Flinders University
Australian Industrial Transformation Institute

True North

Key themes for accelerating the uptake and diffusion of Industry 4.0 technology in manufacturing and the supply chain

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Australian Industrial Transformation Institute

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Executive Summary

In March 2020, the Australian Industrial Transformation Institute (AITI) at Flinders University commenced a program of research with industry partner, BAE Systems Australia – Maritime, to accelerate the uptake and diffusion of Industry 4.0 enabling technologies in shipbuilding and its manufacturing supply chain. The critical point of difference of this multi-year, collaborative project has been the focus on the people using the technology rather than the technology itself. Taking a ‘human-centred’ approach is essential for successful technology adoption.

Technology adoption is predicted by technology acceptance – the extent to which users perceive technology as useful and easy to use. The level of technology acceptance in an organisation influences organisational readiness for, and ultimate success in technology adoption. Implementing new technology will fundamentally change work design and the skills needed to perform tasks, so change management is necessary to ensure the workforce is involved, understands the need for the change and the likely impacts for their work. Organisational appetite and capacity for change depends on their readiness level, and support is needed to assist organisations to move from contemplation to preparation (gathering information and trialling small changes) and on to action - ultimately adopting and actively using new technologies.

The program of research undertaken over the last two and a half years has built knowledge by generating evidence from research trials involving robotics, augmented reality head-mounted displays, motion capture technology, and wearable physiological monitors. Supporting trial outcomes, evidence on broader systems impacts has been summarised in literature reviews and implementation guides.

Content analysis of research outputs identified six themes:

1. Human factors and ergonomics - systems science
2. Technology acceptance (human-technology interaction)
3. Skills and work design
4. Organisational change management
5. The value proposition of human factors and ergonomics in Industry 4.0
6. Business innovation driving industry transformation.

In their totality, these themes represent all levels of the business ecosystem, depicting a systems approach to technology uptake and diffusion that highlights the ripple effects of technology impact across operations. This systems perspective recognises the central role of human actors, whether directly using technology on the job, designing products and services, or making decisions about technology deployment as a business transformation strategy.

Future directions should focus on creating knowledge to support businesses to change by overcoming uncertainty. The technology trials sought to understand human experience at the individual level. Perceived workload, usability and usefulness of new technologies are salient aspects to measure and monitor - they inform the how and why of any changes. Future directions should place greater attention on the ripple effects of user experiences in relation to organisational change, business innovation and industrial transformation, to better understand the dynamics of change and the strategies needed to manage this disruptive process. Building on learning to date, future activities are proposed in three broad areas:

1. Demonstrating value propositions for technology adoption
2. Increasing supply chain capability
3. Enhancing human and technology performance.

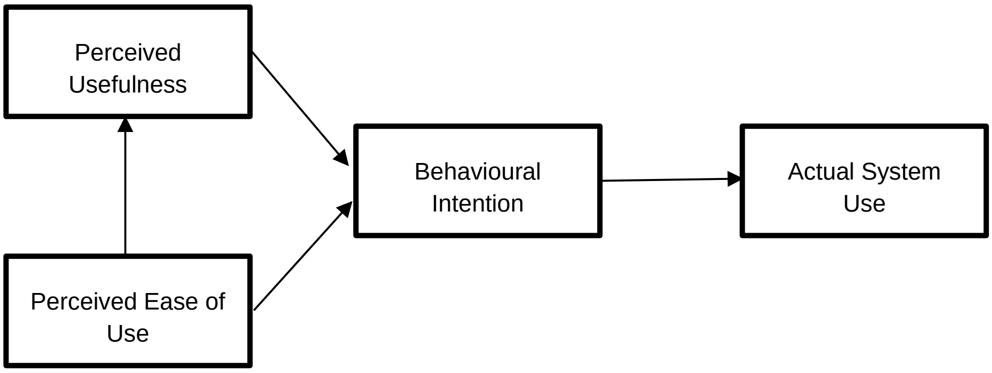
1 Introduction

In March 2020, the Australian Industrial Transformation Institute (AITI) at Flinders University commenced a program of research with their industry partner, BAE Systems Australia – Maritime, (BAESA-M) to accelerate the uptake and diffusion of Industry 4.0 enabling technologies in shipbuilding and its manufacturing supply chain. The work was funded by BAESA-M in collaboration with the Department of Industry, Science and Resources[1] (Innovative Manufacturing CRC). The current program of work is due to conclude in October 2022. The purpose of this report is to summarise key themes that have arisen from the program of research and indicate worthwhile areas for future research.

1.1 Approach to Industry 4.0 adoption

The critical point of difference of this multi-year, collaborative project has been a focus on the human dimensions of technology in order to better understand some of the key barriers and enablers that influenced the uptake and diffusion of specific technologies. Taking a 'human-centred', 'user-centric' or 'human-first' approach is essential for successful technology adoption (Eichler, 2022; Wordham, Tuff, & Briggs, 2018). The uptake and diffusion of technology in the workplace is determined by a range of individual user and organisational attributes as well as the technical features available and the operational environment. Consideration of such an interconnected system of components where the person is viewed as the most important part of the system is referred to as human factors and ergonomics (HFE) and is the chosen overarching approach of this project (O'Keeffe, Moretti, Hordacre, Howard, & Spoehr, 2020).

There are numerous conceptual models that indicate antecedents of technology adoption, from an individual behaviour perspective (e.g. technology acceptance model (TAM, (Davis & Venkatesh, 1996); see

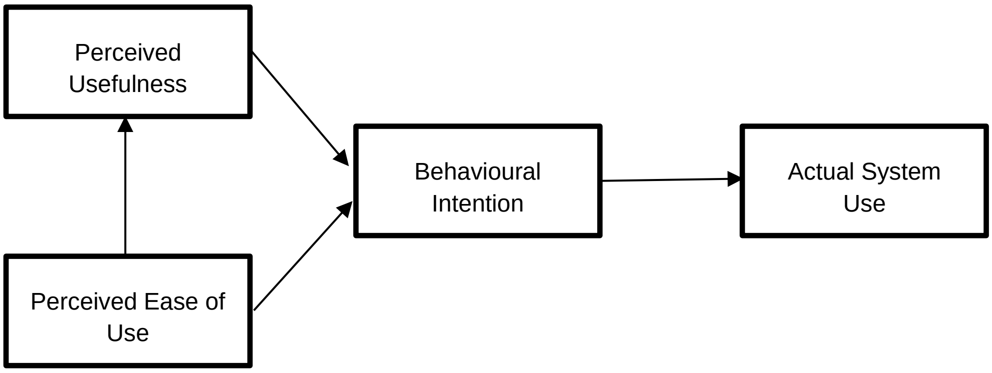


Source: (Davis & Venkatesh, 1996)

Figure 2) to those reflecting broader organisational decision-making (e.g. technology-organisation-environment (TOE) framework, Tornatzky and Fleischer (1990) see **Error! Reference source not found.**). However, at a practical level, Li (2020) concluded that both models show equivalence. For example, similar technology implementation outcomes were found for small and medium-sized enterprises (SMEs) seeking to adopt blockchain regardless of whether an individual or organisational-level predictive model was applied to the ratings of decision-makers. HFE is inclusive of all these concepts (and more) and encourages examination of them at an individual, team and organisational level. An HFE model is presented in Section 3.

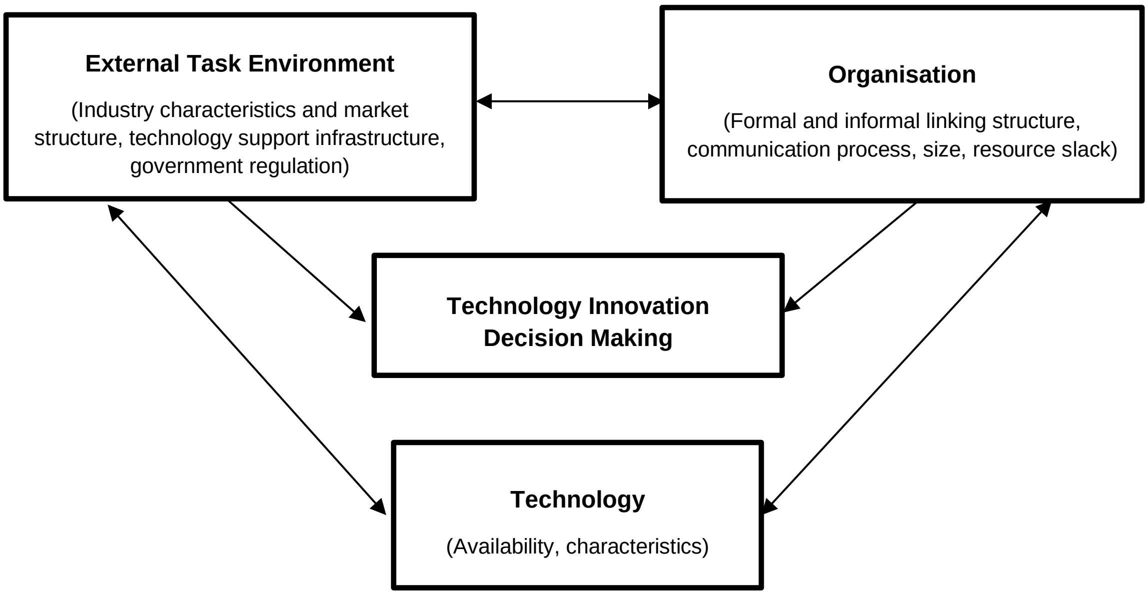
[1] Formerly the Department of Industry, Sciences, Energy and Resources.

Figure 1: Technology Acceptance Model



Source: (Davis & Venkatesh, 1996)

Figure 2: Technology-Organisation-Environment Framework

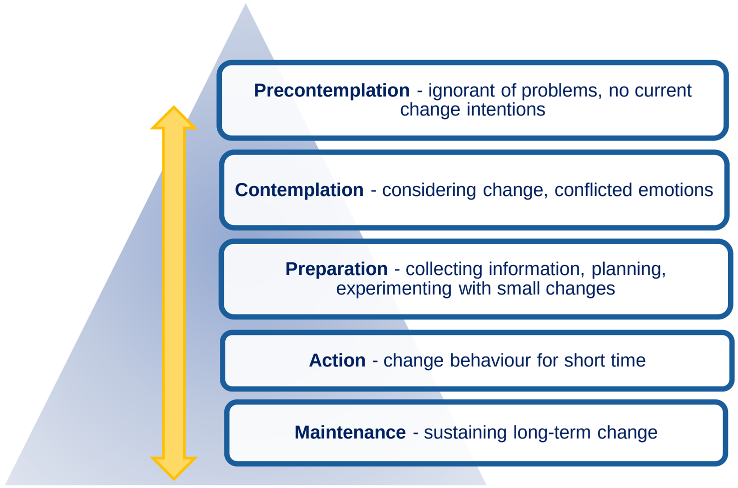


Source: (Tornatzky & Fleischer, 1990)

Technology adoption can also be conceptualised through change management theories and thus stages of behaviour change and change management are also relevant models to support integration and uptake of technology.

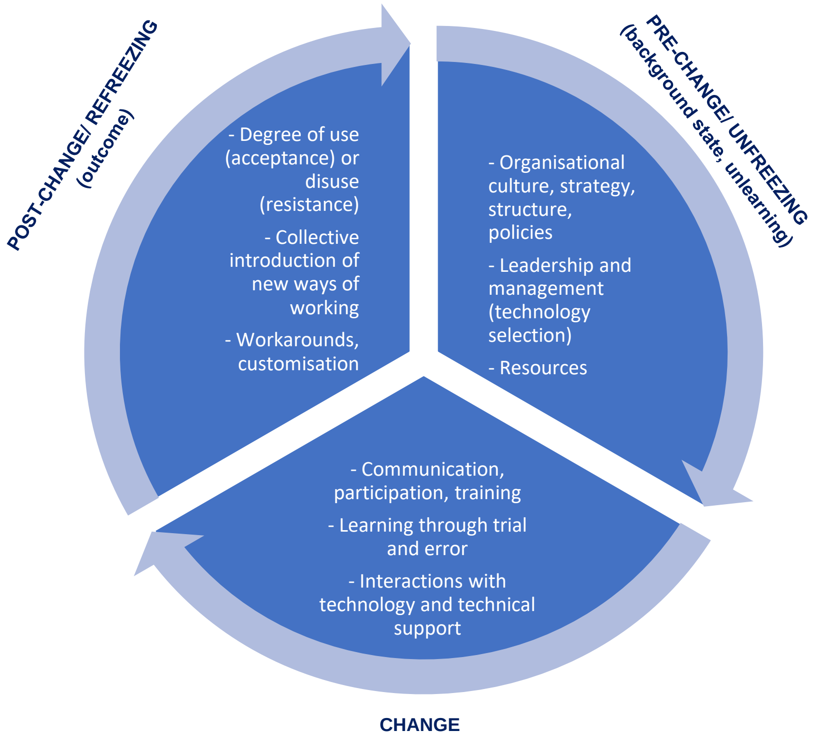
Behaviour change is a process comprising several stages (see Figure 3) which are often not experienced in a linear fashion (Green, Gadomski, & Wissow, 2020). Adequate time spent in the preparation stage is essential to promote success in subsequent stages (Cherry, 2021). Furthermore, change management is a continuous cycle in which systems move from a state of stasis and are unfrozen to allow change, before being refrozen (see **Error! Reference source not found.**) – where previous change experience provides input for future change – driving or diminishing momentum depending on whether required elements are executed well (enablers) or lacking (barriers) (Saghafian, Laumann, & Rasmussen Skogstad, 2021). Our research supports the need to address individual and organisational readiness (ability and willingness to adapt) and reduce barriers to change as key steps to facilitate adoption. These are discussed in more detail in the sections that follow.

