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Technology Factors Affecting Australian Manufacturing SMEs Adoption of Collaborative Robot Technology: A Qualitative Interview Study

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Abstract

Within the context of rapidly evolving technologies, collaborative robots (cobots) are revolutionizing the manufacturing processes of small and medium-sized enterprises (SMEs) and transforming the entire work structure. Several studies have highlighted cobots from an individual level; however, little attention has been given to empirical research that focuses on adopting cobots from an organisational perspective in SMEs. This paper aims to focus extensively on understanding technology factors that may potentially affect Cobot's adoption process within the firm. Based on the Diffusion of Innovation theory (DOI), the paper utilised the five technology factors and followed a semi-structured interview method with decision-makers in Australian manufacturing SMEs. Results discovered the relative advantage revealed is the most significant factor. The other three factors, compatibility, trialability and complexity, were noted to have a lower impact, and the final factor, observability, had an unclear influence. This paper also discussed the mechanisms underlying these impacts and the potential implications.

Keywords: Adoption, SMEs, Collaborative robots, DOI

Introduction

The manufacturing sector has a considerable impact on the development of any country, acting as a backbone for the creation of jobs and the growth of industrial companies. In Australia, this sector is mainly made up of SMEs (1-99 employees), which make up 66% of jobs and contribute to 50% of the total value added (ASBFEO2020).

Significant transformations in business performance have occurred due to the emergence of technological innovations in SMEs (Shahadat et al. 2023). Manufacturing industry decision-makers, such as CEOs, IT managers, and other IT professionals, are likely to discover the potential for success and the issues surroundingthe introduction of new technologies. In recent years, collaborative robots have emerged as a new technology in industrial companies (Hentout et al. 2019; Kopp, Baumgartner & Kinkel 2021); they are designed to work without safety cages and achieve real collaboration between humans and machines; it is evident that collaborative robots have the ability to expand the application of robots significantly (El Zaatari et al. 2019; Kildal et al. 2018). Given collaborative robots features over conventional industrial robots in terms of user-friendly interfaces and being lightweight, all aimed at improving user satisfaction, health and safety (Kopp, Baumgartner & Kinkel 2021). These characteristics make collaborative robots specifically suitable for SME environments, where the flow of products can change quickly (Schnell & Holm 2022) and produce small-batchand customized products (Belhadi, Touriki & El fezazi 2018). However, the research on the industrial Human-Robot Collaboration (HRC) is still limited, particularly in SMEs (Kopp, Baumgartner & Kinkel 2021)

Empirical research at the organisational/firm level is rare, and the existing studies primarily focus on the individual level to adopt cobots (Bröhl et al. 2019; Prassida & Asfari 2022). Although few empirical investigations at the organisational level have attempted to understand collaborative robot adoption in large companies (Correia Simões, Lucas Soares & Barros 2020) and SMEs (Liu & Cao 2022), there is still lacking a deeper understanding of mechanisms and discussing technology factors in detail in the SME context. To the author's knowledge, publications on cobot acceptance/adoption in Australian manufacturing SMEs are scarce. Consequently, this paper explores technology factors related to collaborative robot adoption in Australian manufacturing SMEs. Using the Diffusion of Innovation (DOI) theory (Rogers 2003), this paper aims to uncover the attributes of technology related to collaborative robot adoption and determine a thorough understanding mechanism.

This paper first gives a brief introduction. In the second part, the paper provides an overview of the theory. The third part deals with the method used in this paper. Following this, the paper provides the results in the fourth part. The fifth part presents the discussion. The paper concludes in the final part.

