Prioritising Enabling Factors of Internet of Things (IoT) Adoption in Digital Supply Chain

Abstract:

Purpose - This paper explores the role of IoT enabling factors in adopting digital supply chain. **Design/methodology/approach** - Analytical hierarchy process (AHP) was used to rank performance measures and prioritise the enabling factors. Semi-structured interviews were conducted to validate and support key research findings from the AHP analysis.

Findings - The results show that level of customer demand is the most important indicator in adopting IoT while the level of product/process flexibility is the least important. System integration and IoT infrastructure are the top two enabling factors in increasing the level of process stability, supply chain connectivity, and product/process flexibility respectively. Furthermore, the study suggests that the enabling factors for IoT adoption are directly connected with organisational resources/technological capabilities that support the resource-based view theory. This research identified interdependencies between IoT enabling factors and key performance measures for IoT adoption success in managing the digital supply chain.

Research limitations/implications - Supply chain managers can use the empirical findings of this study to prioritise IoT adoption, based on the relative importance of enabling factors and performance measures. The research findings are focused on broader supply chain practices of large companies rather than a specific industry and SMEs. Hence, any industry-specific adoption factors and SMEs were not evident from this study.

Originality – This research study empirically established priorities of enabling factors for IoT adoption, along with inter-dependencies among enabling factors as a basis for developing guidelines for IoT adoption.

Keywords Digital transformation, Internet of things, Supply chain performance, Enabling factors.

Paper type Research paper

1. Introduction

Internet of Things (IoT) originated from the concept of auto identification through radio frequency identification (RFID) technology (Sarma *et al*., 2000). While it has been espoused that IoT will affect lives and has an increasing interest, it has also been indicated that there isn't enough clarity on what exactly IoT is (Sorri et al., 2022). However, there is a great deal of consensus to suggest that IoT is an important resource that will enable organisations to achieve outstanding organisational performance (Shin, 2017; Rebelo, 2022; Affia and Aamer, 2022). IoT has been adopted in both services (e.g., an automated check-out system at AmazonGo, telemedicine/telehealth and tracking systems in healthcare, smart grids system for security, and hospitality) (e.g. Thangamani et al., 2020; Nadkarni et al., 2020) and manufacturing (e.g., advance notification about an imminent breakdown, smart glasses that help operators to work hands-free, real-time notification of assembly line production status by connecting to the cloud) (e.g. Matsuo and Barolli, 2020; Affia and Aamer, 2022) industries. IoT adoption in manufacturing is frequently used and concerned with improving efficiency and effectiveness in production/operation systems across the whole supply chain.

IoT will significantly change the landscape of the supply chain as a result of its ability to connect all members and enable them to influence one another (Boehmer *et al*., 2020; Zangiacomi *et al*., 2020). Furthermore, it has been suggested that IoT has the ability to connect the physical and virtual world thereby enabling 'things' to communicate automatically (Markfort et al. 2022). Examples of IoT applications include IoT powered servitisation of manufacturing (Rymaszewska *et al*., 2017) and real-time production logistics synchronisation (Qu *et al*., 2016). Li and Kara (2017) proposed a real-time application for environment monitoring in manufacturing using wireless sensor networks to improve resource and energy efficiency.

Key functionality of IoT is the ability to provide real time data about various aspects of the manufacturing process including equipment condition, inventory, and product usage (Bughin *et al*., 2015). This functionality has important implications for various aspects of the supply chain. For example, IoT enables better systems integration and data management in the supply chain (Porter and Heppelmann, 2014) thereby enabling real-time logistics information and increases in the frequency and accuracy of product information (Rebelo et al., 2022; Chhabra et al., 2022). It was such potential that encouraged researchers such as Colli et al. (2021) to not only indicate that IoT is critical to enabling supply chains but also to further describe IoT as the ‘technological backbone’ of Industry 4.0.

While IoT is a desirable digital transformation in many organisations and sectors, it does require the right enabling environment, organisational culture, and infrastructure investment for its potential to be achieved. Shin and Park (2017) identified the importance of the cultural fit of IoT to the users while Tu (2018) also found that key organisational issues such as cost of implementation could act as barriers to IoT adoption. Among a range of technical issues that the industry is facing, key issues include cyber-attacks due to interoperability with multi-devices (Rejikumar *et al*., 2019) and information security risks (Bharathi, 2019). According to Soltani (2022), understanding of relationship management within the context of IoT remains limited and for these reasons, it is important that organisations reach a state of readiness before commencing with IoT (Bharathi, 2019).

The potential of IoT is a key reason why many countries are expending efforts and resources to understand and exploit its potential (Weinberg *et al*., 2015). However, IoT is very much an emerging topic and research is increasingly being carried out to understand its nature and deployment. According to Asadi et al. (2022), the understanding of the enablers and drivers of IoT remain tenuous making it difficult for organisations to make decisions.

Hence, this study aims to reveal enabling factors that support the implementation of IoT in the manufacturing industry as a part of a digital transformation strategy. The main focus is the prioritisation of enabling factors for achieving organisational performance. Thus, this research aims to identify key indicators for measuring the success of IoT implementation and the impact of enabling factors on overall IoT success in the supply chain. The associated research objectives are to:

i. Identify and determine the relative importance of indicators for measuring successful IoT implementation in the supply chain; and
ii. Evaluate and prioritise enabling factors for the success of IoT implementation in the supply chain.

The overall research question associated with the above aim and objectives is "How do enabling factors and performance indicators for IoT implementation relate to each other, in terms of importance (ranking) within the context of the supply chain operations?" The study is based on the input of industry practitioners and academic experts from an emerging economy country.

Methodologically, different approaches have been used to evaluate enabling factors in managing supply chains (Manavalan and Jayakrishna, 2019). Mixed methods research combining both quantitative and qualitative approaches for evaluating technology adoption in the supply chain context is very limited, particularly with respect to IoT implementation. Hence, this paper argues for the use of AHP using quantitative data analysis, followed by verification of research findings using qualitative data. Empirical validation of research findings can be used to develop guidelines towards IoT adoption in the digital supply chain. This approach allows for a quantitative evaluation of IoT enabling factors followed by a qualitative understanding and explanation of the quantitative findings.