Figure 3: Stages of behaviour change



Source: Based on Prochaska and DiClemente (1983)

Figure 4: Change management cycle and influential elements



Source: Based on Saghafian et al. (2021) and Schein (1996)

1.2 Program of research

A multi-pronged research approach was employed to support the acceleration and diffusion of Industry 4.0 in BAESA-M and SMEs in the manufacturing supply chain. Our approach aimed to synthesise key concepts, actively engage with industry partners and SMEs, provide technology trials with hands-on experience of new approaches and workflows, and publicly share the outputs of the research using a multi-modal approach (see summary in Figure 5). Table 1 presents the five research trials undertaken during this research program. A summary of research outputs can be found in Appendix A.

Figure 5: Research approach

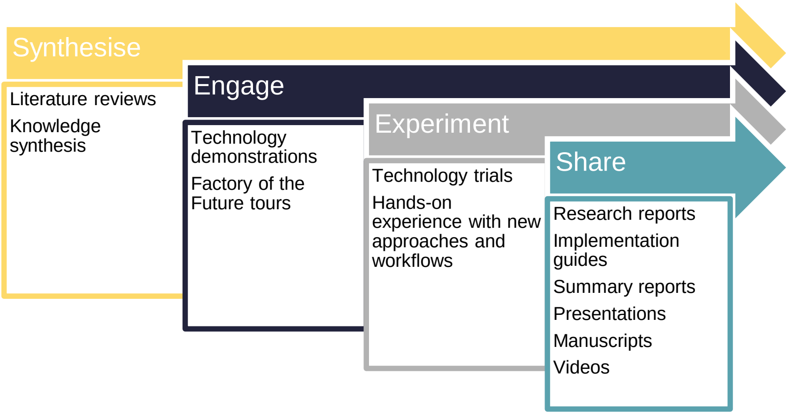


Table 1: Description of Flinders University led research trials

	Trial Task^	Technology
1	**Precision dispensing** Each user guided two different glue-dispensing tools around the same two-dimensional path: (1) taught (hand-guided) a collaborative robot, also involving interaction with the robot's teach pendant (similar to iPad) and (2) used an electric caulking gun	Collaborative robot (Universal Robot UR 10e)
2	**Digital work orders in harsh environments** Users executed a digital work order of a maintenance task on each device at one of three locations: (1) at 3 metre height, (2) inside simulated ship block, and (3) in simulated confined space (laying on floor). The influence of awkward positions and wearing personal protective equipment was assessed	Mobile device (iPhone), augmented reality head-mounted display (Google glasses); digital work order (Upskill Skylight software)
3	**Smart measurement and technical drawings** Users aligned a pipe and flange using two methods: (1) manual technique with clamps and spirit levels and (2) with motion capture technology. In a separate task, users edited and saved a technical drawing of a pipe assembly using a smart projector.	Motion capture system (Optitrack); smart projector (Epson - utilising whiteboard software with digital palette enabling selection of colours, line thickness, shapes and eraser functions with stylus)
4	**Digitally supported visual inspection** Users inspected and digitally recorded the status of gauges and valves in a pump and pipe skid. Two tasks were trialled: (1) working at height using an augmented reality head-mounted display (with integrated digital work order) and (2) remote inspection via quadruped robot's camera (sent into a confined space), completing the digital work order via laptop	Augmented reality head-mounted display (Hololens 2, powered by Microsoft Dynamics 365 Guides software); quadruped robot (Spot); digital work order (Power Apps software); laptop
5	**Electrical cabinet assembly and inspection** Users assembled an electrical cabinet utilising a digital work order accessed through an augmented reality head-mounted display. This was integrated with cobot-aided visual inspection of the work and video call to a supervisor (who was remote) to troubleshoot errors. Wearable technologies were worn to monitor physiological status during task performance	Augmented reality head-mounted display (Hololens 2, powered by Microsoft Dynamics 365 Guides software); digital work order (Power Apps software); collaborative robot (Universal Robot UR 10e); wearables (Polar Heart Rate Monitor and Empatica E4 watch multi-purpose device)

^All trials involved a range of performance, usability and user experience measures (see Section 3.2 for examples)

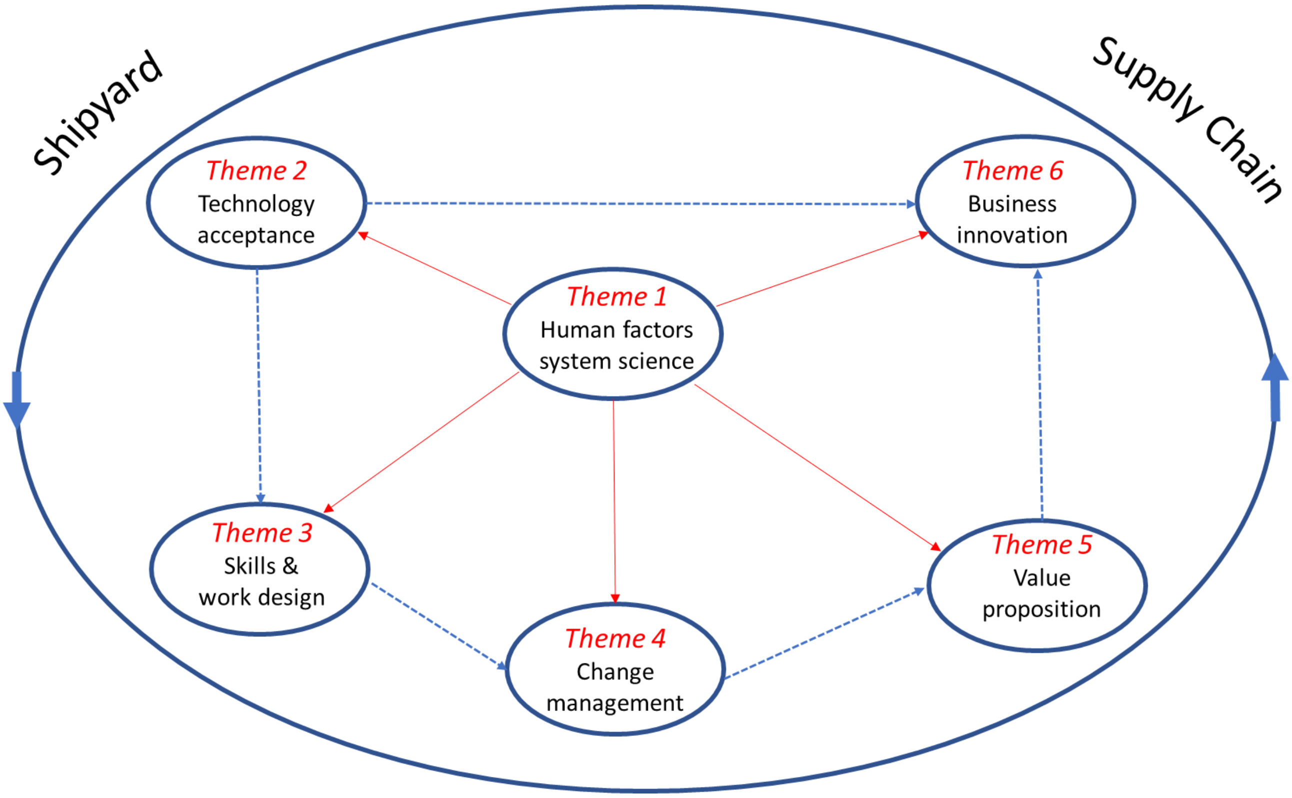
From a technical perspective, research activities concentrated on wearable technologies, particularly those with augmented reality capability (e.g. Google Glass, HoloLens 2), robotics (e.g. collaborative and quadruped robots) and smart cell production (e.g. Optitrack motion capture system, integrated technologies). Human factors and ergonomics methodologies applied included both quantitative (objective and subjective) and qualitative assessments, and observations.

The technology trials were undertaken across several environments, from a Flinders University laboratory (i.e. for collaborative robot trial), the collaborative Pilot Factory of the Future at Line Zero, Tonsley Innovation District (i.e. for pipe alignment) to onsite at the Osborne shipyard (i.e. for assembly and inspection of an electrical cabinet integrating an augmented reality head-mounted display and collaborative robot). Most technology trials took place at Pilot Factory of the Future, Line Zero, a semi-industrial research facility of Flinders University, located at the Tonsley Innovation District in Adelaide. This facility allows simulation of the shipyard environment and a level of fidelity to using technology in practical applications.

2 Key themes

Six broad themes were identified from the program of research.[2] These themes and their interactions are presented in **Error! Reference source not found.**. Their sub-themes are presented along with the themes in the sections below. The aim of the research was to inform technology selection and support its potential uptake in the shipyard and promote translation along the supply chain through adopting HFE principles. The outer ring of the model reflects the recursive relationship of shipyard innovation pushing technology adoption to the supply chain, in turn enabling the shipyard to achieve digital transformation more rapidly.

Figure 6: Key themes from the program of research



In their totality, these emergent themes intersect with all levels of the business ecosystem, depicting a systems approach to technology selection, uptake and diffusion that highlights the ripple effects of technology impact across operations. This systems view recognises the central role of human actors, whether directly using technology on the job, designing products and services, or making decisions about technology deployment as a business transformation strategy. HFE is presented as a framework for Industry 4.0 research (O'Keeffe et al., 2020) which demonstrates how this program of research (see Section 3) has facilitated the uptake of technology in shipbuilding and the supply chain.

[2] For information on the analysis method, see Appendix B. The list of initial sub-themes from the content analysis are provided in Appendix C.

Theme 1: Human factors systems science

Theme 1	Research sub-themes
Human factors & ergonomics as a systems science	Performance, safety, quality, productivity & satisfaction
	Specific systems improvements (errors & risks)
	Human-technology interaction
	Collaboration and participation
	Systems integration

HFE is a systems science that draws on knowledge and techniques from social sciences (psychology and sociology), health sciences (medicine, physiology, biomechanics) and design sciences (engineering, industrial design, and architecture) to promote successful and satisfying task performance. HFE applies systems thinking and human-centred techniques to design processes and products that are useful, easy, and satisfying to use by involving users to understand their needs and motivations (O'Keeffe et al., 2020).

Theme 2: Technology acceptance

Theme 2	Research sub-themes
Technology acceptance (human-technology interaction)	Usability testing identifies challenges and opportunities for uptake
	Interface design
	Familiarity builds confidence and willingness to use
	User driven rather than technology driven
	Context of use matters

Critical to successful technology adoption is user acceptance, which is highly influenced by ease of use and perceived usefulness (Davis, Bagozzi, & Warshaw, 1989). Failure to adequately address user needs and expectancies is likely to lead to under-utilisation, resistance or even sabotage (Howard et al., 2021; Laumer & Eckhardt, 2012), thereby missing the anticipated business advantages of introducing technology. Simple interfaces, matched to context of use enhance usability, making products satisfying to use (Lazard et al., 2016).

Theme 3: Skills and work design

Theme 3	Research sub-themes
Skills and work design	New skills and configurations of skills in jobs
	Lean production – streamlining workflows
	Task variety, meaningfulness, autonomy and social support
	Individuals as life-long learners

New technology fundamentally changes the structure of work, optimising workflows. Job design changes call for new skills and configurations of skills to meet new demands. Well-designed jobs that include variety, meaningfulness and autonomy build a productive, safe and satisfied workforce and help attract new talent to jobs that have previously been perceived as 'dirty, dull or dangerous' (Howard, O'Keeffe, Hordacre, & Spoehr, 2022). Sought-after skills will be technical (digital skills, business process, and manufacturing process knowledge) and non-technical (personal, social, and problem-solving competencies) (Galaske, Arndt, Friedrich, Bettenhausen, & Anderl, 2017).

