Flinders University
Australian Industrial Transformation Institute

All hands on deck

Building Industry 4.0 momentum through University-Industry collaboration

John Spoehr, Ann-Louise Hordacre, Cecilia Moretti, Valerie O'Keeffe, Sara Howard, Ryan Jang, Kosta Manning & Robert Trott

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Building Industry 4.0 momentum in shipbuilding through University-Industry collaboration

Australian Industrial Transformation Institute

College of Business, Government and Law
Flinders University of South Australia

1284 South Road
Clovelly Park
South Australia 5042

www.flinders.edu.au/aiti

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Executive Summary

The value of productive collaboration between universities and industry (UIC) has been the focus of considerable attention over the last decade. Concerned about the need to increase both the quantity and quality of UIC in Australia policymakers have advocated efforts to improve the nation's UIC peformance. This report focuses attention on lessons learnt from a rapidly evolving collaboration between the Australian Industrial Transformation Institute at Flinders University and BAE Systems Australia – Maritime (BAESAM). It examines the contribution played by the *Accelerating the Uptake and Diffusion of Innovative Manufacturing Technologies in Australian Shipbuilding and Supply Chain: The Human Factors* project funded by the Innovative Manufacturing CRC.

UICs play an important role in expanding open innovation capability in organisations, networks and clusters by encouraging innovation activities to be decentralised in a participatory way. Open innovation extends on traditional approaches like research and development (R&D) largely conducted in-house. Collaboration is at the heart of open innovation and has been central in our approach to accelerate adoption of advanced industry 4.0 (i4.0) technologies into manufacturing processes. Implementing i4.0 concepts requires not only new technology and infrastructure, but also developing internal organisational innovation capabilities and openness for external networking. Organisations who actively engage external networks have been found to innovate more quickly.

The *Accelerating the Uptake and Diffusion of Innovative Manufacturing Technologies in Australian Shipbuilding and Supply Chain: The Human Factors* project commenced in March 2020, building on initial work undertaken between the partners at Flinders University facilities at the Tonsley Innovation District.

The UIC was facilitated by co-location of Flinders and BAESAM employees in a Collaboration Laboratory at the Flinders at Tonsley building. Co-location enabled the development of a shared language and mutual understanding of needs and priorities. This rapidly evolved into the establishment of the Pilot Factory of the Future facility at the Line Zero site, Tonsley Innovation District. The Pilot Factory of the Future site enabled multiple test and trial projects to be undertaken and became a compelling site for industry engagement, education and training. It also facilitated joint learning and knowledge transfer across multiple areas of expertise including technology management, health and safety, human factors and ergonomics.

Several models of UIC exist in the literature, with the triple helix model involving industry and universities facilitated by government, being most common. Our UIC is an example, where industry acts as the key site of production, the university as the primary source of societal knowledge, and government oversights contractual management to ensure engagement and resource exchange to develop value for all parties. In the context of UIC, value can be described as the mutual appreciation of knowledge shared for a common purpose, as perceived by those who benefit from it. The value derived from UIC can be classified into three broad categories: commercial, organisational capital and societal and economic.

Five industry participants were invited to provide perceptions via semi-structured interviews of the value of the UIC. BAESAM interviewees attributed the success of the UIC to the calibre of the leadership on both sides of the partnership and their ability to build on a previously established relationship and nucleus of trust between the organisations.

Exposure to advanced technologies for small and medium-sized enterprises (SMEs) through the opportunity to participate in technology trials, was seen as a key outcome of the UIC. SME participants saw the hands-on practice as providing a distinct company benefit by enabling business representatives to better explain emerging technology and its impacts to clients. Exposure to innovative applications of technology served as a 'mindset prompt', to think creatively, challenge the status quo and remain open to possibilities.

Key reflections on the collaboration from a BAESAM perspective included: the need for genuine hands-on engagement by both parties, selecting the right people to be in the team, having a project champion to drive and connect the collaboration from the perspective of their organisation, and working with different cultures of industry and academia. From an SME perspective, key themes included the opportunity to develop a research network, and appreciating the impact of technology in creating new ways of working.

It is too early to tell the extent to which the UIC and the Factory of the Future will lead to greater i4.0 adoption among SMEs. This is an area for further exploration once the foundations built by this project expand into the permanent facility, a collaborative space to facilitate research, development and innovation. Its purpose is to facilitate greater industry participation and knowledge translation, promoting the desired goal of digital transformation in manufacturing.

1 The value of university-industry collaboration

Technologically complex projects and challenges can benefit greatly from mature university-industry collaborations. One prerequiste for success is a sophisticated appreciation of barriers and enablers in the context of what we know about what it takes to establish thriving innovation systems and innovative organisations.

University-Industry collaboration (UIC) plays an important role in expanding open innovation capability for organisations (Ankrah & Al-Tabbaa, 2015) networks and clusters. Essentially, open innovation encourages businesses to 'innovate in a more distributed, decentralised and participatory way' (Dahlander & Wallin, 2020, para 2). Open innovation should be viewed as complementary to traditional 'closed' models of innovation where an organisation has in-house knowledge and their own R&D department (Ankrah & Al-Tabbaa, 2015).

A key catalyst for innovation is knowledge exchange and particularly within this, knowledge diversity (cited by Kotiranta, Tahvanainen, Kovalainen, & Poutanen, 2020 p.3):

> *Alves, Marques, Saur and Marques (2007) contend that the generation of innovations benefits from collaborative, multidisciplinary environments in which both industry and academia coexist and cooperate. In this context, engineering disciplines are a central but not sufficient source of innovation.*

When collaborating across domains of expertise, co-design and coordination are paramount to ensure diverse contributions and knowledge are integrated, thus establishing collaborative innovation (Cirella & Murphy, 2022).

Irrespective of the number or nature of stakeholders involved in the collaboration and open innovation efforts, establishing and maintaining mutual trust is vital for successful knowledge sharing. Other pre-requisite social capital required for effective UICs include organisational commitment (e.g. mutual obligations, common understanding) and resource availability (e.g. access to information and opportunities) (Awasthy, Flint, Sankarnarayana, & Jones, 2020).

Engaging in open innovation and UICs is often complex and at times considered 'messy' (Ollila & Ystrom, 2016, p.363) as established practices, norms and organisational cultures are challenged (Cirella & Murphy, 2022). It is important to acknowledge these challenges and manage expectations of all stakeholders, appreciating that optimal collaboration may take time to establish and is reliant on appropriate steps being taken.

KEY DEFINITIONS

University-Industry Collaboration involves *interaction between any parts of the higher educational system and industry aiming mainly to encourage knowledge and technology exchange*

(Ankrah & Al-Tabbaa, 2015, p.387)

Open innovation is a *business management model for innovation that promotes collaboration with people and organisations outside the company*

(Ennomotive, 2021)

Knowledge management is an *organisational activity in managing knowledge as an asset*

(Sri Pudjiarti, Lisdiyono, & Werdiningsih, 2022, p.462)

Co-design *combines generative or exploratory research, which helps to define the problem that requires a solution, with development design*

(NSW Council of Social Service, 2017, p.1)

Collaborative innovation occurs when *organisations' activities are virtually co-designed, implying coordination of decision making across organisational boundaries*

(Ollila & Ystrom, 2016, p.365)

Social capital can be described as *networks together with shared norms, values and understandings that facilitate cooperation within or among groups*

(OECD, 2002)

Maturity models are *tools that help people assess the current effectiveness of a person or group and support figuring out what capabilities they need to acquire next in order to improve their performance*

(Fowler, 2014, n.p.)