The remainder of the paper is structured as follows. The next section presents a literature review of key themes including IoT adoption, digital transformation, and challenges and factors affecting IoT adoption. This is followed by a description of the research methodology. Next, results of both quantitative and qualitative analysis are presented. Next, research findings are discussed. Finally, implications for researchers and managers, and conclusions are presented.

2. Literature Review

The digital supply chain encompasses a range of topics including technological development of various technologies and operational aspects of implementation/adoption of technologies such as challenges and enabling factors. These two broad areas of technological development and operational aspects form the basis of the literature review in this section.

2.1 Digital Supply Chain - Technology Perspective

In the context of IoT-enabled supply chain, technologies such as cyber-physical systems, additive manufacturing, RFID technology, and information and communication technology (ICT) play a significant role. For example, Boehmer *et al*. (2020), using an exploration of four in-depth cases showed a wider impact of IoT adoption on information exchange and emphasised IoT as an enabler for manufacturers seeking to exploit a range of business opportunities. Similarly, RFID technology integrated with IoT adoption enables supply chain members to inquire, update and exchange information promptly (Liu and Sun, 2011), thereby synchronising existing information and product flows in a supply chain (Fosso Wamba and Boeck, 2008).

Applications of IoT are widespread across a range of industries and examples reported in the literature, including Krell (2015)'s work are shown in Table I. Depending on the type of application/industry, IoT is viewed from a range of perspectives. IoT applications can be differentiated into an impact on society in general that influences economic value creation at the firm and supply chain level. Impact on society is directly attributed to the necessities of specific applications connected with smart products and smart services (Manavalan and Jayakrishna, 2019). On the other hand, IoT integrated with cyber physical systems (CPS), additive manufacturing and cloud computing can influence economic value creation in the supply chain (Manavalan and Jayakrishna, 2019). Queiroz *et al*. (2020) identified key drivers and their impact on business process management (BPM) improvement, taking into consideration of the interplay between smart production systems, big data analytics, CPS and IoT.

[Insert Table I here]

To provide insight into the successful implementation of IoT technologies, several studies have investigated contextual factors that relate to its deployment. These include studies that have focused on the contribution of enabling factors for overall IoT implementation (Ben-Daya *et al*., 2019); practitioners' perceptions of required technologies to leverage digitisation in procurement (Boeck and Fosso Wamba, 2008); the relative importance of enabling factors in different industries (Haddud *et al*., 2017); trust in relationships and IoT systems (Falkenreck and Wagner (2022); and, incentives and concerns behind firms' decisions to adopt IoT (Tu *et al*., 2018). This study will contribute to this budding body of knowledge by focusing on IoT adoption in the supply chain.

2.2 IoT Adoption and Digital Transformation in Managing Supply Chain

Within broader supply chain management, especially in the Industry 4.0 era, the need to transmit information on the flow of goods within the context of an increasingly global movement of goods is what makes the supply chain industry such an enticing prospect for IoT adoption (Longo *et al*., 2019). Consequently, IOT has been described as the force behind Industry 4.0 with the ability to transform conventional organisations to smart organisations (Ali and Xie, 2022). According to Ben-Daya *et al*. (2019), IoT has an impact on various supply chain processes from sourcing to reverse logistics. Furthermore, the potential to combine IoT with other technologies such as cloud computing and Big Data could herald a digital transformation in the way the supply chain industry functions and it has been suggested that IoT is a critical element and an enabling technology for digital supply chains (Ardito *et al*., 2019). Other studies have noted IoT's significant role based on RFID and transponders as mobile data storage enablers and information flow management in inbound logistics (Liu and Sun, 2011). The importance of IoT in the logistics industry is further emphasised by developments such as the increasing use of sensing devices requiring real-time connection and information flow (Hopkins and Hawking, 2018). Although there are a plethora of studies on the adoption of various individual technologies such as RFID, the adoption of those technologies is limited by the scope of each application. The potential of IoT is the ability to enable connectivity between these different systems and applications and therefore, improve supply chain operations.

From potential organisational outcomes perspectives, IoT can enhance overall supply chain outcomes by enabling competitive advantage and facilitating sustainable supply chain practices, and creating value for the customer by meeting ever increasing customer requirements (Manavalan and Jayakrishna, 2019). Aamer et al. (2021) asserted that IoT has the ability to upgrade and reshpe the supply chain while Rebelo et al., (2022) concluded that IoT can address three major issues in supply chain management – tracking, monitoring, and coordinated control.

2.3 Challenges and Factors Affecting IoT Implementation

While the benefits of IoT implementation are widely discussed and researched, it is clear from the literature that several challenges remain. Aziez et al. (2019) remarked that IoT is not reliable, stable, or standardised while Ahamed et al. (2021) noted that applications and platforms behave inconsistently and fail to interpret data thereby making interoperability a challenge. Other researchers such as Rane and Narvel (2021) emphasised the security and privacy threats that IoT poses. Martens et al. (2022) identified eight challenges to IoT (administration, data collection and management, cost innovation, integration, efficiency matrix, people, security, bringing value, and business solution) while Aamer et al. (2021) suggested that IoT challenges fit into five thematic challenges (technical, financial, social, operational, educational and governmental). The challenges inherent in current IoT systems are likely to be key to the variable commercial success of IoT adoption that was identified by Markfort et al. (2022)

The imperative to overcome challenges and achieve success has encouraged research into factors that can enable successful IoT adoption. Martens et al. (2022) suggested that improved IoT architecture, scalability, standardisation, information, security and support were important in overcoming IoT challenges. A few studies investigated enabling factors of advanced technology adoption from different perspectives including Industry 4.0 adoption in hospitals (Ilangakoon *et al*, 2021), relationships among factors (Agrawal and Narain, 2021; Krishnan *et al.*, 2021), and Industry 4.0 enablers from Indian manufacturing industry context (Jain *et al*., 2020). Among several future research directions, Agrawal and Narain (2021) emphasised a need for an allied methodology for estimating the performance of the digital supply chain. Furthermore, while these studies suggest that some underpinning factors influence and support the adoption of advanced technologies in the supply chain, there is a need to identify which factors are particularly relevant to IoT and analyse/prioritise them across supply chain performance measures in a single study. Furthermore, there is a need to evaluate the relative importance of the factors and inter-dependencies among those factors so that orgnisational resources can be effectively deployed and managed.