Theory

The DOI theory (Rogers 2003) is an innovation adoption theory that identifies the factors that influence the adoption of new technology or ideas within society. Users' perceptions of innovation and technology characteristics are mostly considered to be the basis of this theory. It can be used at the enterprise/organisational level of research (Lai 2017; Tarhini et al. 2015)

An innovation is defined by (Rogers 2003) as "an idea, practice, or object that is perceived as new by an individual or another unit of adoption". A collaborative robot is an innovation in the manufacturing sector because it brings together advanced technology and operational flexibility to create more efficient production environments. It offers a range of benefits that make it a promising solution for improving processes and addressing the industry's needs (Matheson et al. 2019; Simões et al. 2022)

Table 1: The Five Innovation Attributes

Attribute	**Definition**	**References**
Relative advantage	“the degree to which an innovation is perceived as superior to its predecessor”	(Rogers 2003, p. 229)
Compatibility	“the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters”	(Rogers 2003, p. 15)
Complexity	“the degree to which an innovation is perceived as relatively difficult to understand and use”	(Rogers 2003, p. 15)
Trialability	“the degree to which an innovation may be experimented with on a limited basis”	(Rogers 2003, p. 16)
Observability	“the degree to which the results of an innovation are visible to others”	(Rogers 2003, p. 16)

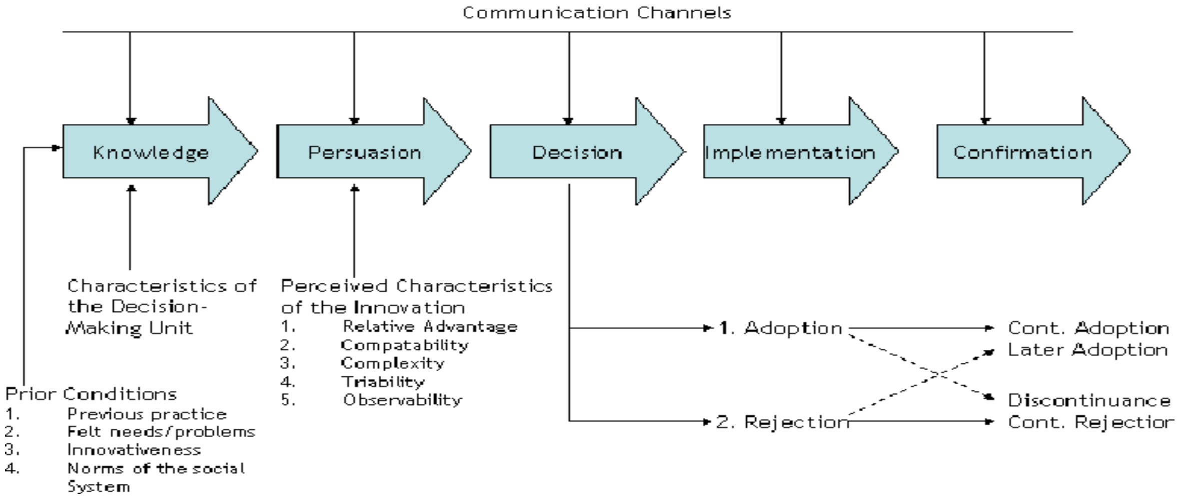

Figure 1. The Five Steps of the Innovation-Decision Process

The decision-making process in DOI theory involves five steps, as presented in Figure 1. In the successful process, all these steps are essential, but in particular, step 2 (persuasion) is considered significant when adopters decide to adopt (or not adopt). This step is based on five main attributes of innovation, as seen in Table 1, which provides a concise overview of their definitions. As Rogers (2003) observed, complexity is the only attribute that negatively influences innovation. There is still agreat deal of study to be done in SMEs environments to explore collaborative robot adoption (Liu & Cao 2022). Furthermore, it is important to understand the full extent of DOI characteristics of collaborative robots in this area. According to the author's understanding, no previous studies have investigated in Australia. Therefore, this paper analyses the impact attributes' of collaborative robots and discovers the essential mechanisms by applying qualitative research.

The paper addressed the following questions:

1) What are the collaborative robot technology factors adoption in Australian manufacturing SMEs?

2) What mechanisms support the significance of technology factors in facilitating the adoption?