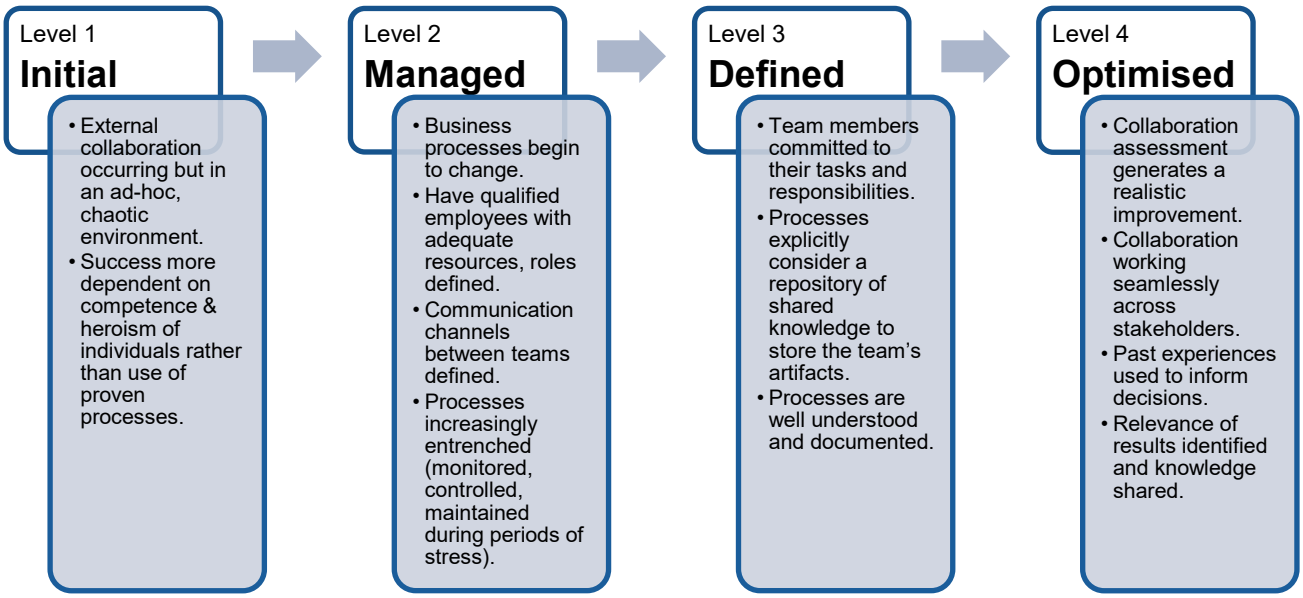
Notwithstanding the challenges, the effort can be rewarding and the benefits of collaboration potentially far-reaching. For example, discussed benefits occur:

- **Locally** such as commercialisation of research and innovation (Tschanz et al., 2020);

- **Regionally** such as revitalisation of regions (Sanni, Egbetokun, & Siyanbola, 2010; van der Sijde, Vogelaar, Hoogeveen, Ligtenberg, & Velzen, 2002); and
- **Nationally** such as a catalyst for techno-economic development (Wonglimpiyarat, 2016).

The maturity model developed by Silva, Ribeiro, Pinto, and Monteiro (2021) defines the levels of UIC as the relationship develops (see Figure **1**). This provides guidance for collaborators about the stages of the relationship from individually-led, to a purposive managed state through to a shared commitment to defined goals, and a seamless optimised collaboration.

Figure 1: A maturity model for collaborative research & development university-industry sustainable partnerships



Source: Content from Silva et al. (2021)

How collaborations are structured can influence their achievements. Living labs and teaching factories (Mourtzis, Vlachou, Dimitrakopoulos, & Zogopoulos, 2018) are dynamic, unrestricted spaces that allow for co-creation of ideas and solutions which can be tested[1]. Living labs (and derivatives) are more likely to advance economic and broader societal goals (Burbridge & Morrison, 2021) because they rely on user engagement and open innovation with the aim of cultivating a long-term community. Living labs can be established in a range of locations including on or off a University campus, in a Science and Technology Park, at precinct scale or virtually (Burbridge & Morrison, 2021).

Knowledge transfer is often dependent on the intensity and quality of interactions between individuals from each organisation (Seppo & Lilles, 2012). Individuals (and their networks) are the foundation of successful UIC (Canhoto, Quinton, Jackson, & Dibb, 2016). Frequent interaction between individuals from each organisation is needed to

KEY DEFINITIONS

Living Labs *are a way for university researchers to conduct studies in vivo, based on experimentation and an integration of research and innovation in real-life situations*

(Lake Superior Living Labs Network, n.d.)

Knowledge transfer refers to the *movement of knowledge, ideas, concepts and techniques from a formative location, generally institutions of advanced education, out to all areas of the social and economic environment*

(Gardner, Fong, & Huang, 2010)

Technology transfer occurs when *the university-driven research and industry expertise make complementary contributions into commercialised technologies needed by market*

(Seppo & Lilles, 2012, p.206)

[1] https://livinglabs.lakeheadu.ca/living-lab-approach/

facilitate the transmission of know-how and tacit knowledge rather than relying on formal exchanges of codified research results (Seppo & Lilles, 2012).

1.1 UIC in the i4.0 context

1.1.1 Open innovation/collaboration and the transition to i4.0

Collaboration is at the centre of the open innovation paradigm, where the aim is merging advanced technologies into manufacturing processes. Collaboration is imperative for innovation, as all relevant knowledge does not exist within one firm (Obradovic, Vlacic, & Dabic, 2021). Implementing i4.0 concepts requires not only applying new technology and infrastructure, but also developing intra-organisational innovation capabilities and openness for external networking.

Case study research has found that organisations actively using external networks innovate more quickly (Halse & Ullern, 2017). As a corollary, innovating organisations are increasingly reliant on external knowledge sources and access to infrastructure, human capital, and partners' innovative capacities. Businesses engaged in i4.0 need both an internal organisational collaborative culture and external collaboration involving an ecosystem of other businesses, academia, and institutions (Lepore, Dubbini, Micozzi, & Spigarelli, 2021). i4.0 collaboration is enabled by people management practices that encourage individuals to embrace change through knowledge sharing that builds trust, cooperation, diversity, teamwork, mutual respect, open communication and empowerment.

SMEs with strong internal and external social capital (relationships and collaboration) are more likely to adopt i4.0 technology. The success of collaborative endeavours to support i4.0 adoption is moderated by multiple factors including top management support and strategic vision, IT competencies, internal social capital, absorptive capacity, and business investment in advanced manufacturing technologies (challenging for SMEs due to their resource limitations) (Agostini & Nosella, 2020). Other supporting features include having a strong partner management approach, well-developed relationship management skills, and a leader or champion within the business 'who is able to search for the knowledge the firms miss, understand and internalise this external knowledge and exploit it successfully to make purposively good use of it' (ibid., p. 637).

1.1.2 UIC supporting i4.0 adoption

Evidence suggests that technological collaboration with external R&D providers like universities is positively associated with productivity, innovation efficiency and resource allocation (Lepore et al., 2021). The innovation capability of large organisations is generally recognised as higher than SMEs, though it is impeded by bureaucracy, risk-aversion and being less responsive to changing market demands. Innovation challenges for SMEs include the high level of risk, complexity, and uncertainty in the innovation process, limited financial resources for R&D, a low multidisciplinary competence base, and less structured approaches to innovation. The role of universities and research institutions is seen as pivotal for offering specialised technologies and knowledge of benefit to SMEs as a basis for developing radical innovation (the ability to develop products that are new to the world or industry) (Parida, Westerberg, & Frishammar, 2012).

The role of universities working through an open innovation model has been shown to support a systemic innovation culture to encourage i4.0 adoption within SMEs. A collaboration framework built around a university-based industrial lab was designed to boost the development and adoption of i4.0 in Brazilian industry (Rabelo, 2021). The framework included components of teaching, research (developing new responses to i4.0 needs), and outreach (providing professional courses, consultancies, technical evaluations and policy guidance to government

and industry). University facilities and research infrastructure were made available to i4.0 adopters and developers to evaluate technologies in near-real environments, supporting decision-making on whether to buy, or invest in innovation projects with unknown technical feasibility (ibid., p. 479). Jassem and Razzak (2021) note that UIC has most notably progressed in countries such as Germany, Canada, Japan and China. They point to a pressing need to develop suitable models of UIC by assessing existing models (discussed further in Section 2.2) and considering how they can be adjusted to fit the demands of local contexts.