3. Research Methodology

Using a mixed-method approach, a sequential study (Venkatesh *et al*., 2013) is adopted, involving both qualitative and quantitative approaches through three stages. The three stages are (i) literature review-based identification of enabling factors and performance measures regarding the success of IoT in managing digital supply chain, (ii) analytical hierarchical approach for categorising the identified factors, (iii) confirmation/verification of empirical findings using input from experts in manufacturing companies, IoT inventors, and policymakers in Thailand.

The first stage was to identify/categorise key indicators/performance measures and key enabling factors for IoT implementation in the supply chain using an extensive literature review. The approach used is an established approach for identifying key measures such as performance indicators and enabling factors associated with technology adoption within broader supply chain management (Somsuk and Laosirihngthong, 2014; Wu *et al*., 2014; Yeniyurt *et al*., 2019). In the second stage, AHP was used to rank the key indicators and determine the weight of each enabling factor contributing to achieving IoT success in the supply chain. The AHP approach proposed by Saaty (1977) is a multi-criteria decision making (MCDM) technique that is capable of evaluating decision alternatives based on combined qualitative and quantitative data (Adebanjo et al., 2016) and has been widely adopted for prioritising key variables/measures in several applications (Somsuk and Laosirihongthong, 2014; Sahu et al., 2017; Sahu et al., 2018). This was based on input from industry and academic experts. Among many other multi-criteria decision methods, the decision-making trial and evaluation laboratory (DEMATEL) is recognised as superior to other MCDM methods due to its capability of exploiting interdependencies of variables to disclose hierarchical relationships (Bag *et al*., 2022). AHP was selected since it is well established method that can be used to systematically integrate various judgments from different evaluators and obtain the relative weights of each qualitative criterion for assessing the overall goal (Yang and Chen, 2006). Furthermore, AHP is an appropriate research method since this study examines multiple decision-making criteria consisting of qualitative and quantitative data (Adebanjo et al., 2016). For the third stage, semi-structured interviews with five executives were conducted in order to confirm and explain the findings from the first two stages. These included senior executives of three Thai manufacturing organisations, one inventor of IoT platforms, and the President of a government agency responsible for the development of IoT ecosystems in Thailand.

3.1 Stage 1: Key Indicators/Performance Measures and Enabling Factors for IoT Implementation

Since the concept of IoT is fairly new and the scope of the research is limited to investigating the key indicators and enabling factors for the implementation of IoT in the supply chain, several broad keywords were used in the literature search to ensure an unbiased search (Tranfield *et al*., 2003). The keywords used for the literature search of key indicators/performance measures include process stability, flexibility, visibility, reliability, connectivity, customer demand, connectivity, and information security and privacy. Each of these keywords was associated with IoT for better search results. Search boundaries included key databases such as EBSCO, Google Scholar, Emerald, Science Direct, and Taylor and Francis. The period covered was up to July 2019. Exclusion criteria included articles with very limited exposure to those measures and no connection to IoT implementation. Inclusion criteria included an article with at least 5 or more performance measures covered.

The literature search yielded a range of potential indicators/performance measures that have been related to the success of the digital supply chain using IoT. Table II shows the list of selected indicators/performance measures identified from the literature search outlined above. The study adopted the four indicators that have been cited most and referred to them as customer demand; process stability; connectivity; and flexibility from herein. For example, connectivity and flexibility refer to the level of SC connectivity and level of product/process flexibility respectively.

To select enabling factors, the literature was searched by the keywords: enabling factor and IoT, using the search boundaries and period outlined above. Exclusion criteria included articles with very limited relation to IoT and enabling factors. Inclusion criteria included articles with a conceptual framework of IoT implementation and scales for measuring at least one enabling factor. Five enabling factors, based on the literature search were identified for success in IoT implementation in the supply chain. The enabling factors refer to the ability of an entity to realize the implementation of IoT in managing the supply chain.

[Insert Table II here]

To ensure accuracy and relevance of the five enabling factors, they were confirmed by assessing them using secondary data (i.e., annual reports of companies, business magazines, technical reports, white papers) to understand their association with industry examples and how they were applied. These enabling factors were developed based on the concept of people (organisational), process, and technology (Sjödin et., al, 2018; Mirvis et., al, 1991). In implementing sophisticated technology, including IoT, these three dimensions need to work harmoniously in order to achieve all expected results. The company should be starting with how people and processes are well-organized before investing in the particular technology and infrastructure (Kayaikci et., al, 2022). The people (organisation), process, and technology (PPT) approach which was introduced by Bruce Schneier (www.Schneier.com) in the late 1990s have been widely acclaimed by practitioners as three pivotal keys to organisational change and successful project implementation (Banks, 2016). Details of the enabling factors, associated scale items, and industry examples supporting these enabling factors are shown in Table III

[Insert Table III here]

3.2 Stage 2: Relative Weight of Importance of Key Enabling Factors for each Indicator/Performance measure

In this stage, AHP was used to determine the relative weight of importance among the four indicators for measuring the success of IoT adoption. AHP was used to determine the relative weight of importance among five enabling factors representing the People (Organisation)-Process-Technology dimensions. Comparing with more recent and advanced MCDM techniques, AHP was most suited to the study because: (i) our complex problem has multiple conflicting factors, in which AHP can deal with complex decision making (Vaidya and Kumar, 2006); (ii) the mathematical features and the data entry is fairly simple to be produced including the pair-wise comparison of the alternatives according to specific criteria; (iii) factors are not only quantitative but also qualitative in nature (Vaidya, 2014), and (iv) it is possible to verify the consistency of the judgments (Saaty, 1994). The procedure of using this technique could be summarised as follows:

- Define the objective
- Establish hierarchical model

- Develop a pairwise comparison questionnaire based on AHP
- Construct a pairwise comparison matrix
- Perform judgment for pairwise comparison by each expert
- Calculate the priority weights of each element
- Check for consistency (less than 10%)
- Develop overall priority ranking

A review panel of 21 experts was selected from a range of industries (14 practitioners) and academia (7 researchers) to participate in the study. Each member of the review panel was briefed on the broader topic of IoT adoption by giving some examples of IoT (e.g., RFID, Robotics, Cloud Computing, Big Data Analytics, Digital Platforms, and Blockchain) in managing the supply chain. The briefing was to ensure that similar applications have been considered and/or implemented in their company. Inputs through interviews were used to prioritise each enabling factor with respect to each indicator/performance measure for assessing the implementation of the IoT. Table 4 shows the profile of experts. The hierarchical model of enabling factors and indicators/performance measures is shown in Figure 1.