Method

The current study employed a semi-structured interview with participants responsible for decision-making for their companies, such as directors, CEOs, and IT managers in Australian manufacturingSMEs. Semi-structured interviews are frequently employed to gather respondents' perspectives, insights, and viewpoints regarding a specific topic (Creswell & Creswell 2018). Therefore, this type of interview is suitable and more flexible, as it allows for new responses and perspectives on the discussed topics while remaining focused on the specific subject without deviating significantly from essential issues. Following DOI theory, the interview protocol was structured into five sections, and the interviewees were asked to discuss the five technology attributes' roles.

The sample size was determined using a data saturation approach following the recommendations in the general qualitative research (Fusch & Ness 2015; Guest, Namey & Chen 2020) and the literature on qualitative interviews (Kvale & Brinkmann 2015; Saunders & Townsend 2016). The process of collecting data was terminated when the following interview did not reveal any new themes, insights, or ideas (Guest, Namey & Chen 2020). Directed content techniques were employed to analyse the data collected,as it is the most effective method for checking the existing theories and framework (Assarroudi et al. 2018). This approach enables a more structured data analysis process compared to conventional techniques (Hickey & Kipping 1996). According to Miles, Huberman & Saldana (2019), this study used the approach for data analysis, which comprised three phases in sequence: qualitative data reduction, data coding, and data display.

Results

This paper used a convenience sampling strategy to recruit participants with decision-making, whether from managerial or technical positions in Australian manufacturing SMEs. The research sample was balanced regarding job title and the type of manufacturing companies (small/medium) in various industries. In interview 11, saturation was reached; 10 participants were included in the final sample (Table 2)

Table 2: Interview Sample

N	Job Title	Industry	Headcount	Type
P1	Chief Technical Officer (CTO)	Appliance Manufacturing	100	Medium
P2	Technical Support Specialist	Textile Manufacturing	126	Medium
P3	Chief Executive Officer (CEO)	Furniture Manufacturing	76	Medium
P4	Operations Manager	Paint manufacturing	19	Small
P5	IT manager	Textile Manufacturing	198	Medium
P6	Production Manager	Paper Product Manufacturing	196	Medium
P7	Process Engineer	Sporting Goods Manufacturing	18	Small
P8	General Manager	Camping equipment Manufacturing	16	Small
P9	Automation Engineer	Plastic Product and Packaging	188	Medium
P10	General Manager	Metal Product Manufacturing	98	Medium

Relative Advantage

The result analysis revealed that the majority of participants rated relative advantage as highly important. Six participants called it a “key technology” for SME manufacturing companies, while others considered it a "crucial" aspect of cobots. The relative advantage of cobots was discussed in terms of providing high productivity through collaborative teamwork between employees and machines, the importance of the cost-saving benefit for SMEs companies, and, In general, there is a persistent need for continual updates with emerging technologies, such as collaborative robots, it enhances safety without the need for cages then this will add value to the company.

Relative advantage is a key factor since productivity will be high when using a collaborative robot at our company. After the COVID-19 crisis, there was a considerable shortage of labour in Australian companies, so at this stage, when we benefit from Cobot, we make the workforce and Cobot work in a collaborative method; this enables us to capitalise the minds of the employees by making them focus on the more complex and interesting tasks and Cobot doing the very repetitive, dirty, dull and dangerous tasks. (P1)

When discussing the relative advantages of collaborative robots in terms of providing cost savings for us as small companies, it is possible to save costs, such as a reduction in setup time and maintenance requirements. (P7)

Ongoing updates are imperative to remain aligned with technological advancements, such as collaborative robots. The advantage of collaborative robots is their ability to work alongside employees safely. This is an essential feature, as it enhances safety without the need for cages, then this will add value to the company. (P9)

Compatibility

Some participants emphasized the critical nature of compatibility as a factor; they spoke about the collaborative robot's compatibility with all aspects of the manufacturing company, whether with its goals, vision, culture, or existing systems.

With regard to compatibility, collaborative robot technology aligns with our company's goals, vision, and aspirations for the optimal use of technology that meets our needs. (P2)

In my opinion, ensuring that collaborative robots are compatible with organisational values and culture is imperative. (P4)

Compatibility matters are essential, especially in collaborative robots' compatibility with the existing systems in the company, whether hardware or software. (P5)

For our company, this factor is critical; it is the basis for making investment decisions in new technology. (P6)

Two interviewees believed compatibility had a moderate impact because they definitely considered new technologies and their fit, and SMEs might take some time to integrate their systems with cobots.