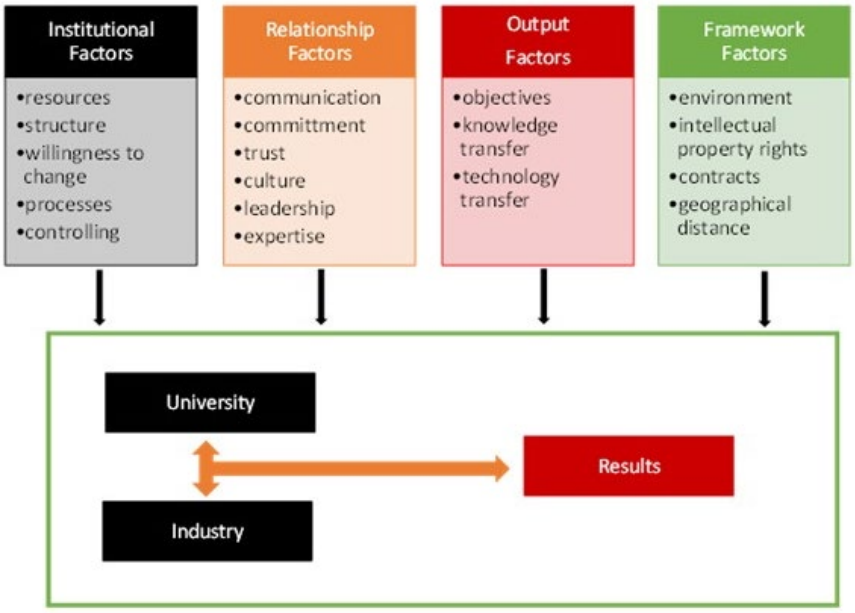
1.2 Models of collaboration

Several models of UIC are discussed in the literature. Most commonly UIC adopts a triple helix model which describes the engagement of industry and universities facilitated by government (Aldabbas, Pinnington, & Lahrech, 2020). Typically, industry acts as the key site of production, the university as the primary source of societal knowledge, while government oversees contractual management that ensures ongoing engagement with exchange of resources. Each collaborative entity maintains a relatively independent and distinct status at their core but interacts through an external-facing layer.

Blending the roles played by industry, university and government may lead to new sites for cultivating innovation, including collaborative research centres, science parks and learning laboratories (Etzkowitz, 2008). Rybnicek & Königsgruber (2019) propose a model of collaboration (see Figure 2) between organisations in two or more sectors aiming to achieve joint outcomes. Factors influencing interaction are of four types:

- **Institutional factors** include resources (finance, staff, equipment) determining the effectiveness of collaboration.
- **Relationship factors** involve the quality of the communication
- **Output factors** focus on the objectives and desired outcomes of the collaboration - the compatibility of goals is critical when managing outcomes (for example, disagreements on disseminating outcomes)
- **Framework factors** include market environment, spaces conducive to collaborating (Osorno-Hinojosa et al., 2022), and geographical distance (Roncancio-Marin, Dentchev, Guerrero, Díaz-González, & Crispeels, 2022), each of which influences the frequency and quality of interactions.

Figure 2: A model for University-Industry Collaboration

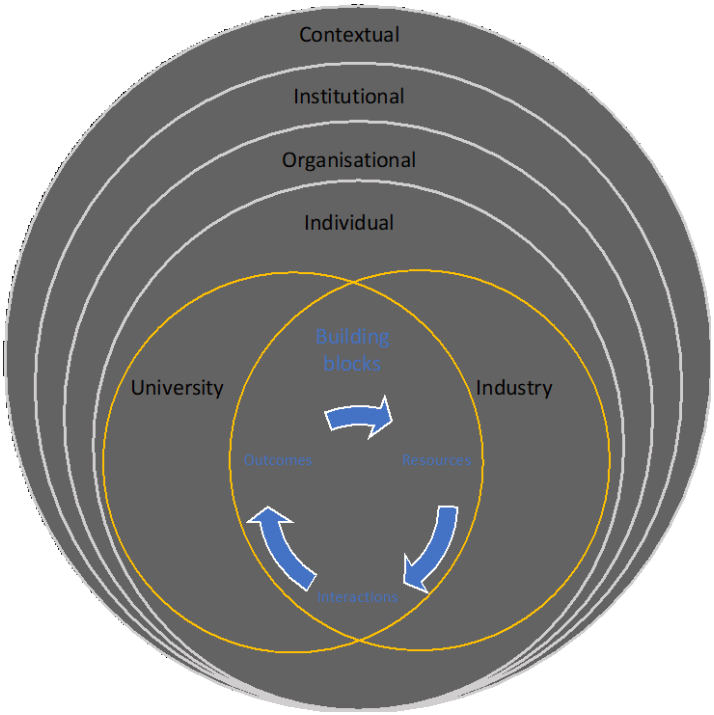


Based on: Rybnicek and Königsgruber (2019)

A systems-based model of collaboration for co-creating value has been developed by Polese, Ciasullo & Montera (2021) (see Figure 3) reflecting similar factors to the model of Rybnicek & Königsgruber (2019). Based on a core set of **building blocks** depicting interactions between resources and outcomes, four layers of structure bidirectionally influence effectiveness of the collaboration. The outer **contextual** layer involves actors with shared links surrounding and influencing value co-creation via the **institutional** layer (where decisions are made about industry policy and market factors), and the **organisational** layer (involving local policies, culture and research disciplines). Institutionally, academic and business actors' efforts in project execution are bound by regulation and orientation toward innovation, through access to funding and the rate and extent to which knowledge transfer occurs. Working at the **individual** level, organisational collaborators may integrate resources while spanning boundaries between projects and organisations and the wider university or industry landscape. At the organisational level, a university brokers knowledge between individual companies and across industries where differences between management and academic world views can create conflict and impede successful collaboration.

This systems-based model has similarity to the human factors and ergonomics (HFE) framework that has provided the scientific underpinnings to the IMCRC UIC (see O'Keeffe, Moretti, Hordacre, Howard, & Spoehr, 2020). Like HFE, effective UIC is a systems process with interdependencies between layers or factors within the system. The HFE framework depicts technology adoption as a process of interactions within a system encompassing four layers. These layers represent an outer environmental context (analogous to the contextual layer – addressing policy, regulation and ethics), the industry layer (analogous to the institutional layer – depicting markets, policy and broader industrial relations), organisational layer (including work design, products and processes), and the human layer (addressing individual characteristics that influence behaviour).

Figure 3: A value co-creation collaboration model



Derived from Polese et al. (2021)

1.3 Realising the value of UIC

A primary aim of UIC is to innovate, bringing economic development through more productive organisations, and societal benefits from enhancement of employment opportunities (Aldabbas et al., 2020). In the context of UIC, value can be described as 'the comparative appreciation of reciprocal knowledge or practices, that are used, exchanged or shared in the interaction for a common purpose, defined ultimately by the beneficiaries' (Osorno-Hinojosa et al., 2022 p.3). Hence, perceived value is in the eye of the beholder. Perceived value is likely to differ depending on the roles of the partners and contexts within which collaboration occurs. However, the value derived from UIC can be classified into three broad categories: commercial, organisational capital and socio-economic.

1.3.1 Commercial value

Commercial value – the value to the collaborating organisations in terms of increasing profit (www.merriam-webster.com/dictionary, 2022), including through innovation of new products and services, process improvement, enhanced reputation, capability, and risk management.

Knowledge transfer through UIC significantly contributes to increased quality, productivity and economic value to businesses (Marinho et al., 2020). The strategic decision to collaborate is driven by market intelligence on potential long-term return on investment, with a focus on gaining through cost savings, improved customer service, better decision-making and innovation. Key drivers for industry partners to collaborate include building economies of scale, expanding organisational learning, improving strategic position, efficiency gains (through capacity to exploit knowledge), competence (in exploring opportunities) and enhancing positional advantage (Pateman, Cahoon, & Chen, 2016). A study of 443 innovative Chinese businesses using an innovation model based on R&D and commercialisation activity (Shi, Wu, & Fu, 2020) showed quantitative indicators of innovation (internal R&D expenditure,

number of granted patents, value of new product), were positively associated with innovation outcomes in both R&D and commercialisation stages.

SMEs collaborating in UIC have demonstrated higher innovation and economic performance through innovating products and processes (Van Hemert, Nijkamp, & Masurel, 2013), with flow-on benefits for revenue growth (Cattapan, Passarelli, & Petrone, 2012), and access to new markets (Rosli, De Silva, Rossi, & Yip, 2018; Verreynne, Torres de Oliveira, & Mention, 2021). Creating an environment supporting innovation is an important foundation for business success. Adoption of ISO 9001 or total quality management systems foster a systematic approach to operations, positively influencing innovation and organisational performance. Through policy settings and regulation, Government plays an important role in promoting collaboration, creating a virtuous circle by enhancing innovation in the economy (Voinea, Roijakkers, & Ooms, 2021) (see Figure 4). The growth in competitiveness and profitability associated with quality management adoption may also leverage improvements in public policy and social impact (Aldabbas et al., 2020).