[Insert Table IV here]

[Insert Figure 1 here]

3.3 Stage 3: Semi-Structured Interviews of Industry Managers

Semi-structured interviews were carried out with five executives with knowledge and experience of adopting IoT in managing supply chains. Each interview of about 90-120 minutes was audio-recorded. The audio-record was then transcribed on the same day of the site visit (one visit/day). The primary purpose of the interviews was to provide a richer context to some of the findings from the empirical analysis in the earlier stages of the research. In particular, the interviews sought to understand why the top ranked enabling factors were regarded so highly. The five interviewees were an inventor of IoT platform and a winner of two international innovation awards for IoT interventions (N); Vice President of the supply chain for a food and beverage manufacturing company - with 22 years of industry experience (T); General Manager of the global supply chain for an automotive manufacturing company – with 27 year industry experience (I); Vice President of global supply chain for a hard-disk drive manufacturing company – with 24 years industry experience (W); and President of a Thai Government IoT and Digital Innovation Institute (D).

4. Results and Analysis

This section presents the findings from AHP and the semi-structured interviews carried out with industry executives.

4.1 AHP Analysis and Results

Table 5 shows the result of AHP analysis indicating the relative importance of each performance measure and enabling factor for the implementation of IoT in the supply chain. From the perspective of the relative importance of performance measures, customer demand (0.3386) is the most important measure, followed by process stability (0.2393), connectivity (0.2315), and flexibility (0.1906). This suggests that the IoT, based on the responses received, should be tailored at customer service on delivering a process that is stable enough to enable operational effectiveness.

[Insert Table V here]

Although process stability and connectivity are almost equally important, flexibility is rated least important for IoT success. This could be due to large companies already operating at a high level of product/process flexibility gained through other advanced technologies and/or improvement projects. It is interesting to note that system integration was the highest contributing enabling factor for achieving the highest level of customer demand, supply chain connectivity, and product/process flexibility. This appears to highlight the fact that supply chain systems need to be integrated to ensure improved performance across different dimensions and a transition to IoT-enabled systems does not alter the importance of systems integration.

Overall, human capital and organisational climate/culture are the least contributing enabling factors for IoT success in the digital supply chain when all four dimensions of performance measures are considered. This may be because at this stage of IoT development, there is a significant emphasis on getting the technological solutions right before focusing on getting the enabling environment right.

4.2 Findings from the Interviews

The primary focus of the interviews was to understand why the highest ranked enabling factors were so important. However, the interviews also undercovered underpinnings for implementation and areas of application of IoT in interviewed organisations. The interviewees were senior professionals with extensive experience in their various fields. Their comments were instrumental in providing a richer context to the perception of enabling factors for IoT.

Importance of System Integration: The interviews indicated that the challenges that characterise compatibility and connectivity among devices is a key reason why there is much emphasis on system integration. Some of this concern is due to the evolving nature of IoT and the lack of general standards. According to interviewee T,

> *"Compatibility among devices, networks, platforms, and applications from different technology and vendors is a big challenge for system integrator (IoT solutions provider) to suggest what IoT architecture will be suitable for our business model".*

The lack of standards was cited by three of the interviewees as a reason for a reluctance to invest more in IoT. In this regard, Interviewee W and I said respectively,

> *"There are a lot of alternatives for making the connectivity. While progress is being made at standard bodies, our company don't want to necessarily replace all of the devices, sensors, and equipment to accommodate the IoT".*

> *"Whenever the global standards of IoT communication protocol for smart devices and systems are well developed, company is willing to bring the digital transformation concept to our supply chain members".*

Supply chain connectivity using IoT also implies that there will be connectivity between supply chain partners. Although interviewees I and W confirmed that their organisations already use internet-based information sharing systems to co-ordinate operations with their suppliers, system integrating via IoT poses new challenges. According to interviewees I, T and W, these challenges are a combination of relationship and operational issues. These were typified in the following two statements:

> *"Before designing IoT architecture, our company needs to improve strategic partnerships with all members in supply chain. This leads to ensure that important and updated information will be shared"* (Interviewee I).

> *"It is complex to connect activities, within and between companies, that have not been connected before and to do it in a way that is secure, and can keep up with the pace on the manufacturing floor"*. (Interviewee T)

The interviewees also suggested that enabling seamless information flow through system integration within the context of IoT may involve significant planning and restructuring of supply chain activities. According to interviewee I,

> *"Effective integration and synchronization of (a) internal activities, (b) external activities, and (c) information/data have to be in place"*. While interviewee T said,

> *"System integrator (IoT solution provider) plays critical roles in reinventing all activities in the supply chain to ensure that all members in the supply chain will be able to receive/retrieve/utilize information efficiently and effectively"*.

However, interestingly and perhaps surprisingly, security concerns were not cited as being immediately crucial by interviewees I and W. According to interviewee W,

> *“I think data integration is a big challenge because you need to get data flowing before you can even worry about other issues such as privacy and security. And there are already a lot of security tools available that are suited for the IoT.”*

Importance of IoT Infrastructure: According to the inventor of IoT systems (N) and interviewee W, stable IoT systems will enable faster computing speeds and better analytical solutions as well as cheaper operations. Specifically, N said,

> “*The stability of IoT infrastructure also leads to promote inexpensive manufacturing that will be able to support Cyber-Physical Systems”*.