Right, I can say that compatibility is a somewhat important factor. We definitely look at new technologies and how they can be implemented and adopted to fit the company they are applying to.(P9)

Ok, I think SMEs might take some time to integrate their devices or systems with collaborative robots, but it is not a highly critical factor that should be given significant consideration. (P10)

As a result, four themes were revealed from the analysis: 1) compatibility is taken into account in all aspects of the manufacturing company, whether with its goals, vision, culture, or existing systems (hardware or software). This makes compatibility an important factor in collaborative robot adoption; 2) It is the basis for making investment decisions in new technology; 3) compatibility will be important when considering new technologies and their fit for the company; 4) SMEs might take some time to integrate their systems with collaborative robots, but it is not a highly critical factor that should be given significant consideration.

Observability

Differing opinions were expressed regarding the impact of observability. Some interviewees argued that observability was significant, particularly in light of the positive influence obtained in different applications of manufacturing and the success of companies in using this technology.

Indeed, observability is extremely important in the operations of SMEs. Assuming that it is possible to easily andefficiently observe the behaviour and performance of collaborative robots within the company environment, this would undoubtedly be a significant motivator for us to adopt and widely implement them in different applications. (P1) Of course, as manufacturing companies, it is essential to keep up with new technologies, specifically those that facilitate operations, reduce the considerable time required for execution, lower costs, and so on. In this case,if we notice these benefits for our company, it will encourage us to adopt it on a wide scale. (P3) Sure, the observation factor is quite important; we should observe if collaborative robots facilitate our work in the company, especially if we notice that companies from the same industry have used this technology and have had success. Our company, in this situation, will decide to adopt it, whether in an assembly line or other applications. (P6) Inour interview, a few participants mentioned that the observability factor somewhat impacts the adoption of collaborative robots. From my perspective, seeing the benefits of collaborative robots doesn't necessarily mean we will immediately start adopting or implementing them. This depends on several factors, with observability not being the most important factor in our decision-making process. (P2) When we look at some manufacturing companies in the same industry that have adopted collaborative robots in their various applications and have seenthe benefits of this technology, this doesn't necessarily mean that it will benefit us in the same way; we need to think about it. (P5)

Two of the interviewees were unsure about the general impact of collaborative robots. Yes, I believe that the observability factor could be important, meaning that if competitors have introduced this technology into their industries, it is possible for us to observe and consider it. However, it is not clear enough at this time whether we will adopt it, perhaps in the near future. (P7) Let's look at adopting new technologies in the Australian manufacturing setting. There are certain procedures, measures, and policies that we need to consider carefully so that this process may take longer time. (P10) Consequently, these themes surfaced mainly about the relationship between observability and collaborative robot adoption: 1) Observability is a significant factor in collaborative robot adoption, though the strength of the impact is not clear; 2) observability is extremely important in the operations of SMEs, particularly if the benefits of collaborative robots can be observed in manufacturing applications; 3)Also, if other companies succeeded in using this technology; 4) Considering the benefits of collaborative robots in different applications for companies, there may be some factors contributing to the decision-making process; 5) Due to the presence of certain procedures and policies, it may take a long time for companies to adopt new technologies.

Trialability

Most interviewees in this study agreed on the influence of trialability, though to varying degrees. For those who assert it has an extreme impact, trialling new technologies on a small scale leads to the possibility of wide-scale implementation.

Definitely, for SMEs the trialability factor is very important; the ability to try out new technology, such as collaborative robots, can reduce potential risks before making a substantial investment. (P2)

Sure, I believe that providing the opportunity to trial this new technology on a limited scale allows our companyemployees to understand the operational dynamics and how these can be more seamless; therefore, I rate this factor as highly important. (P6)

Right, I see trialability as essential when adopting any new technology; it should be tested on a small scale to assess its applicability and achieve the required benefits. This leads to the possibility of implementing it widely in the company. (P9) Also, participants who believed that this factor has a somewhat moderate impact on adoption rates in Australian SMEs argued that new technologies could be trialled, and typically, company leaders make decisions on this quickly and within a set timeframe.