UICs bring advantages to collaborating parties - universities gain practical industry-based knowledge, while business benefits from the theoretical perspective provided by the university. UIC create benefits and value for universities through intellectual property (IP), generation of research income and academic publications. Less tangible benefits include industry placements for students, opportunities for novel research with new and existing partners, and the demonstration of research impact. Benefits for industry include a competitive advantage leading to enhanced profits and markets, developing new and extending current business models, and ongoing access to academic expertise. UIC also bring mutual advantages through blending theory and practice to provide a comprehensive and mutually valuable approach to discovering new problems and solutions, and being better able to solve old problems with new solutions. (Polese et al., 2021).

Figure 4: Proposed virtuous cycle of value co-creation from collaboration in triple helix model

Derived from https://fourweekmba.com/virtuous-cycle/

1.3.2 Organisational capital

Organisational capital incorporates value to the collaborating organisations through developing learning capability and knowledge that can be deployed, acquisition of technical skills (operating technologies, developing applications) and social competencies (negotiating, problem solving, coaching, leading), building networks and growing social capital, which is the foundation of enduring relationships (Marinho, Silva, & Santos, 2020).

Social capital within UIC is regarded as an important value creation mechanism, constituting a form of organisational capital. Social capital is considered a productive resource for boosting organisational growth and innovation performance through group communication and knowledge sharing, enabling greater use of intellectual capital (Al-Tabbaa & Ankrah, 2016). Effective social relationships support the intensive interaction needed to transfer tacit knowledge and foster creative problem-solving but also increase the risk of unintended knowledge leakage – a risk that must be managed to maintain trust (Marinho et al., 2020; Shi et al., 2020).

Social capital skills help manage challenges that may undermine collaborative relationships. For example, conflicts may arise due to different organisational values, norms, policies, principles and beliefs, as well as differences in flexibility, speed and autonomy of decision-making. Achieving shared understanding supports innovation and paves the way to an emergent entrepreneurial culture. As commercialisation potential increases, disputes may arise. Social capital facilitates the frequency of communication, enhancing trust and reciprocity to reach resolution (Benitez, Ayala, & Frank, 2020). However, since collaboration is essential for improving organisational learning capability and innovation performance, relationships must be cultivated, monitored and maintained. Rewarding and motivating staff for their efforts building social capital (for example, through compensation and recognition, access to resources and networking opportunities) is an investment in developing a culture of innovation (Al-Tabbaa & Ankrah, 2016; Galib, Munny, & Khudaykulov, 2015).

1.3.3 Socio-economic value

Socio-economic value can include employment growth that revitalises a sector and/or region (Osorno-Hinojosa, Koria, & Ramírez-Vázquez, 2022) (e.g. the transition from automotive manufacturing to technology hub at Tonsley, South Australia. The benefit to society is increased productivity, business profitability and greater economic security. In Australia, the COVID-19 pandemic highlighted vulnerability in the local manufacturing industry. With supply chains compromised globally, significant shortages occurred in critical medical and domestic products. Rapid innovation and agility in responding to surge demands saw manufacturers converting from producing alcoholic beverages to sanitising gel, and from paper product manufacturing to medical grade face masks, made possible through UIC (Gibson, 2020; University of Technology Sydney, 2020)

Increasingly universities have extended their engagement with industry and government to the *third mission,* described by Secundo, Perez, Martinaitis & Leitner (2017) as the generation, use, application and exploitation of knowledge with external stakeholders to benefit society in general. Evident in this third mission is the expectation that universities will contribute to solving social and economic problems of significance, with UIC an important mechanism (Nsanzumuhire & Groot, 2020). The Australian Government funded collaborative research centres (CRC) program uses public funding to seed competitive grants, taking a project-based approach to encourage and support collaborative research. The aim is to improve the competitiveness and sustainability of Australian industries, while delivering outcomes aligned to government priorities that require high quality research to solve industry specific problems (Noble, Charles, & Keast, 2017).

The desire of universities to develop social sustainability goals is often motivated by a desire to serve the community while enhancing organisational prestige. Industry is also motivated to improve their reputation as socially responsible. Researchers and entrepreneurs can be transformative agents by promoting a shift from a focus on technology advancement to social sustainability (Roncancio-Marin et al., 2022). In developing countries, innovations typically occur in the context of individual motivations against a background of low alignment of organisational norms, leading to low stimulation to engage in UIC. Nonetheless joint collaborations are growing and participants in UICs are motivated by complementary rather than overlapping capabilities and knowledge. Individual characteristics and a desire to innovate and make tangible change in emerging economies are key drivers of engagement, where innovation can promote prosocial behaviour, entrepreneurship culture, social identity, and championing of social welfare (Roncancio-Marin et al., 2022).

2 The AITI – BAESAM UIC

The Australian Industrial Transformation Institute (AITI) is a national leader in industry and workplace innovation research. The AITI multi-disciplinary team undertakes industry, economic and workforce research in response to major change and plays a key role in informing strategy, policy and program development. Key research interests include the future of work in the digital age and the human dimensions of technological change. AITI was established at Flinders University at Tonsley in Adelaide, South Australia in 2015. Tonsley is an innovation district where higher education, vocational education and industry are co-located.

BAE Systems is Australia's most versatile defence and security company. From air and maritime sustainment to shipbuilding, they provide advanced defence technology which protects both people and national security, keeping critical information and infrastructure secure. BAE Systems Australia – Maritime (BAESAM)[2] have responsibility for delivering the Hunter Class frigate program with construction located at the Osborne Shipyard, and the research and technology team co-located with Flinders in the Tonsley Innovation District.

The collaboration between Flinders and BAESAM commenced relatively informally in 2017, united in a shared vision to develop world class capabilities in support of the modernisation of shipbuilding in the context of the Industry 4.0 agenda. Both parties were aware of and keen to emulate the successes of the Advanced Manufacturing Research Centre (AMRC) at the University of Sheffield and the Advanced Forming Research Centre at the University of Strathclyde, which form part of the High Value Manufacturing Catapult in the United Kingdom. A range of mechanisms to foster collaboration with these leading centres have been put in place.

In May 2018, AITI played a central role brokering an agreement between BAE Systems Australia and Flinders University for students and industry to work together to develop new ways to provide Australia's defence force with the evolving capability it needs and to train the shipbuilding workforce of the future. This agreement formalised Flinders University research relationship with BAE Australia providing an opportunity to expand our research and development programs related to the building of the Hunter Class Frigates in South Australia.

In October 2019, AITI led the establishment of a joint Flinders/BAE Systems digital test and trial laboratory in Flinders at Tonsley – '*Lab 419*'. The lab housed the latest technologies from industry and provided a collaborative environment for adapting, trialling and testing research destined for the Hunter Class frigate. Attendance in Lab 419 was initially somewhat transient[3]. However, during peak occupancy, approximately ten additional hot desks were made available outside the Lab and adjacent to AITI.[4]

In January 2020, a collaborative agreement established the Pilot Factory of the Future at Line Zero, Tonsley Innovation District. It acts as an off-site testing and trialling facility for advanced manufacturing and digital technologies in maritime shipbuilding. The Pilot Factory of the Future brings together education, industry and government to facilitate implementation of key enabling i4.0 technologies across the manufacturing supply chain. A collaborative space, it supports

[2] Formerly part of ASC Shipbuilding.
[3] Through most of its tenancy, Lab 419 was also impacted by COVID-19 proximity restrictions which reduced daily attendance to approximately six (down from a potential 20 workers).
[4] Lab 419 was utilised for two years before the BAESAM R&T team relocated to a new building and tenancy within the Tonsley Innovation District.

research, development and innovation. This joint facility further strengthened the relationship between Flinders and BAESAM and laid the foundation for deeper collaboration.

Parallel with the establishment of the Factory of the Future, BAESAM and Flinders University co-designed a Diploma of Digital Technologies to up-skill existing shipyard workers on advanced manufacturing technologies, digital technologies and processes. Around 52 workers at risk of retrenchment undertook the Diploma on a full-time basis. The Diploma has since been delivered to workers from a range of sectors seeking to both better understand and pursue the Industry 4.0 agenda.

