users' perception of trust. Finally, the reliability levels achieved by the three sub-scales/components is encouraging. Component 1 and component 2 achieved reliability of 0.802 and 0.712 respectively which is above the generally acceptable level of 0.7 (Nunnally 1978; Bartneck, Croft, Kulic and Zoghbi 2009). The third component which achieved 0.612, although slightly below the 0.7 mark, it still reflects a good reliability figure given that there are only two items in this sub-scale

## 5. Conclusion

Development of this new industrial HRC trust scale has been a worthwhile venture as there was a need for a tool that would reliably measure this type of 'trust' for the purposes of research and development to enhance system design and efficacy. To that end it has already been used in a number of subsequent research studies in the UK and Europe and found highly effective for gauging levels of user trust in relation to system characteristics. An important ongoing area of work is that the trust scale is being used to develop key behavioural rules such as the relationship between robot speed and trust, robot size and trust, robot autonomy and trust, etc.

In summary, the trust scale developed provides an initial practical tool to quantify the perceived level of human trust in an industrial human-robot collaboration setting. The tool provides practical Human Factors implications that would assist the successful deployment of collaborative industrial robots in manufacturing settings. First, the tool offers the opportunity to quantify trust specifically in industrial HRC. Second, the three major factors identified in the scale highlight to system designers and engineers understand the key system characteristics that can affect operators' perception of trust in industrial HRC. For instance, the scale identified three key design aspects fostering trust industrial HRC namely, perceived safe cooperation, perceived robot and gripping mechanism reliability and perceived robot's motion. Therefore, emphasis needs to be given on these system characteristics. Third, this scale can assist to examine the relationship of each operator and enhance awareness regarding personal tendencies. For example, a poor score on a sub-scale (e.g. robot and gripping mechanism reliability) or on the entire scale can identify those operators in need for further training.

## 6. Acknowledgements

The research was funded by the EPSRC Centre for Innovative Manufacturing in Intelligent Automation

Special thanks to the laboratory technical staff at Cranfield University, Mr John Thrower, and Loughborough University for their assistance, support and providing technical expertise in carrying out the human-robot collaboration trials.

**Affiliations**: George Charalambous is currently a senior human factors consultant for SYSTRA Scott Lister. George has completed a PhD at Cranfield University funded by the EPSRC Centre for Innovative Manufacturing in Intelligent Automation. George's research interests revolve around the exploration of the human factors to enable the successful implementation of human-robot/automation collaboration in safety critical systems, such as rail automated systems.

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**Charalambous, George; Fletcher, Sarah R.**

**2021-10-26**
Springer
https://doi.org/10.1007/978-3-030-78513-0_6
Charalambous G, Fletcher SR. (2022) Trust in Industrial Human–Robot Collaboration. In: The 21st Century Industrial Robot: When Tools Become Collaborators. Intelligent Systems, Control and Automation: Science and Engineering, Volume 81. Springer, Cham

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