We initially trial and test our new technologies in our company and similar industries. Therefore, I do not think there are challenges in experimenting with any emerging technologies for our company. (P1)

We test and experiment with all technologies, and our manufacturing company leaders typically decide on experimentation quickly and within a set timeframe, so I give this factor medium to high importance. (P5)

I expect the trialability factor to affect, to some extent, the adoption rates in Australian SMEs. (P6)

Finally, one participant indicated that this factor is unimportant and that collaborative robots can be integrated into SMEs' operations without needing trialling.

No, this factor is not as important as I see it. In the case of SMEs, they can integrate collaborative robots into their operations more rapidly without the need for trial, as progress here is clear and fast. (P8)

The subsequent themes were uncovered in the analysis process: 1) Trialability plays a significant role in collaborative robot adoption, though it is unclear how strong the impact this factor is; 2) SMEs can integrate collaborative robots into their operations without the need for trialling.

Complexity

One of the interviewees agreed that the effect of the complexity factor was negative, considering the high initialcosts and the total costs that could increase with the need for ongoing support. Others acknowledged the importance of this factor and its strong impact due to the need for diverse and costly training requirements and the challenge of entirely using and understanding collaborative robots.

We must consider the high initial costs when considering the complexity factor and its significant negative impact on collaborative robots. Collaborative robots are characterised by very advanced features and capabilities, which make the initial cost high. As SMEs, we suffer from limited budget constraints. Additionally, the ongoing need for continuous support may further increase the overall cost of this type of robot. (P7)

Of course, collaborative robots require a high degree of collaboration between humans and machines in all factory applications. Hence, a high level of complexity will arise due to the need for diverse and costly trainingrequirements, which will increase the time and cost for companies. Therefore, the subject needs to be studied extensively before adopting this type of technology. (P8)

Until this moment, I expect that complexity remains a highly significant factor. Most Australian SMEs still struggle to understand and fully use collaborative robots. (P10)

Other participants also argued that the impact of complexity would be moderate because these emerging technologies take time to understand correctly and consider safety features and regulatory compliance.

From my point of view, the complexity factor has a moderate impact. It doesn't pose a major challenge or barrier that could prevent the adoption of this technology. […] It may take some time to understand it properly. This is quite natural when adopting emerging technologies. (P2)

When considering the complexity factor, we must consider safety features and regulatory compliance and ensure sufficient support to deal with any issues that may arise currently or in the future. (P9)

Two of the participants, however, did not think that complexity posed a barrier to adoption. They argued that this type of robot is designed with a user-friendly interface and simplified programming because employees are highly trained and have an open mindset.

No, I don't think complexity is a barrier to adopting emerging technologies, especially collaborative robots. Theserobots are designed with user-friendly interfaces and simplified programming, thus motivating SMEs to adopt this technology. (P1)

Overall, this factor is not important at all. In our company, we can adopt new technologies because we have highly trained employees, and they have an open mindset to experimenting with emerging technologies without imposing complexity or difficulty. (P5)

The analysis highlighted the subsequent key themes: 1) perceived collaborative robots negatively impact its adoption due to the high initial costs, costly training requirements, full use and understanding of technology; 2) the negative impact of complexity can be moderate because the nature of technologies and considering safety features and regulatory compliance; and 3) collaborative robots with user-friendly interfaces, and trained employees, decrease the effect of complexity.

Discussion

The paper summarised technology attributes and the main themes related to the impact of these attributes on collaborative robot adoption, as shown in Table 3. In collaborative robot adoption by Australian manufacturing SMEs, four out of five attributes have been revealed as influencers: relative advantage, compatibility, trialability and complexity. However, the impact of observability remains unclear. As previously noted in the result, a relative advantage is widely recognised as a crucial factor in SMEs' adoption of collaborative robots.