The next stage of the UIC involved a major research collaboration supported by the Innovative Manufacturing Cooperative Research Centre (IMCRC). The agreement was signed in February 2020 and launched by then Federal Minister for Industry, Science and Technology, Karen Andrews. The project applied a human factors lens to accelerate the uptake and diffusion of innovative manufacturing technologies in Australian shipbuilding and the supply chain. Research was undertaken from March 2020 to November 2022. Members of the AITI team comprising social scientists (including psychology, human factors and ergonomics) and engineers (mechanical, robotics and biomedical) collaborated closely with BAESAM research and technology (R&T) team consisting predominantly of engineers, technology solutions architects and specialist project managers (often with trades backgrounds, e.g. electrical and boiler making).

Flinders University in partnership with BAESAM secured a $5m commitment from the South Australian Government for establishment of a permanent large-scale Factory of the Future facility at Line Zero in late 2020. This was announced by former Premier of South Australia, Steven Marshall during a visit to the site on January 1st 2021. Flinders University matched this commitment. Further commitments of $4m from the South Australian Government and $10m from the Federal Government in 2022 enable the construction of a purpose-built Factory of the Future facility at Lot 94 Tonsley.

Although the collaboration undertaken as part of the IMCRC research project is the focus of the following analysis and discussion, it is only a part of the overall Flinders-BAESAM UIC. This collaboration does, however, provide a case study for reflecting on the challenges and successes inherent in an organisational collaboration initiated by and led by senior management.

2.1 Communication structure

The IMCRC research project enabled significant growth in the Flinders and BAESAM teams involved in the UIC. Notably the UIC involved co-location of both teams in Flinders University facilities at the Tonsley Innovation District. The group was characterised by significant disciplinary and occupational diversity and had limited experience working in a UIC. Accordingly, the initial stages of the collaboration required considerable attention to team building and development, particularly gaining a common appreciation and understanding of HFE and the value of a trans-disciplinary and multi-occupational approach to problem solving. Of critical importance was the need to ensure Flinders researchers were fully cognisant of the importance of confidential and sensitive information for commercial and reputational reasons.[5]

Both BAESAM and Flinders appointed project managers to manage the engagement, facilitate communication between the organisations, build networks and triage queries. There were challenges and successes in the early stages when new relationships were being forged and

[5] All Flinders University staff working on the IMCRC project signed a non-disclosure agreement at the outset of the project.

mutual understanding gained. In the first instance, most cross-institutional engagement was formal (horizontal) and aligned with their organisational equivalent (i.e. executive engaged with executive, researcher with researcher). Over time, as connections were made and trust was gained (i.e. presence of UIC relationship factors), the organisational hierarchies became more permeable. This occurred slowly, with contact increasing between all as specific skills, competencies and strengths of individuals emerged.

2.2 Mechanisms for collaboration

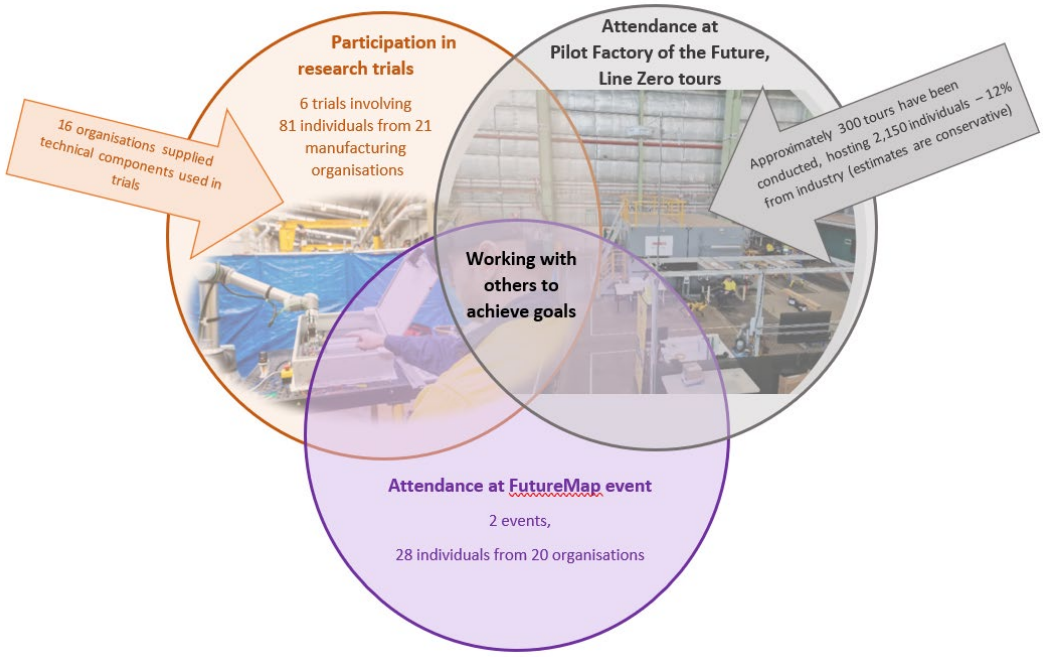
Co-location of AITI and BAESAM employees at Tonsley (i.e. presence of UIC framework factors) was essential to develop a shared language, understand the current state, and mutually support the vision of the future state (i.e. digital transformation; presence of UIC output factors). This was valuable at all levels of the collaboration.

At the executive and senior management level the collaboration was already strong and well-formed, but the co-location paved the way for significant relationship development which extends the collaboration beyond the IMCRC project and into the foreseeable future. Flinders has been successful in achieving significant funding from both the Commonwealth and State Governments to build a permanent Factory of the Future at Tonsley and undertake a program of research aligned with the defence industry – this was supported by and will benefit BAESAM and their supply chain. Discussions are ongoing about potential ARC linkage and other research grants aligned with the research interests of both organisations. BAE has established a tenancy at Tonsley to support the office requirements of a growing number of R&T staff (UIC framework factors).

For researchers and project managers, purposive discovery activities took place to bring the teams together to realise the shared vision. This occurred both formally through regular, scheduled project meetings and informally through shared lunches and impromptu conversations. It took a little time for Flinders and BAESAM researchers to recognise the different cultural contexts and work style of each organisation. BAESAM's approach to R&T was to apply a 'sprint' methodology - 'think big, start small, fail (learn) fast'. AITI applied more systemic academic rigour involving ethics, literature reviews and established research methodologies. In the beginning attempts to bring researchers together to work collaboratively on BAESAM sprints had benefits with a focus on specific technologies and relevant applications. However, it proved too early in the relationship to work successfully as trust and understanding between researchers had not developed sufficiently.

More successful at this early stage was the delivery of university-led research trials (O'Keeffe et al., 2022) conducted in parallel with the BAESAM sprints. The research trials underwent a thorough scoping and approval process to ensure they were complementary to, but not duplicating, BAESAM activities (output factors) and were feasible within time and budget constraints (institutional factors). Conducting research trials that required participants also meant BAESAM and others from the manufacturing workforce had an opportunity to test new technologies and applications (i.e. develop use cases), or see how they were applied (see Figure 5).

Figure 5: Key mechanisms for UIC



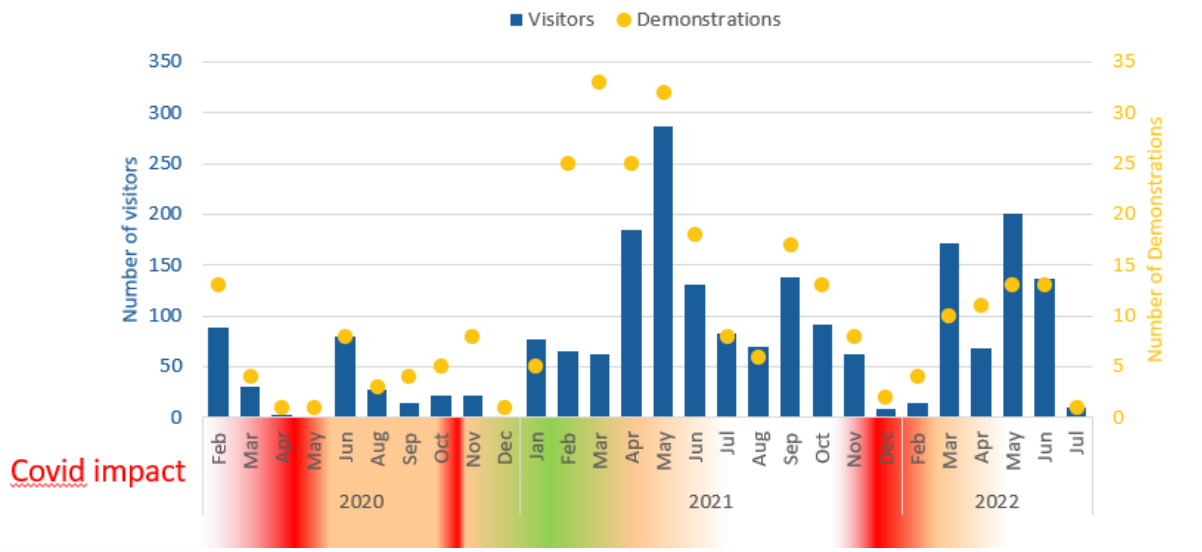
Data presented for March 2020 to July 2022