Theme 4: Change management

Theme 4	Research sub-themes
Change management	Work organisation distal effects
	Participation – early, and on-going, organisation-wide
	Business goals and strategy aligned with people management
	Culture of learning, learning organisation

Change requires new learning, and in Industry 4.0, leaders should actively promote a learning culture and understand the gap between current and desired skill levels (Saabye, Kristensen, &

Wæhrens, 2022). Technology change brings uncertainty (Howard et al., 2021) and sometimes resistance (see Section 3). Embarking on change requires leaders to build trust and psychosocial safety for employees to explore new opportunities (Edmondson, 2018). Change management also involves aligning business strategies with the change and allocating resources (Antony & Gupta, 2018).

Theme 5: Value proposition

Theme 5	Research sub-themes
Value proposition	Demonstrate cost-benefit analysis for human factors methods
	Performance improvements (quality, safety, productivity)
	Identify broadly applicable use cases

The commitment that organisations make in investing in technology adoption is determined by the perceived value it will realise. Often businesses focus on technology, neglecting the impact of human factors. Investing in HFE can achieve process optimisation and realise operational profitability but also provide a competitive edge through products and services that are effective and desirable to use (O'Keeffe et al., 2020). Uncertainty about the overall value proposition is recognised as a key contributor to slow adoption of technology in smaller organisations (Reynolds, Cotrino, Ifedi, & Donthu, 2020).

Theme 6: Business innovation

Theme 6	Research sub-themes
Business innovation	Driving industry transformation
	Process redesign
	Security and risk
	Building capacity of small-medium employers
	Developing and applying digitalisation roadmaps and maturity models

A planned approach to digital technology adoption can harness the benefits of technology to optimise processes and enhance the role of people. This in turn will accelerate business innovation. Success depends on effective strategies for managing organisational change from both technological and people perspectives (Worrall & Spoehr, 2021). Small-medium employers lack absorptive capacity – the ability to use externally held knowledge through gaining awareness, exploring and exploiting it (Tzokas, Kim, Akbar, & Al-Dajani, 2015). Cybersecurity is one such challenge, involving data ownership, ensuring interoperability, and understanding and implementing data management standards (Calabrese, Dora, Levialdi Ghiron, & Tiburzi, 2022; Kinkel, Baumgartner, & Cherubini, 2022).

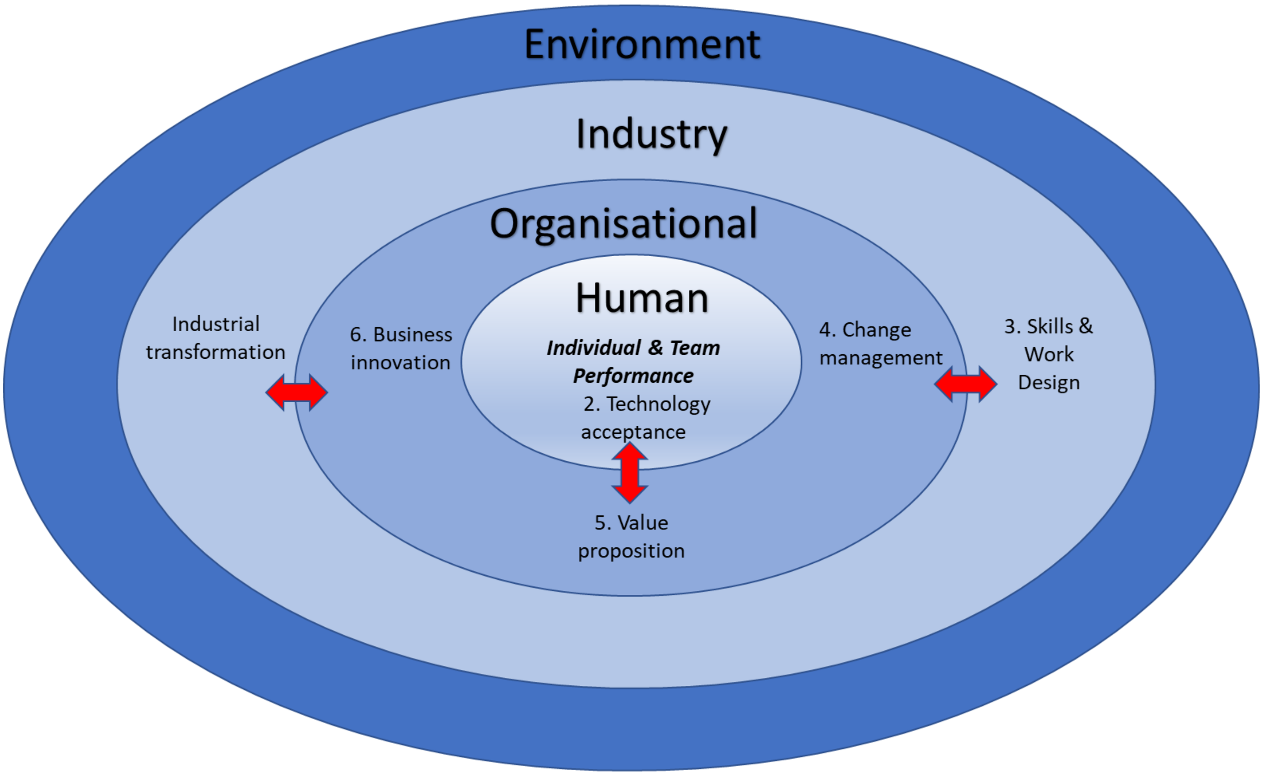
3 Realising an Industry 4.0 HFE framework

3.1 Revisiting the Industry 4.0 HFE framework

A human-centred approach is valuable for understanding the web of interactions within a complex system such as shipbuilding. The proposed Industry 4.0 HFE framework (O'Keeffe et al., 2020) (see Figure 7) places the human at the centre of a system interacting with technologies and processes to achieve organisational goals. Using multiple levels of analysis, influences and impacts of the organisation, industry and environment can be identified and understood, enabling smoother transitions during the digital transformation process.

The project themes (discussed in Section 2) are mapped on the framework, with arrows indicating interactions between themes and levels of analysis. For example, change management underpins the development of new skills and work design, with the aim of creating a supportive environment that reflects a human-centred culture.

Figure 7: Proposed human factors and ergonomics framework for Industry 4.0 research



Based on Corlett, Wilson & Corlett (1995 p. 10)

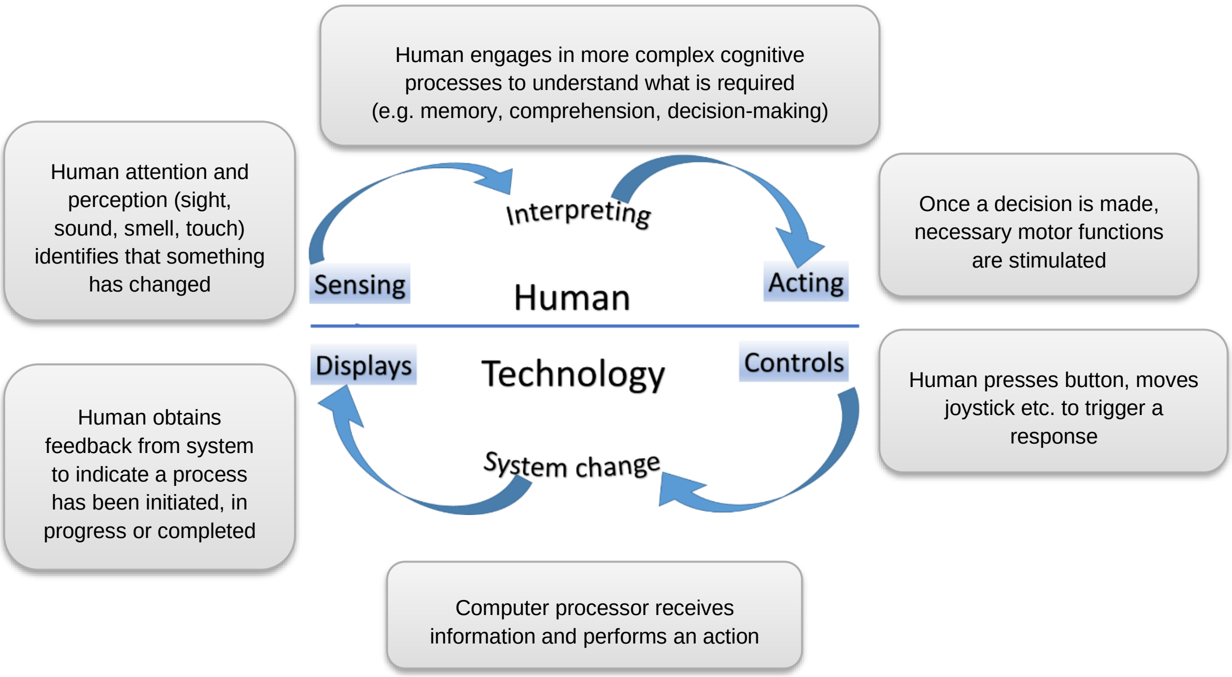
3.2 Humans as the centre of the system

Humans have both capacities and limitations as they explore and understand their world. People have high levels of intelligence and remarkable abilities to detect, process and make sense of information; perform fine and dexterous activities as well as exert strength and force; and to work together in teams, be creative and modify their environments to their advantage. Humans also come with limitations that impede performance, including fatigue, illness, distraction, and emotional and motivational variability. Human performance can be optimised when work is designed to support capacities and risk-manage limitations (Bridger, 2017; Karwowski, 2005).

3.2.1 Individual performance

Humans are unique individuals but share many similarities, allowing performance data to be aggregated to develop evidence-based design principles. At the most fundamental level of human interaction with technology, individuals make sense of their tasks through a process of interpreting information from the technology and environment (through icons and structures), then responding by initiating actions using controls (buttons or joysticks) to change the state of the microsystem and achieve individual goals. User action stimulates a change detectable through the interface, allowing a cycle of interactions to achieve the desired goal, for example, moving the arm on a collaborative robot (see **Error! Reference source not found.**).

Figure 8: Human-technology interaction model – a feedback loop



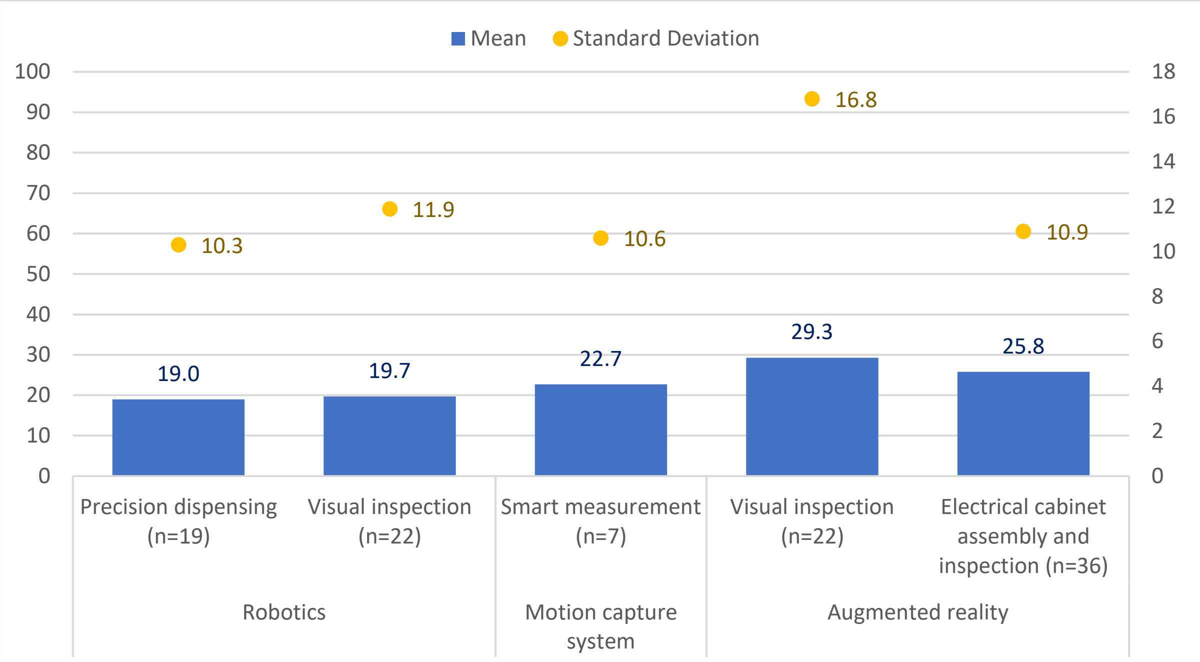
Source: Based on Kroemer & Grandjean (1997 p.158)

3.2.2 Workload

For all types of jobs, workload needs to be optimised and managed to avoid injury (physical and mental) to personnel and poor work performance due to high demands (physical or mental). Emerging digital technologies often influence how work is completed; in many instances they offer reduced physical demands and improved ergonomics. However, care is needed to ensure technology use does not result in unreasonable mental or other demands (Howard et al., 2022). Accordingly, five of the research trials undertaken evaluated workload using the NASA Task Load Index (Hart & Staveland, 1988), a subjective workload assessment tool comprising six dimensions. A task receiving an overall NASA Task Load Index rating of 30 or below is considered to have low demands and above this, high demands (Bernard, Zare, Sagot, & Paquin, 2020).