As indicated earlier, a lack of standardisation poses a challenge for organisations willing to invest in IoT. Interviewee D, whose organisations plays a critical role in the Thai government’s IoT initiative stressed the need to ensure that IoT infrastructure is robust and standardised while, at the same time, acknowledging that achieving this is a major challenge. Specifically, interviewee D said his organisation:

> *“………plans to set testing standards for IoT solutions and platforms to ensure similar quality for industries and individuals using the technology in daily life. …………… Architecting for the immaturity of IoT technologies and managing the risk that IoT creates will be a key challenge for policymakers to prepare and develop the common national and international IoT infrastructures”*

In addition to the role of government and government agencies in putting in place standards, all five interviewees agreed that the basic infrastructure for IoT implementation is not yet available. Interviewee T said,

> *"In our country, IoT infrastructure needs to be established before promoting companies to adopt IoT."*

Similarly, the inventor, N, stressed that,

> *"Wide-Area Networks is very important for implementing IoT. If possible, wide-area IoT network should be able to deliver data rates from hundreds of bits per second (bps) to tens of kilobits per second (kbps) with nationwide coverage".*

Implementation and Application of IoT: As part of the interview process of validating the rankings of IoT enabling factors, interviewed organisations also mentioned their key reasons for adopting IoT and/or the ways in which they implement IoT. While this is only a small subset of organisations, there are some clear patterns that emerge and which may ultimately impact perceptions of the importance of IoT enabling factors. With respect to how IoT is applied, two key points of impact were raised – tracking of products and improving the efficiency of employees. The following statements were made with regards to tracking:

> *"Our company has implemented IoT to improve the real-time tracking of trucks." "IoT has a high potential to exhibit real-time tracking from raw material, all the way to delivery". (W)*

"IoT and cloud-based platform (using in our delivery process) can monitor the temperature and humidity in containers that minimize food spoilage and resource waste. The platform also allows staffs to monitor environmental conditions and improve the precision of vehicle routing". (T)

With respect to improving employee efficiency, the following statements were proferred:

"By implementing IoT in the distribution center operations, our company uses the workforce more efficiently, allowing them to focus on tasks like packing, sorting, or inventory management of spare parts". (I)

"This system also helps us to monitor driving habits and safety issues". (W)

With respect to underpinnings of IOT implementation, the key issue that emerges is the need for supply chain-wide benefits. Key statements made in this regard include the following:

"Before investing in IoT, we have to ensure that the players in our supply chain support IoT implementation project". (I)

"One of the most important success factor is clear understanding about IoT goals and benefits among supply chain members. They have to agree to consider this big investment as a part of a medium or long term business strategy". (W)

5. Discussion

From the perspective of enabling factors of IoT success in the supply chain when a holistic approach to indicators is adopted human capital was the least important enabling factor, followed by organisational climate and culture. In contrast, the most important factors are System Integration and IoT Integration and therefore, the implication is that technological factors are more important than ‘softer’ organisational environment factors. Therefore while Soltani (2022) professes the importance of relationship management and Asadi *et al*. (2022) assert prioritising both technological and organisational factors, this study is clear that the greater emphasis at this stage of evolution lies on technological factors. This may be because the IoT development and deployment are still in infancy and therefore, it is important that the technology is developed first and shown to be working efficiently. Indeed, Sorri et al. (2022) noted that IoT is being adopted at a slower pace than anticipated and found both increasing interest in IoT as well as a failure to understand it. Furthermore, it is important to prioritise enabling factors for the success of IoT adoption, particularly in emerging economies particularly as it has been found that IoT implementation is relatively weak in developing countries (Affia and Aamer, 2022). While it is very clear from the literature that human capital factors and organisational culture are also important in the success of technology deployment (Wong and Tang, 2018), findings from this study suggest that they may be unlikely to become central to focus until the technology is already established.

The findings from the interviews indicated that there is a lack of standardisation with respect to IoT technology and a deficit of installed IoT technology in the industry. The interviews also indicated a reluctance of organisations to commit to purchasing technology until standardisation issues are resolved. These findings are closely aligned with the findings by Aziez et al. (2019) and Sorri et al. (2022) which clearly indicate that the standardisation remains a challenge for IoT have have had a direct impact on the willingness of organisations to commit to IoT. Within, this context, it is reasonable to expect that 'soft' issues such as human capital will not be at the forefront or organisational endeavour. However, it is likely that once the technical issues have been resolved, the softer issues will take on the same sort of prominence that has been come to be recognised in other organisational initiatives like Total Quality Management. Some early studies have already emphasised the importance of human capital by suggesting that it could be one of the key factors that hinder the adoption of IoT (Lee *et al*., 2018; Ryan and Watson, 2017).

5.1 The Importance of Different Indicators

The results of AHP analysis indicates that level of customer demand is the most important indicator. The high ranking given to level of customer demand and the significant difference in weighting between level of customer demand and the other indicators sends a clear message that the ability to satisfy customers remains prominent in the strategies of manufacturing organisations. It also suggests that they are open to new approaches and technologies that may help them improve the service that they give to customers. This is an important finding as the customer-centric perspective is not widely acknowledged in the literature. Rather many studies have focused on operationa performance (e.g. Martens *et al*., 2022); Chhabra *et al*., 2022). Based on this, it is likely that IoT may in time, be considered as one of the suite of tools and techniques such as TQM, VMI, CRM, etc. with a predominant focus on customer satisfaction.

The other three indicators – level of process stability, connectivity, and flexibility – are more technological or 'hard' indicators that, on the face of it, appeal to process management. To a certain extent, process management will also impact customer satisfaction (Lee *et al*., 2018). However, these indicators are likely to have wider impacts on the organisation. For example, it has been argued that a stable process, as well as flexibility, can impact process efficiency, operational performance, and ultimately, financial performance, particularly financial improvements as strategic outcomes from the implementation of disruptive technologies (Frederico *et al*., 2020). The importance of these performance measures is further evident from the significant impact of IoT enhancing operational excellence, in particular proving real-time visibility across the supply chain industry (Coronado Mondragon *et al*., 2020). Hence the effects of implementing IoT within organisations are indicated as multilateral and comprising both internal and external perspectives.

5.2 The Role of Enabling Factors in Achieving Different Outcomes

The study showed that not all the different indicators impact the performance indicators in the same way. Therefore, while system integration and IoT infrastructure were the two most important enablers for three of the indicators (as well as overall holistic performance), this hierarchy did not apply to the single most important indicator – level of customer demand - when considered on its own. Indeed, IoT infrastructure was ranked least of all five indicators while system integration and supply chain responsiveness were ranked as the most important enablers. These findings suggest that if the level of customer demand is the sole or key priority of the organisation, then they may need to consider a higher emphasis on supply chain responsiveness when determining their IoT strategy. These are important complementary findings as the literature on IoT has not emphasised the importance of customer demand and supply chain reponsivesness within the context of IoT.