The Pilot Factory of the Future at Line Zero, Tonsley Innovation District provided a jointly developed facility to undertake research and support industry engagement. Once operating, many of the research trials and their pilot activities (UIC framework factors) were undertaken there. This location presented opportunities for joint troubleshooting and informal knowledge transfer applied to multiple areas of technical expertise (e.g. software and engineering challenges), health and safety (e.g. risk assessments) and human factors and ergonomics principles and methods (e.g. comfort, stress, design and usability). Fortnightly tours of the Factory of the Future were also scheduled for much of the project[6] (see Figure 6) where BAESAM, AITI and other SMEs involved in BAESAM's Innovation Challenges demonstrated their work to interested stakeholders and the general public. Visitors represented a range of sectors including defence, manufacturing, government and education providers and students.

AITI and BAESAM also worked together with the IMCRC to host two FutureMap events at Tonsley (output factors), prompting SMEs to reflect on their business goals and how they want to position themselves going forward in relation to i4.0.

[6] COVID-19 pandemic restrictions permitting

Figure 6: Overview of attendance at Pilot Factory of the Future, Line Zero tours



2.3 The collaboration

Five industry participants provided insight into the effectiveness of the collaboration.[7] Two interviewees were sourced from BAESAM and three from local businesses in the supply chain. Interviews were audio-recorded and transcribed. Thematic analysis was undertaken to identify context for collaboration, successful elements of the UIC and main benefits derived from the UIC.

2.3.1 Context and rationale for the collaboration

BAESAM interviewees characterised the collaboration as growing out of an existing relationship with Flinders University. The opportunity to leverage IMCRC funding was viewed favourably given its potential to produce positive outcomes organisationally (for BAESAM), for the Hunter Program, and the wider shipbuilding supply chain. Flinders University was viewed by BAESAM as a partner of choice because it had the 'right people' to work with collaboratively, and for bringing HFE research expertise to a technologically focused team.

BAESAM placed strong emphasis on working with researchers and academia across a range of projects, and for local business engagement - 'the CRC project really ticked a few boxes in that continuous naval shipbuilding base'. BAESAM also valued the project's potential to increase awareness among their staff and supply chain about i4.0 technologies. This was achieved by trialling potential application of technologies, capturing knowledge from trials, and using it to inform a range of resources to support an i4.0 vision. The 'artefacts' produced included videos, case studies, guidelines, publications – 'those kinds of things that academia is good at producing'.

Another driver was understanding barriers to i4.0 adoption, particularly in relation to acceptance of technology in the workplace (i.e. pursuing an HFE focus):

[7] Purposive sampling was based on role and level of engagement across the course of the 2.5 years duration of the project. Semi-structured interviews were undertaken with five consenting participants, who were given the option of telephone interviews or face-to-face interviews at a location of their choice.

It was an unusual project because rather than focusing on the tech, we focused on what it means to people's jobs - the future of work. What did it mean to people and how they adopted the technology? There's a lot of hype around Industry 4.0 and I was keen that we debunk some of the myths around it; and that we could spill that benefit over into the supply chain.

An important goal of the collaboration was extending benefits of i4.0 exposure, knowledge and engagement to local businesses in the supply chain:

From an IP perspective, learning how to work with a cobot is not an IP that we would want to keep to ourselves. It's something that you'd absolutely want to share with your supply chain because there's no point in us being good if our supply chain is not. It was a good project … we were creating knowledge that we could share with industry. That was what I was trying to achieve.

2.3.2 Features of the collaboration

BAESAM had engaged in UICs before - but not of this scale: 'this is probably the biggest one that we've done. I've done some work with universities prior to that, but this is the big one!' The collaboration represented a new approach for BAESAM, in terms of working through the College of Business, Government and Law (CBGL) rather than Engineering and Science. However, the key relationship was in CBGL and the focus was on 'people' rather than the College.

The research project plan was developed and undertaken over an extended time. As such, parties needed to be responsive and reflexive to business requirements and changes. Hence the project was formative, rather than fixed on the original plan:

There was the intent to collaborate with a partner that was willing to lean forward to be involved in our program. What exactly that would be at the time was not very clear, but it had the right people, the likes of John Spoehr [AITI Director] and Tony Kyriacou [Flinders University Defence Partnerships Director].

A key feature was the sense of being in an 'equal partnership' rather than a 'master-slave arrangement', underpinned by BAESAM's close involvement in the recruitment of the Flinders University research team. The co-location of BAESAM staff and Flinders staff on the Flinders University campus was another core feature of the UIC.

2.3.3 Foundations for collaborative success

Interviewees identified a range of factors underpinning the success of the UIC collaboration. These included establishing mutual benefit and a common goal; high level leadership; and strong teamwork - having the right people on board and working cooperatively. The willingness to co-invest and capacity to co-locate were also seen as signature features of the UIC, with support from Flinders University. The shared collaboration facility set up on Level 4 of the Flinders University Tonsley building, and subsequent establishment of Line Zero, were considered 'absolutely key' to the success of the collaboration:

We are eternally grateful to the AITI Director and his team, who not only made us welcome at the university, which was awesome, but extended that welcome into the facilities and the team. We had an office, and people came to visit… the side effect of that was, from a business perspective, the BAESAM lead team… had to go to offsite meetings at the uni and it did a lot to build the credibility of the university as a partner.

Another success factor was the respective partners' willingness to step outside their comfort zone, this involved significant confidence and trust. It was evident in the administrative arrangements implemented between Flinders and BAESAM involving both financial investments associated with the decision for BAESAM to move their R&T team to Tonsley, and peppercorn leases from Flinders for the office space and the Factory of the Future. It was also evident in the

management of the critical health and safety and security arrangements required by BAESAM. This involved a great deal of organisational effort and goodwill by both parties and was only possible because of a shared vision.

Interviewees identified high level leadership demonstrated by Flinders University as a crucial enabler for the UIC; extending from the AITI Director and Defence Partnerships Director to the Flinders Senior Leadership team including the Deputy Vice-Chancellor (Research) and President and Vice-Chancellor. In particular, the AITI Director demonstrated a 'passion and the appetite to work together' that has helped to propel the collaboration forward.

Teamwork was seen as critical and in the case of the UIC hinged on recruiting the 'right people' into the team, with the 'right persona' – this is characterised as 'the willingness to listen and learn and be prepared to work together in a collaboration environment'. Regular communication builds a 'clear, concise context' in which parties can operate with a shared understanding and is essential for engendering trust in the team.

The point was also made that successful collaborations involve more than assembling the right people in a high functioning team; tangible organisational commitment and investment is critical to collaborative outcomes and outreach:

> *There's no point in just having a couple of personalities who get on well together. That's not what this is about. It's actually from business decisions that you make—Flinders decided to invest in a more permanent version of what we've established, and it attracted the state government funding and the federal government funding because people could see the benefit. You could see it: "Oh, yeah. I get it now."*

2.3.4 Collaboration outcomes

The UIC was seen as successful in generating **knowledge transfer** about different aspects of i4.0 technologies. It provided an opportunity for local businesses to access and learn about i4.0 technologies, where there may not otherwise have been an opportunity:

> *That's the whole idea that they can come and play in the sandpit and do that risk reduction, that learning and understanding of what it is to adopt the type of technology they want to introduce to their business. [Independently] they can't afford to have that facility made available, nor can they have all the personnel. By collaborating and engaging with Flinders as the research partner… they don't have to onboard and take that responsibility.*

For BAESAM, it was less about accessing the i4.0 resources from an internal capability building perspective, and more about setting the foundation for others (e.g., local businesses in the supply chain) to have that opportunity to develop: '*If we can uplift our supply chain… that benefit will trickle through to our business*'. The Pilot Factory of the Future (Line Zero) was a paramount outcome of the UIC, representing a focal point for the project, and a valuable physical asset enabling co-working and industry engagement around i4.0.