This indicates that adopters need to understand this technology thoroughly, as it is superior and adds value compared to the existing systems in industrial companies. This also motivates decision-makers to see what provides high productivity and cost- saving for their companies. The interviewees indicated compatibility is a comprehensive process because it considers all aspects of the manufacturing company, including goals, vision, existing systems, and even the organisation's culture.

In the case of trialability, the participants expressed the importance of this factor, noting that any new technology can be tested on a limited scale to see its effectiveness. This may lead to applying this technology on a league scale. On the other hand, those interviewees who argued that their companies have resources and factors that contribute to the decision-making process see the observability factor as less important than other factors. Then, these companies could be innovators or the early majority, who are the group most ready to adopt technological innovation quickly and have the required resources to do so (Rogers 2003). As collaborative robots are still intheir infancy in Australian manufacturing SMEs, this may be of significance.

Table 3: Technology Factors and Emerging Themes in Collaborative Robot Adoption

Technology Factors	Key Themes Relevant to Collaborative Robot Adoption
Relative Advantage	• Perceived as the strongest technological factor for collaborative robot adoption; • Providing high productivity; • Cost-saving benefit for SMEs companies; • The advantage of collaborative robots is enhanced safety without the needfor cages, which will add value to the company
Compatibility	• Perceived as a moderate influence on the process of adopting collaborative robots.; • Compatibility is taken into account in all aspects of the manufacturing company, whether with its goals, vision, culture, or existing systems, this makes it an important factor. • It is the basis for making investment decisions in new technology; • Compatibility will be important when considering new technologies andtheir fit for the company; • SMEs might take some time to integrate their systems with collaborative robots, but it is not a highly critical factor.
Observability	• Unclear impact on the adoption process; • observability is extremely important in the operations of SMEs, particularly if the benefits of collaborative robots can be observed in manufacturing applications; • Also, if other companies succeeded in using this technology; • Considering the benefits of collaborative robots in different applications, there may be some factors contributing to the decision-making process; • Due to the presence of certain procedures and policies, it may take a longtime for companies to adopt new technologies.

Complexity	• Perceived as a moderate influence on the adoption; • Complexity because of high initial costs, costly training requirements, full use and understanding of technology; • The nature of technologies and considering safety features and regulatory compliance • Collaborative robots with user-friendly interfaces and trained employees decrease the effect of complexity.
Trialability	• Perceived as a moderate influence on the adoption; • Trialability is a significant factor in collaborative robot adoption, though it is unclear how strong of an impact this factor is; • SMEs can integrate collaborative robots into their operations without the need for trialling

It appears that technological factors, in general, do not fully present the process of adopting collaborative robots. This is because there are organisational factors mentioned above and present in some mechanisms of factors influencing. As the study results have shown, some factors have potential impacts, such as organisational culture and required resources (human and financial). Moreover, the participants mentioned the existence of contextual variables, such as policies and standards. When considering the integration of the technological factors discussed above with organisational and contextual factors, this could provide a comprehensive framework characterised by a clearer understanding of collaborative robot adoption for SMEs. Given this integration, the Technology- Organisation-Environment (TOE) framework may seem appropriate for this case (Tornatzky & Fleischer 1990).

When decision-makers decide to adopt collaborative robot technology in general, they should understand the current systems in their manufacturing companies and how long it will take to integrate collaborative robots. They need to comprehend the process comprehensively and the value it will add to productivity shortly. Additionally, there should be a significant focus on providing required financial or operational resources and offering intensive training programs to employees to acquire or enhance skills for effectively adopting and using this new technology.

Conclusion and Limitation

This paper shows the five technological factors that influence SMEs' adoption of collaborative robots. The aim is to understand these factors and the mechanisms behind them. Qualitative research was conducted to collect and analyse data, and a quantitative study will be needed to confirm the relationships. Furthermore, considering a more holistic model, the technological factors can be used alongside organisational, context, or human factors. This study provides actionable insights for industry stakeholders. There are several ways to continue and expand this research to further understand the theoretical and practical knowledge.

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