As shown in **Error! Reference source not found.**, completion of different tasks using Industry 4.0 technologies did not appear to over-burden users – noting tasks were typically fairly brief (approximately 30-45 minutes in duration) and simple (i.e. involving static, structured activities to be completed by one individual at a time with support and clarification available as needed). However, the variation or spread of workload ratings (i.e. standard deviation) was relatively high across the task/technology test cases reflecting individual differences in users' skills and experience, and at times, variable performance of the technology (e.g. dependent on reliable internet connection).

Figure 9: Overview of Industry 4.0 workload evaluations (NASA Task Load Index – overall average rating)



An average (mean) score of 30 or below is considered to indicate a task of low demands and above this, high demands.

See Table 1 for technology and trial details.

Variation was greatest for the visual inspection task supported by augmented reality trial which was the only task requiring a change in location from practice environment (on ground) to task execution (working at height). For some, this change introduced additional challenges finding and accessing information presented through the device. The work order interface for the task also involved interacting with a drop-down menu which was time consuming for some and required more refined gesture interactions than other menu features (i.e. pressing radio buttons).

Moreover, as shown in the workload dimension ratings from the NASA Task Load Index (Appendix D provides these for all trials, see Figure 16 for this trial), this combination of task and technology yielded the greatest number of dimensions exceeding 30 (low demands). Specifically, higher mental effort was required to complete this task to achieve the necessary level of performance which was accompanied by some stress and irritation. For comparison, Figure 17 (Appendix D) summarises augmented reality-supported assembly of an electrical panel showing a similar (but more subdued) pattern of ratings. This is likely to reflect a combination of task differences (e.g. assembly of an electrical cabinet involved a more contained work space), interface design choices and skills and experience of users.

Two trials (precision dispensing and smart measurement; see Table 1) compared task performance and perceived workload between the traditional, manual method and the technology-assisted method. Generally, the technology-assisted method resulted in lower demands across the six workload dimensions. Exceptions included comparable mental demands when using a collaborative robot for a glue dispensing task (Howard et al., 2021) and some scepticism that a digital measurement system supports successful, satisfying performance and goal accomplishment (O'Keeffe et al., 2021).

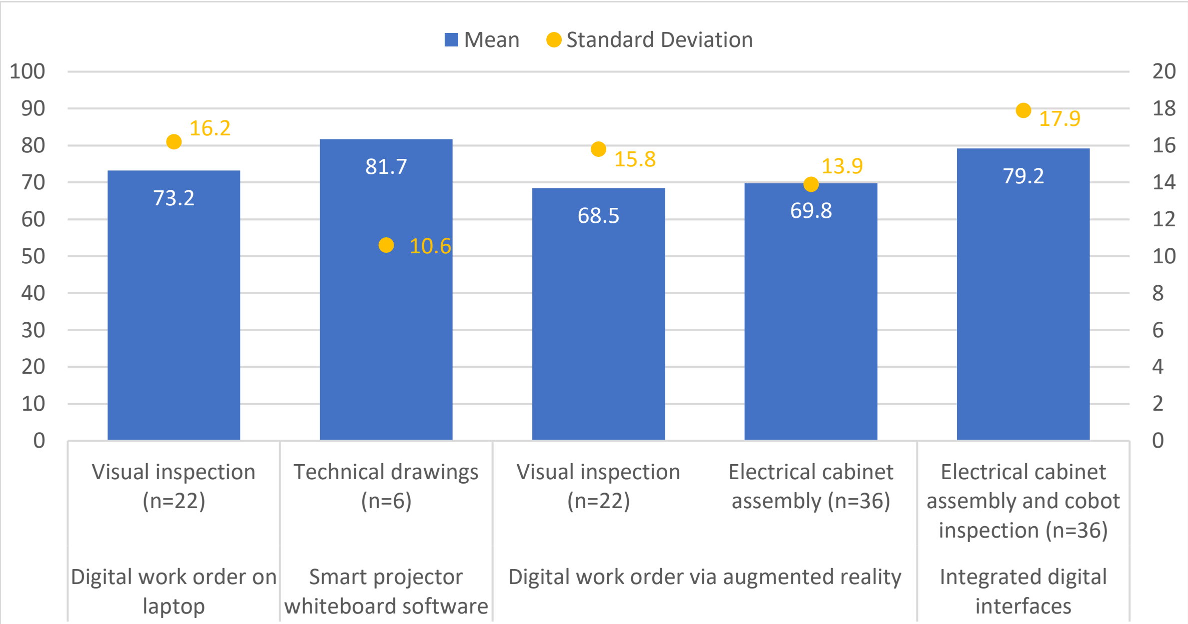
3.2.3 Technology readiness and acceptance

System usability and ease of use

Industry 4.0 can be described as the digitisation of manufacturing (Butt, 2020) which creates numerous computer software systems (interfaces) to be navigated by users. Software and hardware come together to form cyber-physical systems. How well this can be done (preventing high workload demands) is often referred to as usability, the "*extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (International Organization for Standardization, 2019, p.3). The usability of each system is likely to vary depending on its features, purpose and the diversity of users. The 10-item System Usability Scale (SUS, Brooke, 1996) is a commonly used global indicator of perceived system usability (Lewis, 2018) and can be helpful in determining acceptability of a system (e.g. prototyping, aiding achievement of a 'minimum viable product') and indicating the scale of improvements needed. A standard score of 68 reflects an 'average' outcome and 80 is considered a 'good usability' outcome (Lewis & Sauro, 2018).

Five trial activities utilised the SUS and all met 'acceptable' effectiveness, efficiency and satisfaction ratings (see Figure 10:). The smart projector was the only system to receive a 'good' usability average[3]. It is likely that this task received positive ratings due to its similarity with other paint or drawing software programs used for other devices. Users reported that support from a technical person would not be needed to use this system (also see item summary provided in Appendix E).

Figure 10: Overview of Industry 4.0 system usability evaluations (SUS)



A standard score of 68 equates to an 'acceptable' system, 80 to a 'good' system.
*See Table 1**Error! Reference source not found.** for system usability context.*

[3] *This trial activity had reduced participant numbers due to the COVID-19 workplace shutdowns and isolation measures required during this time (August 2021). We acknowledge that findings are less robust the smaller the sample size. However, there is value in demonstrating the variation in and relationship between task, technology and perceived usability.*

Lower usability was related to perceived need for support from a technical person for system use and perceptions of the cumbersomeness and complexity of the system (see Table 2 for a summary or Appendix F for all details). Interface design should focus on simplicity and delivery of essential information with the tested system and real work scenarios closely matched (Nielson, 2020).

Table 2: Summary of aspects where systems could be developed to improve usability

System attributes	Research Trial (Industry 4.0 technology)				
	Visual inspection (digital work order on laptop)	**Technical drawings** (smart projector whiteboard software)	**Visual inspection** (digital work order via augmented reality)	**Electrical cabinet assembly** (digital work order via augmented reality)	**Electrical cabinet assembly and cobot inspection** (integrated digital interfaces)
(1) Like to use frequently	X				
(2) Unnecessarily complex	X	X			
(3) Easy to use					
(4) Need support to use			X	X	X
(5) Functions well integrated	X				
(6) Too much inconsistency				X	
(7) Most learn to use very quickly			X		
(8) Very cumbersome to use		X		X	X
(9) Felt very confident using					
(10) Need to learn a lot before get going					

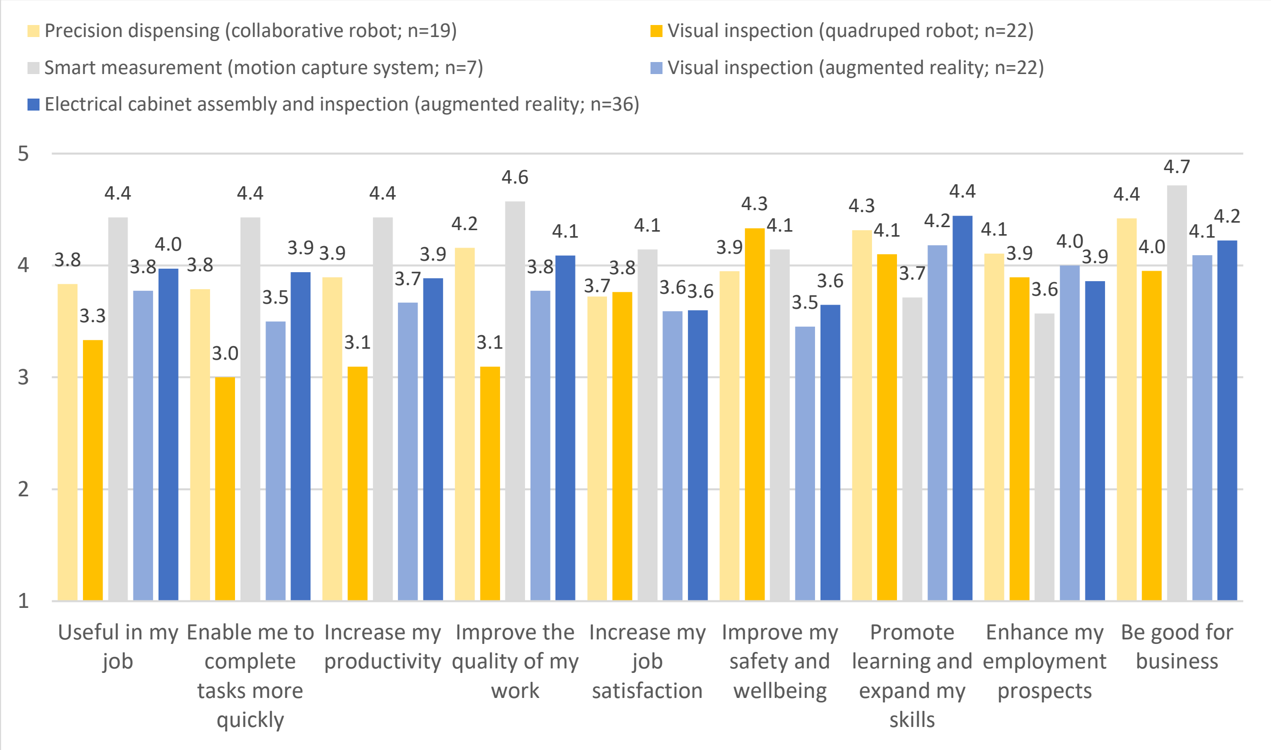
Note: Odd-numbered items are framed positively (thus an 'X' indicates disagreement with the item) and even-numbered items negatively (thus an 'X' indicates agreement with the item).
*See Table 1**Error! Reference source not found.** for system usability context*

Usefulness

For effective uptake, technology not only needs to be easy to use, with appropriate support for employees, but also needs to address pain points for the workforce and business. It is sensible to begin technology uptake with options that can achieve small wins to build momentum, confidence and optimism.

Nine usefulness items were examined with average ratings presented in Figure 11. The smart measurement activity rated highest overall with nearly all usefulness items rated 'agree' to 'strongly agree'. The two exceptions to this concerned *promoting learning and expanding skills* and *enhancing employment prospects*. For individuals and organisations with interest in achieving these goals, alternative technologies and/or task applications may offer more opportunities. The novelty of the quadruped robot used for the visual inspection trial may have reduced certainty for some items, although participants rated this as most likely to *improve safety and wellbeing* – perhaps due to a reduction in time spent in harsh environments.