In contrast, human capital and organisational climate/culture were ranked lowly across all four indicators. Irrespective of this relatively low ranking, it is not in doubt that human capital, as well as the organisational climate and culture, play a crucial role in the success of technological solutions according to Zdravković *et al*. (2018). What is also not in doubt, based on the findings from the interviews, is that many organisations are reluctant to invest in IoT until technological issues such as standardisation, IoT information security risks (Bharathi, 2019), wide area networks, integration and compatibility are resolved. For example, it has been highlighted that technology integration is one of the major challenges hindering IoT implementation (Haddud *et al*., 2017, Ahamed *et al*., 2021). It is also clear from the interviews that manufacturers are looking up to the technology providers and government to take the lead in resolving the technological issues. Therefore, it seems reasonable to expect that until the technological issues are resolved, manufacturers are unlikely to invest in human capital. Similarly, they are unlikely to begin to chain their organisational climate and culture until they are certain of the technological solutions that they will adopt and have a clear understanding of how these solutions will affect their internal and external processes and relationships. It is also interesting to point out that system integration and IoT infrastructure are 'hard' issues while human capital and organisational climate and culture are 'soft' issues. Therefore, the message from this study with respect to the key enablers of IoT at this point in its evolution is that, in general, 'hard' enablers lead and 'soft' enablers follow. However, as technology becomes more robust and embedded, the likelihood is that focus and prominence will turn to the 'soft' enablers.

5.3 Enabling Factors and Performance Measures from IoT Framework/model Perspective

The importance of enabling factors across several performance measures for IoT success in managing the digital supply chain is further evident from several studies of IoT frameworks/models. Priorities of enabling factors are used to support various stages of IoT adoption through supply chain 4.0, technology deployment, and product development, guided by essential enablers as a possible implementation approach of the framework of Industry 4.0

adoption (Frank *et al*., 2019). Since system integration and IoT infrastructure are the highest ranks across overall performance measures and IoT infrastructure positively impacts organisational performance (Brous *et al*., 2020), both enabling factors could be considered as key enablers at stage 1 of the framework of IoT adoption. Furthermore, enabling factors considered and prioritised in this research also cover key determinants of technological, organisational, and environmental factors of the framework of digital transformation success proposed by Ghobakhloo and Iranmanesh (2021). Priorities of enabling factors can also be used as key inputs into planning for implementation, aligned with IoT high priority areas as one of the four building blocks of the IoT theoretical framework proposed by (Nord *et al*., 2019).

5.4 Industry and Academic Insights

The findings from the study enable further industry and academic insights into IoT implementation beyond the prioritisation of enabling factors. From an industry perspective, it enables an analysis of the internal discussions that organisations have with regards to IoT implementation. From an academic perspective, it enables a contribution to an understanding of theoretical underpinnings to IoT implementation. These issues are discussed as follows.

5.3.1 Analysing industry positioning on IoT implementation

From both the AHP analyses and the interviews, it is clear that the supply chain effect of IoT implementation is both a powerful enabler and a key outcome. The AHP analyses clarified the importance of customer demand while the interviews highlighted the importance of supply chain-wide benefits and integration. However, with respect to the non-technical aspects of IoT implementation, the findings suggest that there might be a dichotomy. While the AHP analyses rank human capital and organisational climate/culture as the least contributing enabling factors for IoT success, the interviews are clear that the organisations consider employee efficiency and behaviour as key issues monitored as a result of IoT implementation. This may suggest while the ‘softer’ issues relating to human capital are not perceived to be very important input or enabling factors of IoT implementation, they are considered as important output measures of such implementation. The authors of this study suggest that with time, if human capital outcome issues continue to be perceived as important, then organisations will have to change their perception about human capital input and allocate more emphasis and resources to ensuring that their employees are in the best position to generate maximum benefits from IoT implementation.

5.3.2 The relevance of resource-based view (RBV) theory to IoT implementation

The findings from this study enable a discussion of the theoretical underpinnings that may be central to the adoption and success of IoT. The five enabling factors studied – System Integration, IoT Infrastructure, Supply Chain Responsiveness, Human Capital, and Organisational Climate/culture – may be viewed as resources or capabilities that organisations need to have to successfully implement IoT. The implication is that organisations that can best acquire and utilise these resources and capabilities are more likely to succeed with their implementation of IoT. Therefore, this suggests that resource-based view (RBV) theory is a relevant theory that should apply to IoT implementation. RBV theory posits that competitive advantage may be gained by organisations that are able to acquire resources and capabilities that are valuable, rare, inimitable and non-substitutable (Halley and Beaulieu, 2009; Yu *et al*., 2018). The authors of this study would argue that the enabling factors studied align with this description. Furthermore, it has been argued that RBV resources can be either tangible or intangible assets (Amabile *et al*., 1996). Enabling factors such as System Integration, IoT Infrastructure Supply chain responsiveness can be classified as tangible assets while Human Capital and Organisational Climate/Culture can be described as intangible assets.

From the literature, it is already clear that human capital and organisational culture resources are accepted as being relevant to RBV and competitive advantage (Gannon *et al*., 2012). With particular emphasis on the ranking of the five enabling factors studied in this research, the authors would argue that at this stage of its development, IoT implementation and success is primarily driven by tangible assets while intangible assets are generally lower ranked. However, this may change in the future. As IoT Infrastructure and System Integration become more standardised, the ability of such tangible assets to provide significant competitive advantage may become more limited. It may well be that at that stage of development, RBV and competitive advantage from IoT implementation will be driven more by intangible assets.

6. Conclusions and Implications

This study set out to identify and rank the enabling factors for successful IoT implementation in the supply chain. It also identified and ranked the key indicators/performance measure that relates to IoT implementation in a supply chain context. It found that level of customer demand and process stability are the two top performance measures that relate to IoT implementation. The study also found that system integration and IoT infrastructure were the most important enabling factors for IoT implementation. Conversely, human capital and organisational climate and culture were the lowest ranked enabling factors. Interviews with key stakeholders indicated that, at this time, the key priority is to get the technology and hardware for IoT right. Therefore, while factors such as human capital and organisational climate, and culture have a role to play in IoT implementation, they do not appear to be the primary focus at this stage of the evolution of IoT technologies.