From a **networking and relationship building** perspective, BAESAM places a premium on research relationships and has collaborations with multiple international university partners. In this context, the UIC was seen to deepen and strengthen the relationship between BAESAM and Flinders University - it 'means we've got more in common'.

In terms of promoting **new ways of working**, the collaboration was instrumental in developing a research culture across the organisation:

> *Getting our team, even people from the shipyard, used to working with researchers. I absolutely loved it when Flinders went into the shipyard and were running trials there. We've got a very curious organisation - they like to see things and get interested in things. Don't*

forget, some of our R&T team came from the shipyard. People who'd never done this kind of thing, ever.

Flinders also transferred research processes, knowledge and know how to BAESAM which provided value for how the latter conducted its research activities:

Even things like some of the trials that the [BAESAM] team did themselves - we didn't do them through Flinders - we've provided feedback to say, "You need to do it more like a university trial," with all the stuff that [Flinders] sent; the permissions forms and all that stuff. It's been good learning from that perspective.

The **focus on HFE** in the research program gained traction, particularly among the safety team at BAESAM. However, there is still some distance to travel to ingrain an HFE approach across different business domains. This was largely seen as a function of developing awareness and perception of benefit over time:

It's opened people's eyes to things like how the technology can support safety; how the technology can support the way that people work - how we design jobs. We could've done more from our side... we could've got our HR team… more involved in the designing of jobs, but it's probably a bit too soon for them.

BAESAM and Flinders extended the collaboration with joint submissions for large Commonwealth grant opportunities. Although these bids were unsuccessful, Flinders was successful through other funding opportunities. The UIC means that BAESAM will be a major beneficiary and contributor to the extension of the Factory of the Future at Tonsley:

[The Factory of the Future] convinced my company that continued funding to these kinds of projects is a really great thing for our program [and] it also attracted funding for Flinders to build a bigger version of the Factory of the Future.

BAESAM interviewees also noted a **valuable brand advantage** for both BAESAM and Flinders University because of the collaboration:

From a program perspective in terms of the Hunter Class program, we've created a lot of great good-news stories off the back of Line Zero, not just with the university but with local businesses… the social media has been very good from a reputational perspective for both parties.

A notable outcome of the IMCRC project was a transformation in how people on both sides of the collaboration viewed the feasibility and potential benefit of **working in a university-industry partnership**:

There was definitely an impression, from an industry perspective, that universities were difficult to deal with; that there are a lot of arguments around IP; that industry just had to fund expensive resources; and, at the end of the day, [collaboration] was hard. I think we've proven that's actually not the case. Certainly, that engagement has really opened people's eyes.

I think that from a [University] perspective, they're starting to see that a close relationship with industry is not just something that you've got on your brochure; [there is] lateral business benefit from a systems perspective. There's a benefit beyond the collaboration or the project itself.

2.3.5 Key themes and lessons drawn from the collaboration

Based on their experience with the UIC, BAESAM interviewees identified a range of pre-requisites for successful collaboration. Of foremost importance, there needs to be **clarity from the outset about expectations** relating to project outcomes and roles. Some formality is required in terms of documenting these:

One of things that I've encouraged… around the governance of the Factory of the Future is to articulate the principles and the ethos of what you're trying to achieve so it's really clear for all the partners.

It helps to include UIC as part of an **organisational charter** as this demonstrates genuine commitment and recognition of their value at an organisational level. Moreover, a successful research collaboration involves genuine **hands-on engagement by both parties**, not sending the university off to do the research and report findings back to the business:

It can't be just, "Hey university, go and do this - and come back in a month or two and let us know how you're going." The business needs to embed itself inside the project teams. They cannot be left to their own devices… The other critical piece is it needs to be part of its ethos, considered as part of the day-to-day workings, and not at arm's length.

Collaborations benefit from having some relational history behind them. They are an evolutionary process; the key to success is to learn from and build on what has gone before:

Everything we've done has come naturally because we have got a number of key people we've worked with. We have got some long history of experience, and we know… what not to do and the things you can do. We had a fair idea of what we needed to put in place.

In the interests of a long term, sustainable partnership (as opposed to a shorter-term transactional relationship) it is essential to have the **right people in the team**, particularly in leadership roles. This means people and leaders who are committed to and have a passion for a shared vision, who embrace collaboration and mutually reinforcing relationships, and who can communicate openly and productively, particularly when there are differing viewpoints. Each partner needs to have a **project champion** to drive and connect the collaboration from the perspective of their organisation. Additionally, BAESAM needed a **trusted person internally** to connect the interests of and build trust between shipyard workers and university-based academics. They were lucky to find a shipyard worker:

…who wants to change his pathways, his career. He's got that trade background… People believe in him. When we needed to get access to people in the yard, leveraging off [this representative] who is our borrowed staff person from the yard… it wasn't too difficult to make it happen.

The establishment of the Pilot Factory of the Future – Line Zero was considered the pinnacle achievement of this UIC. The interviewees agreed that such a substantial piece of physical infrastructure, providing extensive access to i4.0 technology, and scalable to accommodate future needs, could never have been achieved without the principled commitment, specialist expertise, and investment streams brought together by the collaboration.

Although the interviewees highly endorsed the overall value of the UIC, some challenges were identified. Mostly this concerned the **different cultures of academia and industry**, particularly relating to pushing for rapid impact as opposed to consolidating around research quality:

Because we're generally running up against a deadline… sometimes you have to do something when it's 80 percent and then make the rest happen. From an academic perspective, it's more going for the 100 percent, a little bit slower, probably not as much focus on, "Right, we've got to get this done. We've got to get it out!"

One concern was flagged for the ongoing UIC. It was noted that collaborations work well when they are contained, however they become more difficult with more partners involved. While it was recognised that impact is enhanced by **increasing the number of partners**, it makes cementing a shared ethos as the platform for the collaboration even more important:

The more that get involved - and we do need to get more people involved - but if they don't share that ethos, you can find yourself being diluted, and not achieving what you set out to achieve - which would be disastrous.

2.3.6 Perceptions of local business representatives

Representatives of three local businesses were invited to evaluate the i4.0 technology in test use case scenarios and to provide feedback about usability and applicability in industry settings. The relationship between the UIC and these businesses was in the early developmental stages, but there were significant shared interests in the technology and its potential for them – as well as in the Factory of the Future.

[This was an] opportunity to be exposed to some of the technologies that I either had some awareness of - but not necessarily firsthand practical experience, in terms of what it's actually like to interact with those technologies in a simulated work environment. It's one thing to read a marketing brochure, it's another thing to actually try to use these technologies to do tasks.

One interviewee participated to enhance their existing and valued relationship with Flinders University and BAESAM; while another used the opportunity to challenge the thinking of several early career staff:

Even though I knew the technology was not that applicable for us — [the goal was] to challenge staff thinking a bit to see something else, and then have that conversation with them that, even though it's not applicable, where could it be used, or if it was different in some way, would it be more relevant? It's probably just more of broadening their mindset.

One of the interviewees considered that **knowledge transfer** was the primary benefit received from the collaboration:

Firsthand exposure to the technologies in the simulated applications that were provided at Line Zero (because occasionally I do get asked about these things by potential clients). We're always looking at how we can improve the way that we do things, so getting some firsthand experience with these technologies is really useful because it gives you a level of understanding and insight beyond reading articles on the internet.

Although the i4.0 technology used in the trials was limited, it did provide staff with valuable experience, although not all the answers:

Here, as in a lot of businesses, [we are] grappling [with] what Industry 4.0 is and means. Everyone talks about it, everyone says they're doing it, 98 percent of businesses say they're doing it, but they're nowhere near 4.0. I suppose part of this was how do we start going down a digitisation path leading to a 4.0 path? It was really, "Here's some pretty cool, exciting concepts for doing such," really just to get thinking and involved… The graduate manufacturing engineer came back buzzing, but when we sat down and spoke about it, the concrete things to do next are not clear.