Figure 11: Overview of the perceived usefulness of Industry 4.0 technologies (average ratings)



Rating scale: 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree. Also see ***Error! Reference source not found.*** *for technology and trial details.*

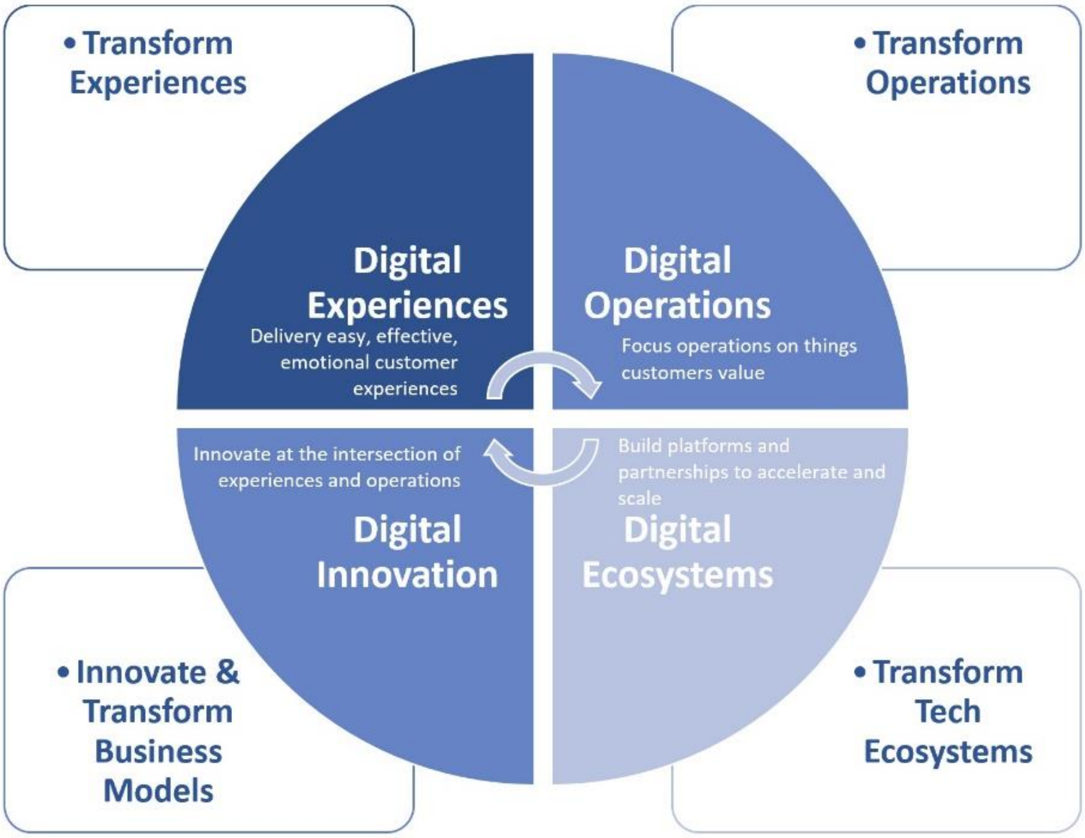
3.3 Organisational context

3.3.1 Business innovation

Business innovation involves making changes to operations to add value. Recognising value occurs in ecosystems, changes are often planned using a systems framework (Adams, Jeanrenaud, Bessant, Denyer, & Overy, 2016) (see Figure 12Figure 12). Systems-oriented digital maturity models provide guidance on scoping and sequencing activities, indicating organisational readiness and identifying gaps. Models typically address process integration, product and service, manufacturing operations, leadership and strategy, workforce development, supply chain capacity, digitalisation, and governance (Bumann & Peter, 2019).

HFE identifies impacts on work processes, skills and work design, and change management to realise and consolidate business advantage. Human capital, investments in research and development, and collaboration with scientific partners have been identified as drivers of innovation (Apanasovich, Alcalde-Heras, & Parrilli, 2017) highlighting the importance of a business-industry ecosystem to support learning from others (Sako, 2018).

Figure 12: Basic digital innovation model for business



Source: Based on Forrester.Com (2022)

Our collaborative program of research examined these issues in a literature review on opportunities and challenges for digital transformation of the shipyard (Spoehr et al., 2020). The review identified the value of faster routine bespoke processes supporting sovereign shipbuilding capability in Australia, with challenges in addressing security and risk and the change management for optimising human resources and business system integration.

3.3.2 Value proposition

Organisational performance has its origins in individual performance. High levels of usability promoting technology acceptance, facilitates an organisational value-add through gains in productivity, quality and safety. All research trials examined elements of productivity, quality and safety, with one trial comparing human manual performance to cobot-assisted precision work in a glue dispensing task (Howard et al., 2021). This task achieved measurably higher safety outcomes, improving musculoskeletal disorders risk, and quality by achieving faster task completion with fewer errors. The value proposition was positive for performance outcomes but less clear based on high establishment costs.

3.4 Industry context

The need for new skills, work design and change management is ongoing when organisations engage in technology adoption (Waschull, Bokhorst, Molleman, & Wortmann, 2020). At an industry level, production changes will boost flexibility, industrial transformation and the creation of new jobs in supply chains, with standards that will be integrated into sustainable human resources management strategies (Petrillo, De Felice, Cioffi, & Zomparelli, 2018).

Industrial transformation can be accelerated through exposure of SMEs to supportive environments where technology adoption can be de-risked in a controlled environment (Planes-Satorra & Paunov, 2019). We have built capacity to adopt technology and tested its impact by engaging SMEs in the innovative Pilot Factory of the Future at the Line Zero site of Tonsley Innovation District.

In this context, our research found that participants in the smart measurement trial expressed preliminary concerns that the introduction of technology and subsequent changes to job tasks and responsibilities would result in them being deskilled and left with unsatisfying jobs (O'Keeffe et al., 2021). However, they recognised the need for proficiency in welding processes and capacity to problem-solve defects, and could see the advantages of faster and more accurate performance when using the technology. On a positive note, they could also see that the skills they could develop applying the technological solution to pipe fitting could transform their role to one of higher value.

3.5 Environment

Enabling and constraining environmental factors for technology adoption and industry transformation include strategic deficits, security and standards, legacy investments, competence and skills, and business investment support (Worrall & Spoehr, 2021). However, context matters – creating a vibrant environment to foster technology-led industrial transformation requires responsive regulation focusing on risk management. Key risks include ethics associated with product and work health and safety (Burton et al., 2020); and trust, security and privacy of information – both individual and organisational. These issues have been highlighted in the literature, with blockchain technology an exemplar (Pólvora, Nascimento, Lourenço, & Scapolo, 2020). Standards are also emerging for establishing systems for technology uptake and innovation[4], providing standardised systems-based approaches guiding business adoption (Benraouane & Harrington, 2021).

From the HFE perspective, the workplace environment must support people to feel safe to use technology and promote a culture where people are valued, learning is encouraged, work is well-designed and the workforce participates in creating satisfying, productive and safe jobs. Our AR, wearables and inspection trial examined perceptions of safety and security related to personal data collected from physiological monitoring technologies. Participants indicated a moderate willingness to use the technology - specifying conditions for protections such as policies to govern workplace use.

[4] See ISO 56002:2019 Innovation Management and supporting guides as examples

4 Accelerating the uptake and diffusion of advanced technology

Industry 4.0 technology is already making an impact, changing the nature of work across industries; but to realise the full benefits of adoption, organisations will need to adapt quickly, while managing risks. Future research should focus on creating knowledge to further inform and cultivate conditions to support such change. The stage of change model (discussed in Section 1), describes the process of adopting change, including the critical time spent in the preparation phase (collecting information, planning, and experimenting with small changes) that allows organisations to overcome uncertainty and accelerate efforts to adapt. The research trials reported here have sought to promote understanding about the finer level impacts on workers when engaging with advanced technologies. To maximise the value of this knowledge, future efforts should place greater attention on how user experiences flow through and influence organisational change, business innovation and industrial transformation. Ultimately this contributes to building an understanding about the dynamics of change and the actions and strategies needed to manage this disruptive process.

The hands-on exploration of technology in the Pilot Factory of the Future facility has provided a rich learning ground for participating individuals and organisations. We have gathered evidence on effective use of technologies, we have also learned to collaborate and understand implications and develop guidance for effective technology adoption.

Significant value can be gained by extending the current research to further:

1. Demonstrate value propositions for technology adoption
2. Increase supply chain capability
3. Enhance human and technology performance.

Specific activities to extend project outcomes and enhance the impact of work to date are summarised in Table 3.

To maximise impact, we have taken a multi-pronged formal and informal approach to dissemination of research findings to facilitate knowledge translation and technology adoption. This has included:

- Preparation of research reports
- Development of implementation guides
- Videos of trial activities
- Demonstrations of research trials and technology
- Academic papers (journal submissions and conference presentations)

Our approach is outward facing to share the research lessons and learning with our partners and SMEs. All publicly available research collateral is available on the Australian Industrial Transformation Institute website.[5] Having gathered a significant body of information, the opportunity also presents to target the findings to industry (e.g. in defence, manufacturing, technology) and government. This can include contributing to industry newsletters and other publications, and providing workshops and seminars for industry groups and education providers. Greater and more formalised engagement with peak bodies (e.g. Australian Industry Group) has potential to enhance reach and relevance of outputs for a wider audience.

[5] All publicly available research collateral is available on the Australian Industrial Transformation Institute website at https://www.flinders.edu.au/australian-industrial-transformation-institute/human-factors-in-advanced-manufacturing

Tours and demonstrations, both formal and informal, of the Pilot Factory of the Future facility have been extremely successful. They have enabled national and international business, industry, government, supplier and research representatives to visit, see and experience new technologies and learn about the value of the HFE approach in technology adoption. Extending this outreach, Factory of the Future will enhance capacity to engage with a broader audience through practical applications of technologies in problem-led and opportunity-testing trials. Relationship building and establishing a shared understanding remain at the heart of successful change such as technology adoption.

Table 3: Proposed research activities to extend project outcomes and impact

Theme	Further research
Value propositions for technology adoption	• Determining the value proposition of using HFE methodologies in technology adoption evaluations, including development of models and tools
	• Documenting case studies of technology implementation and the business innovation process as learning exemplars, including the development of models and tools
	• Assessing the impact of government-industry-academia partnerships in building capability in key supply chain organisations, focusing on the human factors of decision-making influences of leaders
Increasing SME capabilities.	• Extension of Factory of the Future programs to facilitate greater participation in trialling technologies in use cases aimed at solving real-world problems generated by business
	• Partnering with business to co-design and document case studies of process transformations through implementing technology solutions
	• Developing training and coaching programs on implementing/embedding HFE principles and methodologies into organisations as a strategy to accelerate technology adoption
	• Integrating HFE systems principles into digital maturity models and programs, promoting the value of HFE in innovation and change management systems
	• Examining human, technical and business factors and their interactions in the process of innovation management, including the development of models and tools
	• Extending HFE principles and content for technology adoption into business/government ecosystems to support technology uptake in related industries (e.g. renewable energy and clean production) to promote sustainability
Enhancing human-technology performance	• Assessing performance in higher complexity tasks and processes in research trials integrating multiple technologies (e.g. examining the human impacts and safety of artificial intelligence or Internet of Things (IOT)) and monitoring team interactions and responses to critical incidents (e.g. how people respond when technology fails or there is a lack of information)
	• Assessing the impact on usability and performance of technology-mediated collaboration e.g. augmented reality remote interactions with greater complexity tasks
	• Applying digital human models as a human factors methodology – adopting technology to study technology and compare to traditional methods
	• Examining the human factors of developing the technical knowledge necessary for technology adoption (e.g. coding, networking and interface design), by understanding the process of moving from novice to proficient in identifying new applications, reconfiguring technology solutions and integrating new knowledge into business systems

5 Conclusions

5.1 Human factors and ergonomics as an enabler of technology adoption

This research has explicitly promoted and accelerated the uptake and diffusion of technology in shipbuilding and its supply chain. The enabler for this process has been the application of HFE as a systems science that places the focus on people rather than technology. This approach improves technology acceptance in individuals with a view to scaling this to the organisations they work in. To adopt the inevitably broader change that comes of technology adoption, organisations must manage uncertainty and be prepared to explore and experiment with small changes. This program of research has enabled individuals and organisations to begin this exploration in a low-risk environment, cultivating curiosity and building confidence and networks to progress toward technology uptake and process improvement.

5.2 Contribution of research outcomes to project objectives

Applying a HFE lens to technology adoption begins with the human at the centre of the system of interactions. Consequently, we focused on introducing employees from shipbuilding and the manufacturing supply chain to advanced manufacturing and digital technologies and examined their responses. Much of our work has therefore focused on the individual and identifying the implications for broader human factors and business systems. The project has contributed to the objective of accelerating the uptake and diffusion of technology in shipbuilding and the supply chain by:

- Raising awareness of the value and understanding of how HFE can be applied to promote successful technology adoption
- Providing evidence to inform technology adoption and changing work practices, with emphasis on human resources management practices, including implications for skills development (reskilling and upskilling), and job design
- Increasing technology familiarity and acceptance in the shipbuilding and manufacturing workforces through opportunities to participate in trials
- Building capacity through acquiring new skills and knowledge about:
    - the practice and value of HFE in technology adoption and process improvement
    - specific advanced technologies, applications and operating systems
    - technology ecosystems, including integration, connectivity, and cybersecurity
    - business systems and practices
    - working in collaborative and multi-disciplinary teams.