6.1 Practical Implications

This study has important implications for the industry. First, it indicates that the IoT implementation is a technological undertaking, and the most important performance indicators are not technical. Rather, the most important indicator is the level of customer demand and how agile the organisation and its IoT strategy and infrastructure, can respond effectively, efficiently, and securely to that customer demand and expectation. The clear message is that the IoT should not be pursued for the sake of it but for its ability to improve customer outcomes. The study also suggests that organisations seeking to deploy the IoT need, at this time in its evolution, to focus significantly on getting the technology and infrastructure right, as system integration and IoT infrastructure are found to be the highest priority enabling factors for IoT implementation. This also can be considered to be directly associated with the broader theme of industry, innovation and infrastructure as one of the sustainable development goals. At the same time, organisations also need to follow with other softer aspects of technology deployment and change management after implementing IoT systems for some time. Similarly, government and its regulatory agencies need to be more agile and proactive in setting standards for IoT solutions so that organisations can start to invest in such solutions.

The study also has implications for research. The findings indicate that industry practitioners are engaging proactively with IoT adoption and therefore, academic research needs to be focused on implementation challenges. Hence academic research needs to pro-actively anticipate and address challenges that will be faced at each level of IoT development as the technology evolves.

6.2 Limitation and Suggestions for Future Studies

This research study is limited by the scope of enabling factors considered. There may be other factors that impact IoT adoption that have not been considered in this study. In addition, data was collected from a range of industry practitioners, and so the research findings are focused on broader supply chain practices of large companies with both upstream and downstream entities rather than a specific industry and SMEs. Hence, any industry specific adoption factors and SMEs were not discernible from the study.

Finally, since IoT technology is at an early stage of evolution and it will face challenges as it develops, future research should be focusing on expediting identification and analysis of challenges faced and how both 'hard' and 'soft' challenges could be addressed. In addition, models for implementing IoT and evaluating its success are lacking and could be a focus for future studies.

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Figure 1. Hierarchical model of enabling factors and indicators for measuring IoT success in managing the digital supply chain.

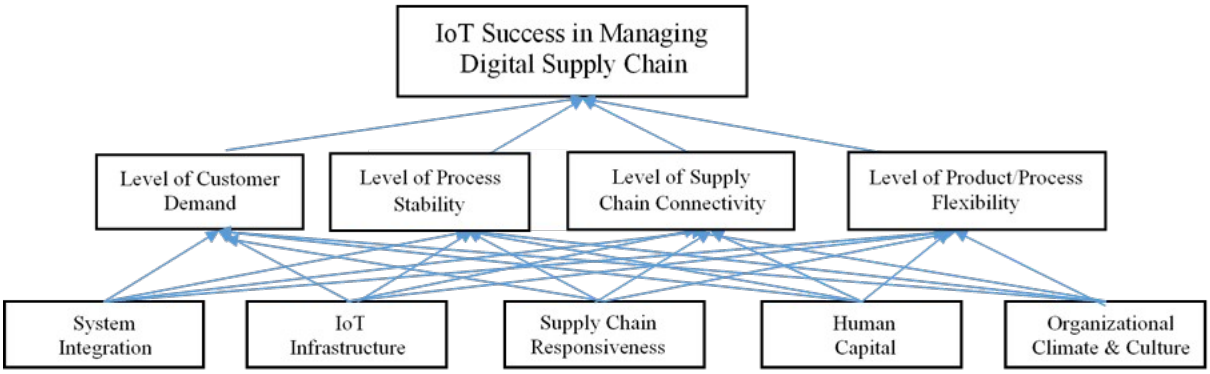

Table I. Examples of IoT applications in major industry segments.

Industry Segment	Applications of IoT in Supply Chain	Examples
Manufacturing	Facilities management, Asset management, Machine condition, Smart manufacturing (Cheng et al., 2018).	Real-time monitoring of equipment, man-machine interaction, automated guided vehicles for smart shop-floor/storage using 5G-based IIOT.
Resources and Utilities	Power generation, Large farm management, Mine operations, Smart grids and power systems (Reka and Dragicevic, 2018).	Substations using the smart switch and smart meters connected through LAN.
Retail	Inventory management, Supply chain control, Smart shopper applications, Inbound and outbound the supply chain automation (Majeed and Rupasinghe, 2017).	Automation of ERP system transactions using RFID technology and BAPI technology in SAP.
Healthcare	Patient monitoring/tracking, Assent tracking, Personal wellness. (Babu et al. 2013)	Monitoring physiological statuses of patients through sensors, analyzing collected data remotely and then sending analysed patient's data/information to make suitable decisions.
Government	Building automation, Lighting control,	Adopting IoT cybersecurity and IoT-

	Public transportation, Smart government (Ben-Daya et al. 2019).	enabled dynamic capabilities for smart government performance — a shift from digital government to smart government
Transportation	Air traffic monitoring, Fleet management; Freight management, Intelligent traffic/driver management (Sherly and Somasundareswari, 2015).	Real-time traffic controlling and monitoring through RFID
Consumer	Wearables, Home automation, Home healthcare, Smart home management (Stojkoska and Trivodaliev, 2017).	Energy management system connecting utility company and smart devices

Table II. List of indicators/performance measures for implementing IoT in the supply chain.

	Process Stability	Flexibility	Visibility	Reliability	Responsiveness	Connectivity	Privacy
R1	✓		✓	✓	✓	✓	
R2	✓	✓	✓	✓	✓	✓	✓
R3	✓	✓	✓		✓	✓	✓
R4	✓		✓		✓	✓	✓
R5	✓	✓	✓	✓	✓	✓	
R6	✓	✓		✓	✓	✓	✓
R7	✓	✓	✓	✓	✓	✓	

R8	✓	✓	✓		✓	✓	✓
R9	✓			✓	✓	✓	
R10	✓	✓		✓	✓	✓	✓
R11	✓	✓	✓		✓	✓	
R12	✓	✓		✓	✓		✓
R13	✓	✓	✓		✓	✓	✓
R14	✓	✓		✓	✓	✓	✓
R15	✓	✓	✓	✓	✓	✓	✓
R16	✓	✓		✓	✓		✓
R17	✓	✓		✓	✓	✓	✓
R18	✓	✓	✓		✓	✓	✓
R19	✓	✓		✓	✓		✓
R20	✓		✓		✓	✓	✓
Sum	20	16	12	13	20	17	15