For one interviewee, the collaboration provided an opportunity to extend their valued Flinders University **research network** and has led to some small jobs undertaken for Flinders University. Another found it of limited utility as the people and companies involved were already part of their network. However, the network function should be an important element of any collaboration: 'everyone, personal and business, has their own customers–suppliers network, but you bring two together, and it just multiplies'.

In terms of **new ways of working**, one interviewee understood the collaboration objective of increasing exposure to new and emerging technologies, building toward new ways of working enabled by the technology. They were aware of the HFE user-experience angle, but not as a primary focus of their engagement (although considered important from a change management perspective). Another interviewee noted that they had learned a lot about HFE: 'We're learning

as we go and understanding the impact on the employees and the people implementing those technologies'.

For one business, the advantage of engaging with the technology trials was mainly about deepening their engagement with Flinders University, although the business was not entirely sure where the collaborative activity would lead. For another, the collaboration was useful for branding their company at the forefront of technology exploration which is important for attracting the top students into the business.

It was felt that collaborations of this type (concerning industry development and knowledge transfer) need a dedicated entity to facilitate proceedings and universities are well positioned to perform this role. They are seen as effective in structuring programs, they have done the research and bring the evidence base; and they are effective at bringing people together and connecting the right organisations.

One local business identified a key UIC theme as establishing **mutual understanding**. The key messages include the importance of the relationship with Flinders and BAESAM and others, knowledge transfer, and the potential for branding. It can be a challenge that university processes can be slow and cumbersome, and misaligned with industry timeframes. However, the same can be said for government and multi-national businesses. It is important for all parties to be nimble as opposed to tied down by administrative and bureaucratic processes.

Another local business highlighted potential opportunities for greater value from networking, by encouraging participants to come together after the trials 'to discuss what they did and what they could do in their own business'. Collaborations are essentially for 'filling in the missing gaps':

> *What's becoming more apparent now is a lot of businesses are not trying to employ and hold all their expertise inside their business. There's more consulting, or contracting, or partnering. You don't see many places now that farm the land and then go all the way through. Everyone specialises in their part of the chain, but then it's how to collaborate with the rest of the chain. On this one, innovation is right at the start because no one knows what we're doing yet.*

One local business considered the collaboration to be highly useful and was very interested in participating in further trials. It was characterised as a valued learning experience, and they were invested in continuing to foster UIC relationships. Another local business saw significant potential for local collaborations across the spectrum, building on the value of the IMCRC UIC:

> *Adelaide is a unique place because it's generally quite open to networking and collaborating compared to eastern states… Maybe because it's a bit smaller and a bit closer, but also, there's not that many competitors. I think there's lots of businesses that're different enough that we can collaborate without competing.*

3 Conclusion

The *Accelerating the Uptake and Diffusion of Innovative Manufacturing Technologies in Australian Shipbuilding and Supply Chain: The Human Factors* project co-funded by the IMCRC supported a collaboration between AITI (Flinders University) and the R&T team from BAESAM. This UIC has sought to develop and apply a unique joint capability in technology assessment and application, applying open innovation principles where traditional closed innovation processes often prevail (for example, in-house R&D) (Ankrah & Al-Tabbaa, 2015). Open innovation is of central importance to the i4.0 agenda, as implementing i4.0 concepts requires not only implementing new technology and infrastructure, but also new organisational processes (Halse & Ullern, 2017). If businesses want to innovate, collaborating with others is imperative, because any one business cannot hold all the relevant knowledge and skillsets to innovate effectively (Obradovic et al., 2021). The literature consistently reinforces that businesses with strong internal and external social capital (relationships and collaboration) are more likely to adopt i4.0 technology. External collaboration provides essential expertise, as well as financial and structural supports to assist businesses to digitise (Agostini & Nosella, 2020).

The current UIC is founded on the understanding that open innovation is essential for creating the conditions to support i4.0 uptake and productive use in local industry. The UIC draws on a triple helix model that seeks to combine the strengths and resources of industry, government and academia in pursuing a common goal – in this case i4.0 adoption. Both AITI and BAESAM are seeking to deepen the relationship, share complementary expertise, skillsets and infrastructure, and maximise knowledge interchange (i.e. a focus on intensity and depth of collaboration (Petruzzelli, Murgia, & Parmentola, 2022). The collaboration successfully led to the establishment of the Factory of the Future Pilot – Line Zero, a cutting-edge piece of physical infrastructure located onsite with Flinders University at the Tonsley Innovation District. Line Zero is Australia's first large scale advanced manufacturing accelerator, a test lab where potential applications of advanced manufacturing technologies in the maritime shipbuilding sector are being explored. The Pilot is the first step in the establishment of a permanent Factory of the Future at Tonsley.

While the Pilot was considered an outstanding success by BAESAM interviewees, they also identified a further range of key outcomes flowing from the collaborative process. These included bi-directional knowledge transfer, deepening of networks and relationships, a brand advantage for both organisations; and new ways of working in BAESAM. Work practices at BAESAM now engender a stronger research appreciation and culture across the organisation and an increased awareness of HFE principles. The perception of mutual benefit is a core property of meaningful collaboration and was emphasised in feedback about the collaboration.

BAESAM interviewees attributed the success of the UIC to the calibre of the collaboration leadership on both sides of the partnership that built on a previously established relationship and nucleus of trust between the organisations (relationship factors). Having the 'right people' on the project team facilitated the establishment of a shared vision, project management based on open and honest communication, and clarity about expectations concerning roles and responsibilities of the various parties. These features align closely with many of the principles of successful open innovation collaborations identified in the literature (Awasthy et al., 2020; Lepore et al., 2021). Similarly, there was close alignment with facilitating organisational and management features identified by Agostini and Nosella (2020), namely top management support and strategic vision, business investment in advanced manufacturing technologies, and incorporating champions to drive the collaboration. Importantly, BAESAM and AITI-Flinders University both shared a focused

interest and investment in Defence research and local industry development and recognised the collaborative benefits of bringing together complementary strengths to achieve a common goal.

While the in-depth open innovation collaboration between BAESAM and AITI was one element of the UIC, opening the Pilot Factory of the Future to local SMEs and other stakeholders grew the breadth of the open innovation. A key objective of the UIC was to increase awareness about i4.0 potential across the supply chain, and to build advanced manufacturing capability more generally. This was believed to be of benefit to all involved, including BAESAM at the head of the chain. The Pilot Factory of the Future was accessed by many stakeholders through trials and tours, and through media exposure. Knowledge transfer for SMEs who were given an opportunity to 'play in the sandpit' – something they would not otherwise have access to (framework factors) - was seen as a key outcome of the collaboration.

Based on the nature of interactions between SMEs on one hand and BAESAM and AITI on the other, it is probably more accurate to characterise the i4.0 trial experience as awareness raising rather than knowledge transfer. As Seppo and Lilles (2012) point out, UIC-based knowledge transfer depends on the intensity and quality of collaborative interactions and frequency of interactions. Noting that the major thrust of the HFE research project centred on the AITI – BAESAM collaboration, the inclusion of local businesses via involvement in the trials was more a by-product of the main collaboration than a concerted collaboration in itself.

Of the three SME interviewees, one reported being deeply invested in their relationship with Flinders University and the opportunity to deepen this through collaborating in the i4.0 technology trials. The participant saw the hands-on exposure as providing a distinct company benefit by enabling them to better explain emerging technology to clients. A second participant from a company with more sophisticated technology exposure viewed the engagement less as a 'meaningful collaboration' and more as a community and corporate responsibility (to test and provide feedback about the technology) and opportunity to expose and challenge some staff to different ways of thinking about technology and applications. The third participant had a low level of previous UIC exposure. Nonetheless, he was personally enthusiastic about engaging with new technology and was keen to maintain involvement into the future.

The AITI-BAESAM UIC has matured over a relatively short period of time, reaching a 'defined' level of maturity (i.e. committed team members, explicitly sharing knowledge and well understood and documented processes). This report is one example of how the collaboration is seeking to shift to an 'optimised' maturity level (i.e. assessing the collaboration and identifying areas for improvement, learning from past experiences, and improving the seamlessness with other stakeholders). This successful UIC provides a foundation for the Factory of the Future as we work together to incorporate greater industry participation and knowledge translation, and support the desired goal of digital transformation in manufacturing.

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Australian Industrial Transformation Institute
College of Business, Government and Law
Flinders University
GPO Box 2100
Adelaide SA 5001
P: 08 8201 5083
E: aiti@flinders.edu.au