Awareness has grown in individuals and businesses including BAE Systems Australia – Maritime, Flinders University and the many SME collaborators. The value of this university-industry collaboration, including perspectives from key partner and supply chain participants, is the focus of research summarising project outcomes[6].

An important outcome of this program of research has been reinforcement that application of a single system or technology rarely fits all situations and should be tailored to the context, providing options to maximise employee acceptance. Furthermore, demonstration of the limitations of technology as well as its benefits, invariably alleviates concern around technology replacing people’s jobs, and energises focus on how technology can best support them in their work.

[6] See *All hands on deck: Building Industry 4.0 Momentum through University-Industry Collaboration* https://www.flinders.edu.au/australian-industrial-transformation-institute

Appendix A: Summary of research program outputs

Table 4: Principal research outputs from the Industry 4.0 collaborative project

Type of activity	Name of output	Overview
Literature reviews and knowledge synthesis	*Quicker off the blocks: The role of human factors & ergonomics in the uptake and diffusion of advanced technologies in shipbuilding* (O'Keeffe et al., 2020)	Describes the discipline of human factors, and how it can be applied to contribute value to the adoption of advanced technologies in shipbuilding and manufacturing
	The Digital Shipyard: Opportunities and Challenges (Spoehr et al., 2020)	Describes the concept of the digital shipyard and its development based on the adoption and integration of Industry 4.0 technologies to transform shipbuilding capability
	Naval Shipbuilding and Industry 4.0: Building the Value Chain and Industry Capability (Worrall & Spoehr, 2021)	Discusses the present position and future role of digital technology in the Australian naval shipbuilding industry to drive development along the supply chain, identifying success factors and benchmarking tools
	Robotics and the Digital Shipyard (Manning et al., 2021)	Reviews the 'current state' of robotics applications in Australian manufacturing to inform considerations about potential applications of the technologies in shipbuilding
	Manufacturing work by Design: Pillars of successful integration of Industry 4.0 technology into jobs (Howard et al., 2022)	Describes the interaction of job design and skills in the implementation of advanced technologies using a job design framework of six building blocks – technology, task content, job demands & resources (work health & safety, skills & knowledge, and social support) with the overarching element of sustaining change management
	All hands on deck: Generating knowledge through University-Industry Collaboration (currently being finalised)	Describes the perceived process, outcomes and value of the current university-industry collaboration
Technology trials	*From ship to shore: Reducing the barriers to collaborative robot uptake in shipbuilding and manufacture through human factors* (Howard et al., 2021)	Describes the human factors outcomes of a laboratory-based research trial assessing performance on a path-guiding task using a collaborative robot compared to human hand-held tools
	Staying on course: Human factors in navigating digital work orders in harsh environments in shipbuilding (O'Keeffe, Jang, Howard, Hordacre, & Spoehr, 2021)	Describes the human factors outcomes of a research trial using augmented reality technologies (Apple iPhone and Google Glasses) to access a digital work order to complete low complexity pipe and instrument tasks in simulated harsh environments (working at height, constrained space and simulated confined space)
	Setting it Straight: Human factors, technology and pipe alignment in shipbuilding (O'Keeffe et al., 2021)	Describes the human factors outcomes of a research trial using motion capture technology (' Optitrack') to accurately align pipe fittings in a smart production cell. A smart projector was also trialled to assess usability during editing of a digital technical drawing of the pipe assembly

Note: This table captures primary activities completed to 30 September 2022 but should not be considered an exhaustive list. Once published all outputs are available at https://www.flinders.edu.au/australian-industrial-transformation-institute

Table 4: Principal research outputs from the Industry 4.0 collaborative project (continued)

Type of activity	Name of output	Overview
Implementation guides	*HoloLens 2*	This is an augmented reality head-mounted device providing a digital alternative to hard copy work instructions and information
	Spot	This is a mobile, four-legged robot (quadruped) modelled on animal morphology (e.g. a dog)
	Collaborative robot (cobot)	This is an industrial robotic arm which is speed and force limited. Designed with pinch-points and built-in safety sensors, it does not need to be 'caged' like other industrial machinery
	Google Glass	This is a wearable device designed to provide hands free information on a semi-transparent screen in a field of view
	Optitrack Motion Capture System	This is a precision digital 3D optical measurement and object tracking tool
	Empatica E4	This is a medical grade wearable device worn on the wrist and is capable of measuring body temperature, skin conductance, activity (acceleration), heart rate and inter-beat interval
	Polar Watch and Heart Rate Monitor	These are capable of measuring heart rate. Heart rate and heart rate variability measures are comparable to that obtained from medical grade devices
	Creating change	Describes five key lessons for businesses to keep in mind when adopting technology
Videos	*Visual inspection technologies*	Footage showcases users completing visual inspection of a pump and pipe skid using both augmented reality (HoloLens 2) and a quadruped robot (Spot) at Pilot Factory of the Future, Line Zero. The relevance of human factors and the broader objectives of the program of research are discussed.
	Electrical cabinet assembly and inspection technologies	Footage showcases users completing assembly of an electrical cabinet using augmented reality (HoloLens 2), integrated with inspection by a collaborative robot at Pilot Factory of the Future, Line Zero. The relevance of human factors and the broader objectives of the program of research are discussed.

Note: This table captures primary activities completed to 30 September 2022 but should not be considered an exhaustive list. Once published all outputs are available at https://www.flinders.edu.au/australian-industrial-transformation-institute

Appendix B: Content analysis method

The formal outcomes of the project have been captured in a series of research outputs comprising literature reviews, and empirical research (see **Error! Reference source not found.**).

Table 5: Summary of research outputs reviewed for content analysis

Title	Type	Description
Quicker off the blocks: The role of human factors and ergonomics in the uptake and diffusion of advanced technologies in shipbuilding	Literature review	Explains the systems approach and user-centred perspective of HFE, the transformation of manufacturing promised by advanced technology adoption, and proposes a human factors framework for the uptake of Industry 4.0 technologies
Manufacturing work by desIgn: Pillars of successful integration of Industry 4.0 technology into jobs	Literature review	Provides a framework of technological and people considerations when introducing change to a business, built on sociotechnical systems theory and emphasising job design and skills development
Digital shipyard: Opportunities and challenges	Literature review	Describes the concept of the digital shipyard and its development based on the adoption and integration of Industry 4.0 technologies to transform shipbuilding capability
Naval shipbuilding and Industry 4.0: Building the value chain and capability	Literature review	Discusses the present position and future role of digital technology in the Australian naval shipbuilding industry to drive development along the supply chain, identifying success factors and benchmarking tools
Robotics and the digital shipyard	Literature review	Describes the opportunities for robotics to improve safety, quality and productivity in shipbuilding, including Australian case studies of implementation in manufacturing
Human factors in designing a digital work order: Proof of capability case study	Empirical research report	Presents a case study of the value in applying human factors and ergonomics methods to evaluating initial capability of a digital work order for shipbuilding. The laboratory-based trial assessed volunteer shipbuilding personnel completing a digital work order representative of typical shipyard production tasks using portable digital devices
Usability of portable digital devices in harsh environments[7]	Empirical research report	A technical report on usability of selected portable digital devices (phone, tablets) in simulated harsh environments to inform decisions on shipyard deployment. Technology acceptance depends on fit with task and environment
Staying on course: Human factors in navigating digital work orders in harsh environments in shipbuilding	Empirical research report	Describes the human factors outcomes of a research trial using augmented reality technologies to access a digital work order to complete a low complexity task in simulated shipbuilding harsh environments
Visual inspection with augmented reality head-mounted display: An Australian usability case study	Empirical research draft journal article	A summary of a usability trial involving augmented reality inspection in simulated shipbuilding environments, applying performance, workload, and systems usability measures
Forming a view: A human factors case study of augmented reality collaboration in assembly	Empirical research draft journal article	This study examined the use of an augmented reality head-mounted display in a simple electrical assembly task integrating cobotic visual inspection and human-human collaboration

[7] This report was not publicly released as it reported a trial conducted by BAE Systems Australia – Maritime supported by Flinders University human factors expertise.

The content analysis proceeded in three stages:

1. Familiarising with and summarising each document to identify key content for each focus area
2. Content analysis to identify repeated patterns of concepts, results and implications enabling content to be categorised into sub-themes (see Appendix B for a summary of sub-themes)
3. Repeating the process to aggregate sub-themes into main themes (Braun & Clarke, 2012). Main themes and sub-themes were collated in tables supported by illustrative content.

The analysis produced six broad themes that summarise the work of the project, namely:

1. Human factors and ergonomics - systems science
2. Technology acceptance (human-technology interaction)
3. Skills and work design
4. Organisational change management
5. The value proposition of human factors and ergonomics in Industry 4.0
6. Business innovation driving industry transformation.

Appendix C: Content analysis sub-themes

Table 6: Sub-themes by analytic focus of context

Theme	Sample content
HFE as a process & (sociotechnical) systems science	Evidence-based frameworks for understanding and facilitating successful technology adoption
	Improving quality, productivity, safety & wellbeing
	Mixed-methods – qualitative and quantitative
Human - technology interaction	Usability – ease of use, usefulness, satisfaction
	Digital work management – phones, tablets, AR
	Robotics – cobot, quadruped robot
	Smart production cell – motion capture measurement, integration of AR & cobot
Environments	Simulated harsh environments – work at height, confined space, work bench
	Laboratory – digital work order proof of concept, cobot
Industry transformation (Digital shipbuilding)	Value proposition – use cases & return on investment
	Integration – horizontal & vertical
	Value chain – firm size matters

Table 7: Sub-themes by analytic focus of outcomes

Theme	Sample content
Human versus technology	Mental demands perceived as lower using technology-aided method
	Technology-aided perceived as more accurate than human performance
	Technology-aided perceived as safer than human performance
	Performance time faster when technology-aided
Performance (safety, quality, productivity)	Lower reported musculoskeletal discomfort
	Visual fatigue and possible situation awareness impairment
	Design and performance are interdependent
	Trend for equal or better productivity with technology assistance
Frequently recommended systems improvements	User interface design
	Greater integration of functions
	More logical process flows
	Less complexity to reduce errors and workload
Technology acceptance	High willingness to use tech (self-selected participation)
	Need for new skills – upskilling, reskilling esp. for workers using traditional methods ('older' workers)
	Impact on work organisation
	Cost-benefit of adoption
	Familiarity increases willingness and confidence (iPhone, gaming experience)
Human-technology interaction	AR interaction challenging but low familiarity (gesturing, field of view, moderate mental effort)
	Integration of techs and remote collaboration well accepted by users
	Technologies with familiar features experienced more positively (iPhone, games experience)
	Robotics perceived as having low workload (not including programming)
Industry transformation (Digital shipbuilding)	Process redesign
	Security & risk
	Strategic deficits
	A digitalisation roadmap

Table 8: Sub-themes by analytic focus of implications

Theme	Sample content
HFE value proposition	Identify broadly applicable technology use cases
	Demonstrate cost benefit analysis for human factors methods
	Develop models for SME cost-benefit analysis
Usability testing identifies challenges and opportunities to uptake	User/goal-centred rather than technology-centred
	Technology-specific strengths and limitations
	Context of use – harsh environments, nature of tasks, user goals
	Organisational context – culture, work organisation, skills
Proactive change management	Work organisation and job design changes – ripple effects
	Participation – early and ongoing, whole of organisation
	Business goals and strategy aligned with people management
Collaboration	Multidisciplinary skills – engineering, psychology, business, HRM, production
	Business ecosystem – designers, suppliers, consultants, researchers
	Government and industry policy and programs
Systems integration	Technologies – digitalisation of organisations – scale and diffusion
	Organisations – joining up processes and streamlining interfaces (lean principles)
	SME support

Theme	Sample content
Meta-learning	New skills and configurations of skills
	Individuals as lifelong learners
	Learning to learn – unlearn, relearn, learning through doing
	Learning organisations
	Learning factories, innovation hubs
Industry transformation (Digital shipbuilding)	Maturity models – digital readiness
	Legacy investments
	Programs for business investment & support

Table 9: Sub-themes by analytic focus of future directions

Theme	Sample content
HFE in technology-systems integration	Engaging users in redesigning lean workflows to support technology adoption
	Developing roadmaps and 'how to' guidance for SME technology adoption
	Organisational management and design approaches – integration into strategy, production planning, operations and HRM
Effective change management for technology adoption	Effective engagement, participation, and involvement
	Developing psychosocial safety to develop a learning culture e.g. growth mindset, seeking behaviours
	Recruitment and retention strategies to achieve technology-ready workforce
Skills development in technology adoption	Contribute to research on effective methods for acquiring technology-related skills in collaboration with educators
	Examining complementary models (innovation, agile management, high performance workplaces, lean production, learning factories) – similarities and differences and effectiveness
Extensions of HFE trials	Usability trials in field settings – assess durability, reliability, context of actual use
	Larger sample sizes and tasks of longer duration to validate findings
	Adopt a variety of more sophisticated methods – technology-mediated (e.g. digital human modelling, physiological monitoring)
Interface design	Develop skills and expertise in user interface design
	Develop research capability in user interface design
	Contribute to development and uptake of accessible user interface design guidelines and standards
Digital shipbuilding supply chain	Development of digitalisation roadmaps/guides
	Building SME absorptive capacity – knowledge, skills
	Building return on investment models

Appendix D: NASA Task Load Index dimensions across trials

Note that for all figures shown here, an average (mean) score of 30 or below is considered to indicate low demands and above this, high demands. A full description of each trial can be found in Table 1.