Notes: R1 Addo-Tenkorang and Helo (2016), R2 Ben-Daya *et al*. (2019), R3 Bogataj *et al*. (2017), R4 Feng *et al*. (2014), R5 Haddud *et al*. (2017), R6 Dweekat *et al*, (2017), R7 Del Giudice (2016), R8 Kache and Seuring (2017), R9 Raman *et al*. (2018), R10 Helo and Hao (2017), R11 Mishra *et al*. (2016), R12 Ng and Wakenshaw (2017), R13 Parry *et al*. (2016), R14 Strozzi *et al*. (2017), R15 Tu *et al*. (2018), R16 de Senzi Zancul *et al*. (2016), R17 Yan (2017), R18 Wu *et al*. (2016), R19 Weinberg *et al*. (2015), R20 Strange and Zucchella (2017)

Table III. Grounded concept, enabling factors, scale items that relate to indicators/performance for implementing IoT in supply chain

Grounded Concept	Enabling Factor	Scale item	References
Technology	System Integration (SI)	1. Platform/Devices compatibility	Aamer et al, 2021; Boehmer et al, 2020; Yeniyurt et al, 2019; Haddud et al, 2017
		2. Supplier's willingness to share information through system integration	Bag et al, 2021; Frederico et al, 2020; Dweekat, 2017; Kache and Seuring, 2017
		3. Seamless information flow	Ardito et al, 2019; Bharathi, 2019; Yeniyurt et al, 2019; Rymaszewska et al, 2017
	IoT Infrastructure (IoTI)	1. Stability of IoT Infrastructure (IoTI)	Tu et al, 2018; Haddud et al, 2017; Kache and Seuring, 2017
		2. Increased level of data security and privacy	Bag et al, 2021; Ilangakoon et al, 2021; Dweekat, 2017
		3. Capacity/Speed of data transfer	Aamer et al, 2021; Boehmer et al, 2020; Manavalan and Jayakrishna, 2019

		4. Supporting government policy to promote the implementation of IoT	Frederico et al, 2020; Manavalan and Jayakrishna, 2019; Haddud et al, 2017;
Process	Resilience of Supply Chain (RoSC)	1. Quick response times in case of emergency	Bag et al, 2021; Ilangakoon et al, 2021; Tu et al, 2018; Feng et al, 2014;
		2. Flexibility to respond to unexpected process changes	Boehmer et al, 2020; Dweekat, 2017; Yeniyurt et al, 2019: Kache and Seuring, 2017
		3. Mitigate supply chain risks	Aamer et al, 2021; Bharathi, 2019; Rymaszewska et al, 2017

Table III. Continued

Grounded Concept	Enabling Factor	Scale item	References
People (Organization)	Human Capital (HC)	1. Technical expertise (coding/design of user interface)	Manavalan and Jayakrishna, 2019; Dweekat, 2017; Haddud et al, 2017
		2. Employee ability to use new data analytic tools and methods	Bag et al, 2021; Frederico et al, 2020; Ardito et al, 2019; Kache and Seuring, 2017
		3. Incentives and policies to maintain	Ilangakoon et al, 2021; Bharathi, 2019;

		talented/skilled staff	Yeniyurt et al, 2019; Feng et al, 2014
	Organizational Climate & Culture (OC&C)	1. Clear comprehension about IoT benefits	Ardito et al, 2019; Bharathi, 2019; Tu et al, 2018; Haddud et al, 2017
		2. Cross-function team to develop IoT systems	Aamer et al, 2021; Boehmer et al, 2020; Feng et al, 2014
		3. Reduction of transactional inter-enterprises reaction	Bag et al, 2021; Frederico et al, 2020; Tu et al, 2018; Dweekat, 2017; Kache and Seuring, 2017
		4. Decentralization of decision making	Yeniyurt et al, 2019; Ardito et al, 2019; Haddud et al, 2017; Feng et al, 2014

Table IV. Details of experts (researchers and practitioners).

No.	Group	Profession	Experience
1	Academic	Associate Professor	Transportation research, more than 15 years.
2	Academic	Assistant Professor	IoT and factory automation research, more than 10 years.
3	Academic	Associate Professor	Supply chain research, over 15 years
4	Academic	Assistant Professor	Supply chain research, more than 10 years.
5	Academic	Associate Professor	Smart packaging in the supply chain research, more than 10 years
6	Academic	Associate Professor	Sensors and automation systems research, more than 10 years.
7	Academic	Associate Professor	Algorithmic design in supply chain management research, more than 10 years.
8	Private company	Engineer	Design of automatic loading and unloading equipment for IoT, more than 7 years.
9	Private company	Supply Chain Manager	International supply chain management and development of IoT system, more than 15 years.
10	Private company	Independent Consultant	Automated manufacturing process design, over 12 years
11	Private company	Logistics Officer	Supply chain management (Global), more than 7 years.
12	Private company	Sale Manager	Manufacturing and installation of automation systems, more than 10 years.
13	Private company	Product Manager	RFID equipment, more than 20 years
14	Private company	Distribution and Supply Chain Manager	Warehouse management and development automation, more than 15 years.
15	Private company	Director of Factory Production	Hard disk drive device Production and transport management with IoT, over 20 years.
16	Academic	Director of Information	Information Communication and Technology, over 3 years

No.	Group	Profession	Experience
		Technology	
17	Private company	Global Sourcing Manager	International supply chain Management, more than 5 years.

Table IV. Continued

No.	Group	Profession	Experience
18	Private company	Assistant Manager	Warehouse management, more than 10 years.
19	Private company	Trucking Technology Developer	Logistic management, more than 8 years.
20	Private company	Scheduling and Planning Division Manager	Automatic production process design, more than 5 years
21	Private company	Supply chain Manager	Logistics management, more than 8 years.

Table V. Relative importance of performance measures and enabling factors.

Dimension (Enabling factor)	Indicators (Performance measures)							
	Level of Customer Demand		Level of Process Stability		Level of Supply Chain Connectivity		Level of Product/Process Flexibility	
	0.3386 (Rank = 1)		0.2393 (Rank = 2)		0.2315 (Rank = 3)		0.1906 (Rank = 4)	
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
System Integration	0.3420	1	0.2456	2	0.2748	1	0.2690	1
IoT Infrastructure	0.1377	5	0.2809	1	0.2437	2	0.2065	2
SC Responsiveness	0.1856	2	0.1619	4	0.2097	3	0.2045	3
Human Capital	0.1829	3	0.1726	3	0.1080	5	0.1429	5
Organizational Climate and Culture	0.1517	4	0.1390	5	0.1639	4	0.1771	4