Figure 13: NASA Task Load Index dimensions for precision dispensing with a collaborative robot (n=19)

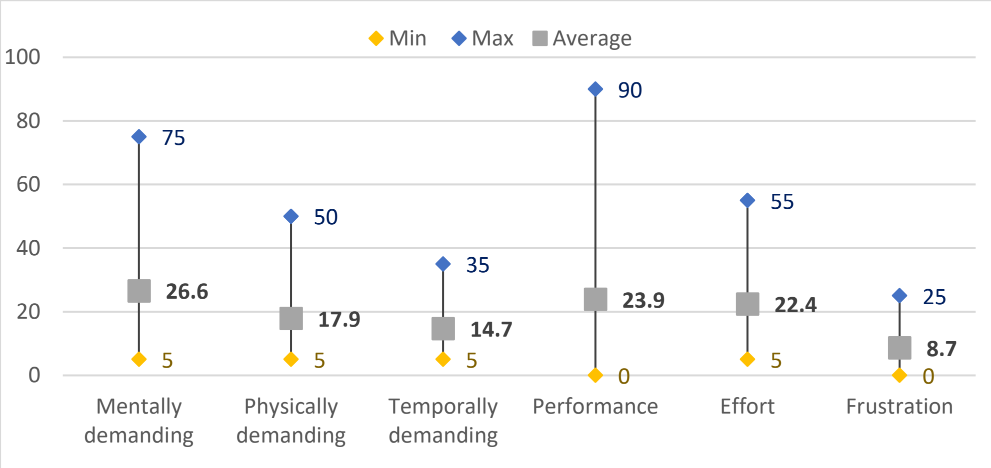


Figure 14: NASA Task Load Index dimensions for completing a visual inspection task supported by a quadruped robot (n=22)

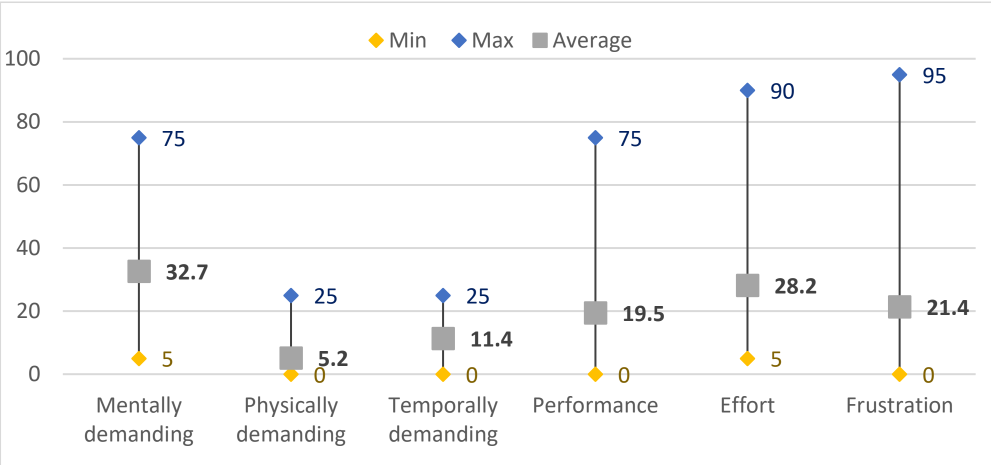


Figure 15: NASA Task Load Index dimensions for smart measurement of pipe alignment with a motion capture system (n=7)

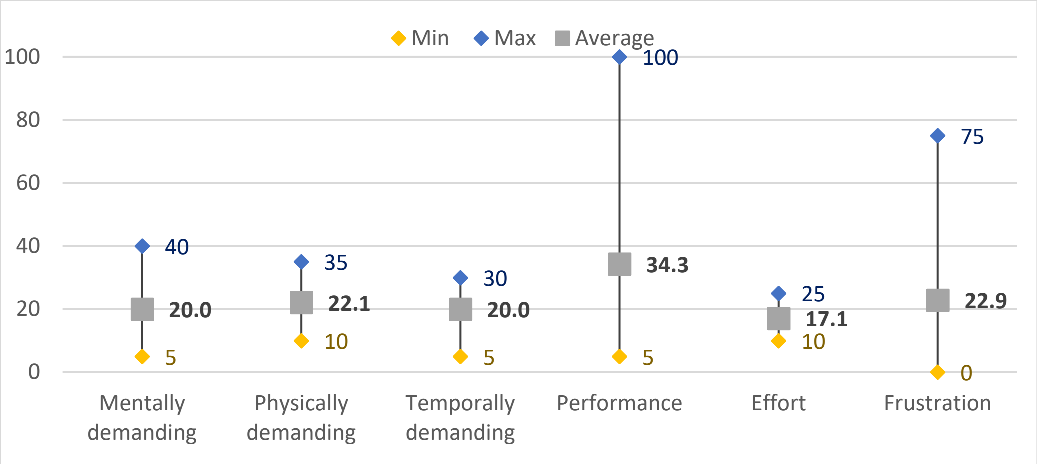


Figure 16: NASA Task Load Index dimensions for completing a visual inspection task supported by augmented reality (n=22)

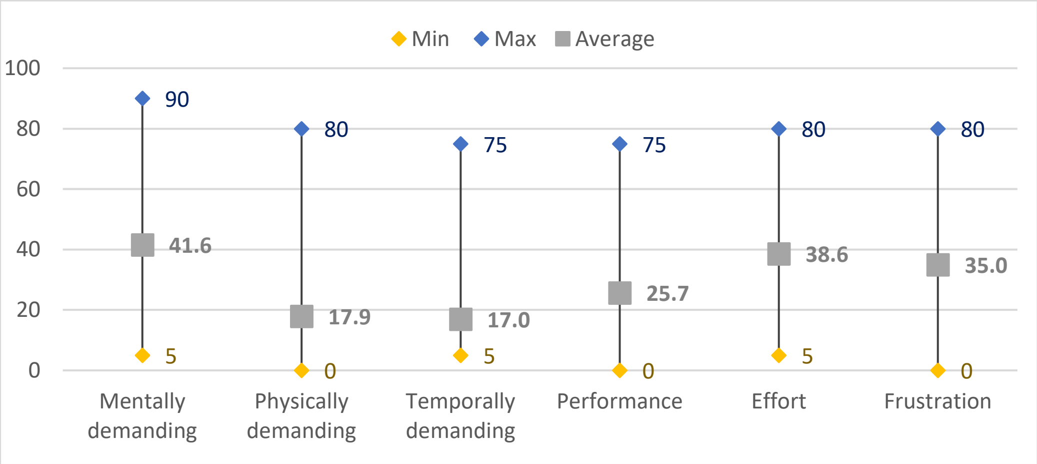
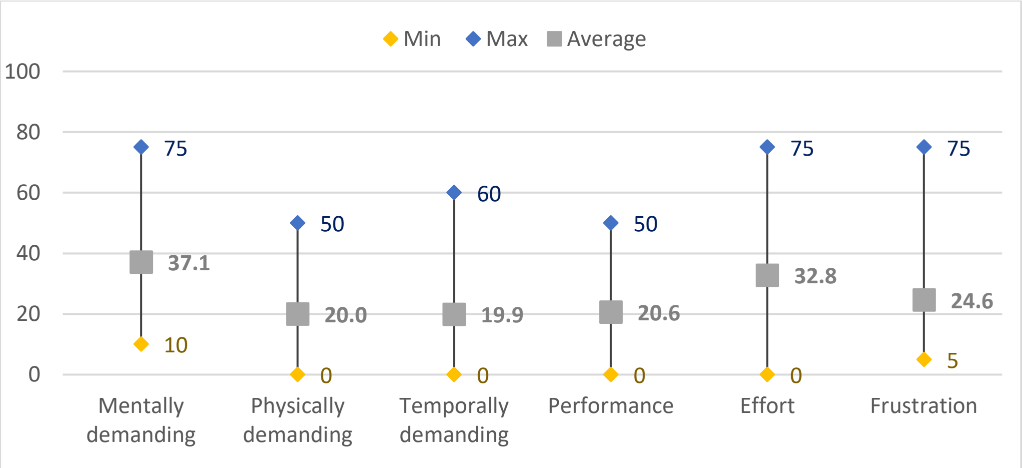


Figure 17: NASA Task Load Index dimensions for assembling an electrical cabinet supported by augmented reality (n=36)

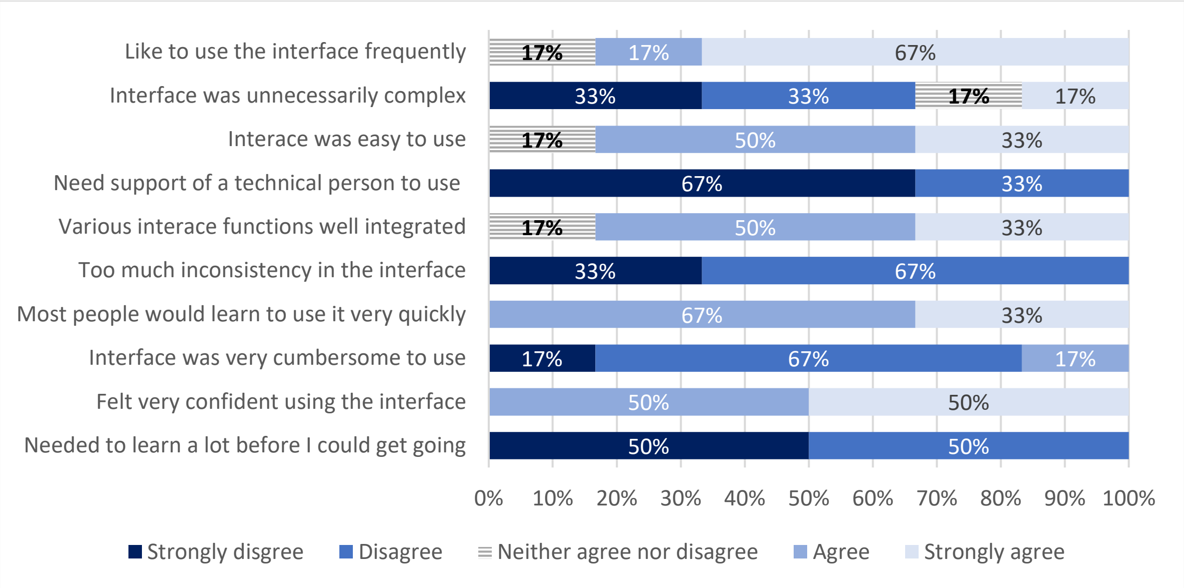


Appendix E: SUS raw scores (Smart Projector)

The SUS provides several different types or layering of scores:

- The **raw score**, ranging from 1 (strongly disagree) to 5 (strongly agree) – this is presented below as a proportion (%) of responses, is converted to
- An **adjusted score** (including reversal of negative statements), ranging from 0 (poor rating) to 4 (best rating), - this is provided in Appendix F, which is summed and multiplied by 2.5 to achieve
- A **standard score**, ranging from 0 (poor usability) to 100 (excellent usability) – this score is provided in Section 3.2.3.

Figure 18: SUS raw scores for editing technical drawings using a Smart Projector (n=6)



Appendix F: SUS adjusted scores across trials

The SUS provides several different types or layering of scores:

- The **raw score**, ranging from 1 (strongly disagree) to 5 (strongly agree) is converted to
- An **adjusted score** (including reversal of negative statements), ranging from 0 (poor rating) to 4 (best rating) – this is the score provided below and which informed **Error! Reference source not found.**,
- Which is summed and multiplied by 2.5 to achieve a **standard score**, ranging from 0 (poor usability) to 100 (excellent usability) – this score is provided in Section 3.2.3.

Note, the **mean** of a set of values is the sum of all the values divided by the number of values. This figure is mostly referred to as the 'average' and is most frequently reported. The **median** or midpoint is the middle value in a set of numbers. It is the value that separates the higher half of values from the lower half of values. The median is useful because it is not influenced by the presence of extremely large or small values and can provide a better understanding of a typical or common value in a data set.

Figure 19: SUS adjusted scores for completing a visual inspection task by digital work order on a laptop (n=22)

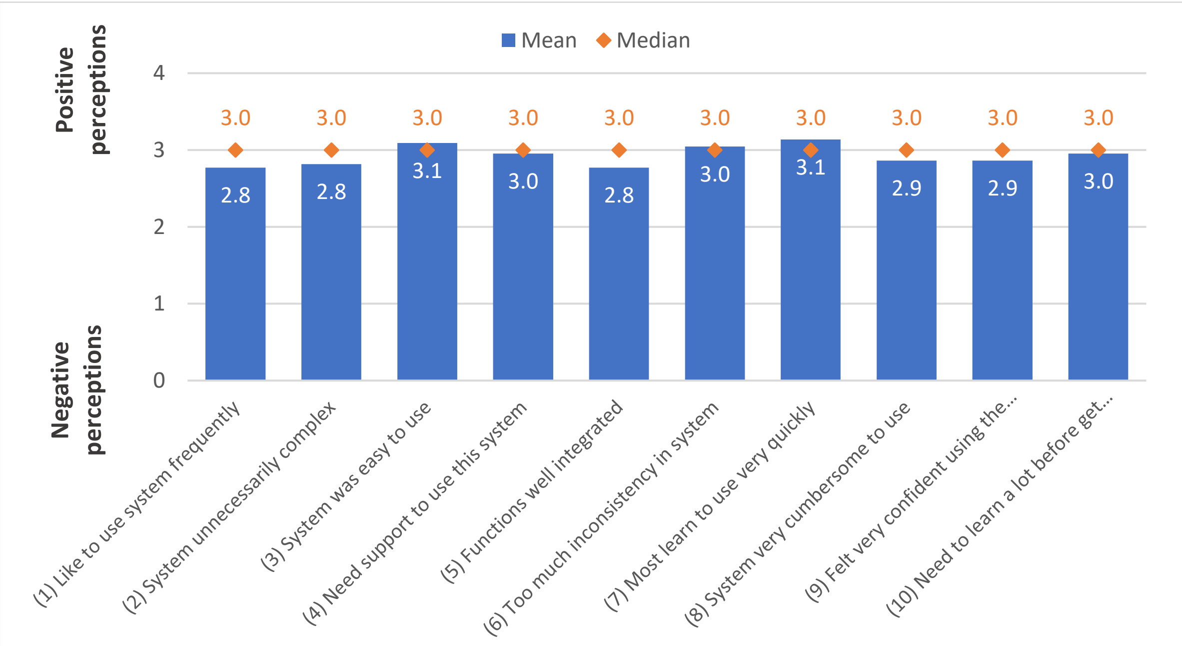


Figure 20: SUS adjusted scores for editing a technical drawing using a smart projector (n=6)

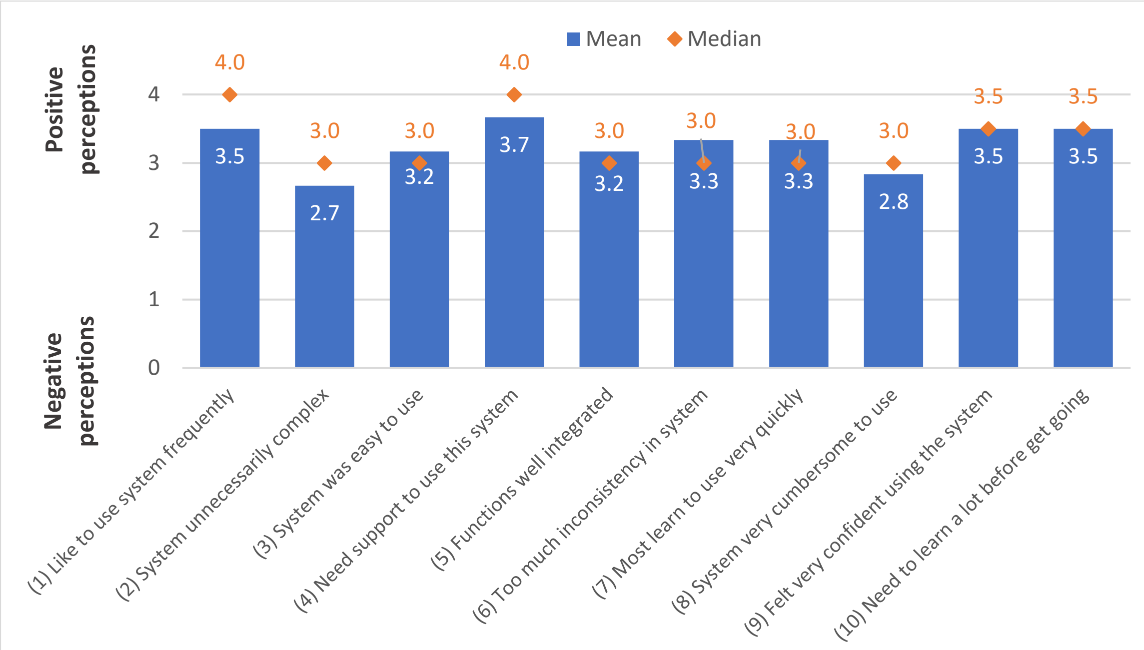


Figure 21: SUS adjusted scores for completing a visual inspection task via augmented reality(n=22)

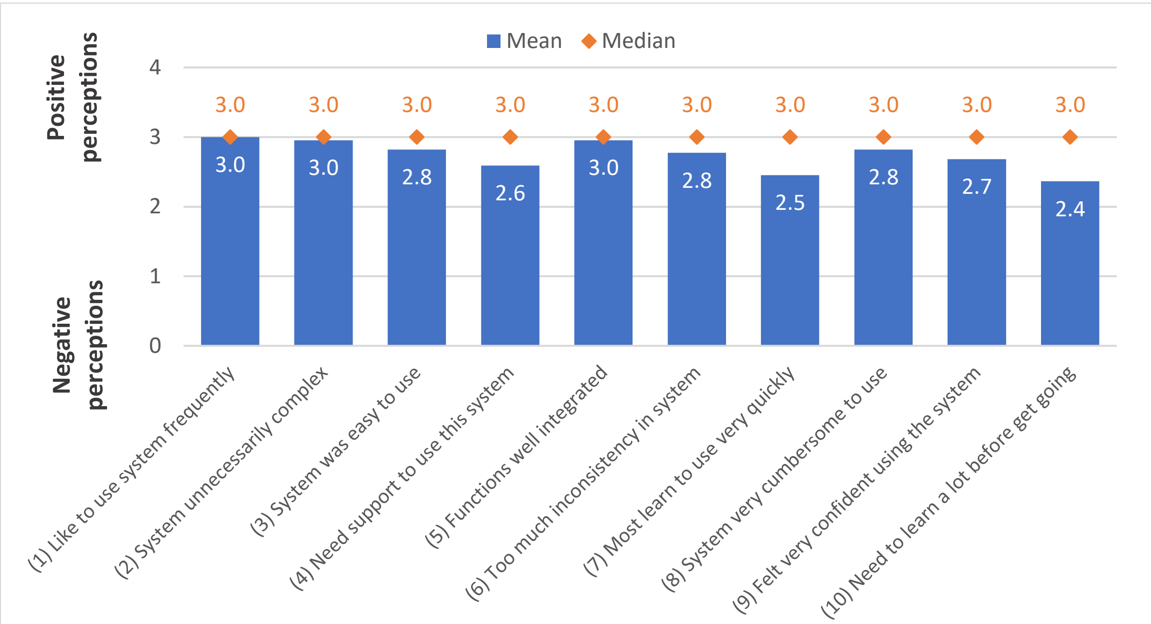


Figure 22: SUS adjusted scores for completing an electrical cabinet assembly via augmented reality (n=36)

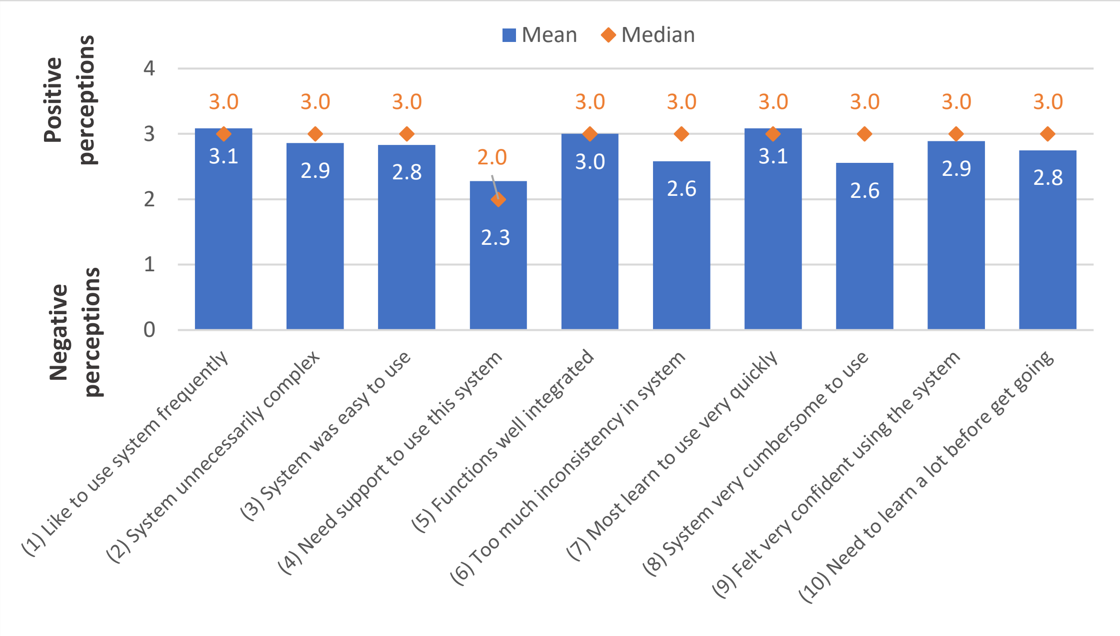
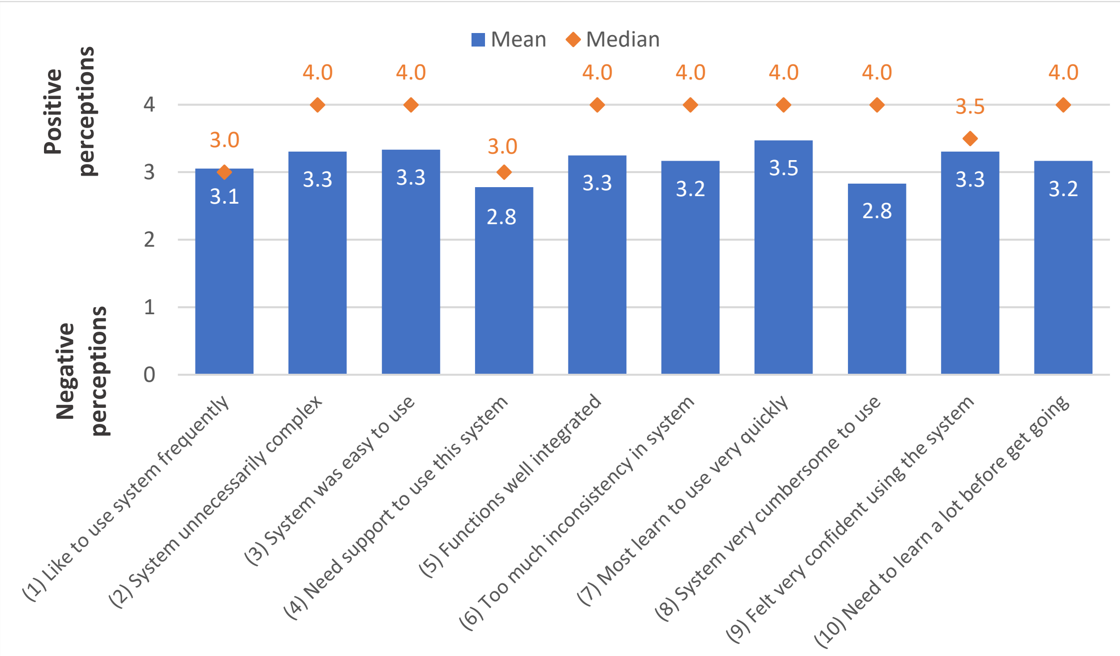


Figure 23: SUS adjusted scores for completing an electrical cabinet assembly with integrated collaborative robot inspection (n=36)



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