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Nexus among blockchain visibility, supply chain integration and supply chain performance in the digital transformation era

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Abstract

Purpose – Digital transformation (DT) in the semiconductor industry goes beyond traditional business operations and supply chain management (OSCM) to the digital world. Despite significant developments in recent years, blockchain implementations for OSCM remain relatively underdeveloped in the semiconductor industry. Therefore, this research aims to examine the relationships between blockchain visibility, supply chain integration (SCI) and supply chain performance (SCP) in the era of DT in Malaysia's semiconductor industry to shed light on this emerging area.

Design/methodology/approach – A convenience sampling of 71 operations and supply chain managers attached to semiconductor manufacturing firms in Malaysia were invited to participate in a survey. In assessing blockchain visibility within the industry, key terms namely business intelligence gathering, information exchange, information technology (IT) and knowledge of asset status, were conceptualised from the literature review. The questionnaires developed to collect data were validated by industry and academic experts.

Findings – The results from the analysis confirmed that SCI mediates the link between blockchain visibility (information exchange, business intelligence gathering and knowledge asset status) and SCP. Likewise, the importance-performance matrix analysis (IPMA) outcomes revealed that IT played a minor role. The results suggested that semiconductor manufacturers should pay less attention to IT since this was identified as having the least priority towards improvement.

Practical implications – The outcomes from this research enable policymakers to strategise and integrate blockchain technology in the era of DT to ensure sustainable SCM in the semiconductor industry in Malaysia.

Originality/value – The research bridge the knowledge gap by revealing the value that blockchain visibility can facilitate SCP and explore SCI as the prevailing factor and demonstrates how Resource-Based Theory and Network Theory can be applied in this study.

Keywords Digital transformation, Blockchain, Performance, Visibility, Supply chain, Integration, Technology

Paper type Research paper

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1. Introduction

In recent years, disruptive technologies have significantly altered the way industries and businesses operate. However, while this is true to some extent, companies that fail to consider the effect of such technologies may ultimately pay the price by losing market share to competitors that have chosen to integrate these technologies into their business operations. Having said that, from a supply chain perspective, it is critical for manufacturing industries, to rely heavily on their supply chain partners to deliver products. Manufacturers, suppliers, shippers, distributors and customers are the principal stakeholders in the supply chain of manufacturing industries. Indeed, manufacturing companies have increasingly recognised the importance of supply chain performance (SCP) and efficiently managed supply chains as critical factors in remaining competitive. As pointed out by Kumar *et al.* (2017b), globalisation has also amplified the effects of these factors, thus increasing the need to incorporate disruptive technology into the supply chain management (SCM) system.

An inter-organisational information system (IOIS) can be described as a data network that enables information sharing between organisations. As manufacturers continue to advance towards hybrid cloud and cloud-native applications as part of their digital transformation (DT), they will have to determine if and where blockchain can play a role. Blockchain technology is a novel approach towards establishing inter-organisational information systems (Pedersen *et al.*, 2019). Xu *et al.* (2021) explained that a blockchain is literally a chain of blocks, or more precisely, digital data (the "block") kept in a shared database (the "chain"). Furthermore, blockchain usage and smart contracts in the context of SCM have been proposed. As explained by Yoo and Won (2018), a company may operate more efficiently in the long-term, by sharing information securely through a blockchain network. Indeed, innovations are posing exciting prospects for supply chain improvement (SCI), and incorporating blockchain technology into the supply chain making it possible to improve supply chain visibility while lowering operational costs (Laaper *et al.*, 2017).

As depicted by Queiroz *et al.* (2020), blockchain is considered a prominent and highly disruptive technology, contributing to remodelling traditional business models and creating new opportunities across the entire supply chain. More than 70% of all businesses across sectors consider blockchain to be part of their digital transformation plan now and the years to come (Stacey, 2020). Blockchain applications in SCM have been shown to have a tremendous, transformational effect on businesses. This is supported by recent research suggesting that the introduction of blockchain applications in SCM helps to improve business performance (Manupati *et al.*, 2020; Queiroz *et al.*, 2019).

From an Operations and Supply Chain Management (OSCM) perspective, blockchain is considered a potential solution for SCM traceability problems (Lu and Xu, 2017), enabling trustworthy relationships to be developed between organisations and their suppliers along the entire supply chain and management. In responding to this, while Industrial Revolution (IR) 4.0 has ushered in a new era of economic disruption, manufacturing companies are closely looking beyond the latest technologies and identifying the real potential of these technologies to elevate SCP, particularly the most complex digitalised industries, namely the semiconductor manufacturing. Although blockchain technology has a great potential for acquiring high levels of efficiency with a decentralised, transparent and visible operation to SCM (Cole *et al.*, 2019; Dolgui *et al.*, 2020; Wong *et al.*, 2020), blockchain remains relatively underutilised and understood. The five most leading blockchain research studies based on the number of publications are in the United States (US), China, the United Kingdom (UK), Germany and South Korea (Wamba and Queiroz, 2020). However, there still remains a lack of research data on blockchain visibility outside of these countries.

On the other hand, scholars and researchers worldwide have started concentrating on blockchain technology features and adoption within OSCM. Babich and Hilary (2020) highlighted five key strengths in the interplay between blockchain and operations management: visibility, aggregation, validation, automation and resiliency. In fact, some studies reveal that the key features of blockchain are considered to be safer, more transparent and traceable (Queiroz and Wamba, 2019). Among these features, blockchain's traceability has attracted the interest and attention of scholars in investigating its potential to prevent fraud across supply chains (Chen, 2018). Other features appear to be neglected in past research. Therefore, this study principally aims to conceptualise blockchain visibility as the key determining factor in improving supply chain performance. Blockchain visibility supports real-time data gathering and provides end-to-end visibility that enables managers to access massive amounts of data for better decision-making, thereby favouring SCP (Li *et al.*, 2021).

Generally, blockchain performance is verifiable and quantifies the efficiency or effectiveness of actions and processes. As a result, performance management is important in supply chains to ensure and facilitate effective decision-making. Indeed, blockchain performance has been measured in terms of the execution time of data transactions that would assist end-to-end supply chains, which is becoming more efficient. It is also viewed as a platform to accelerate the sharing of data streams between parties. Therefore, improving blockchain visibility will undoubtedly provide an auditable trace of a product's footprint, which is particularly attractive to industries where the provenance of a product is crucial. This aspect could help boost consumer confidence in supplier-customer relationships (Zanon *et al.*, 2021).

Furthermore, given that technological connectivity helps an organisation enhance data integration and improve accuracy in carrying out business activities, SCI could help create and share information across organisational functions, suppliers and customers (Queiroz *et al.*, 2019). In light of this, the literature generally shows that the SCI's connection to organisational performance is positive (Munir *et al.*, 2020). Moreover, SCI has enabled organisations to coordinate supply chain activities, integrate production and resource planning and execute joint decision-making, subsequently enhancing the organisation's overall performance (Shi *et al.*, 2021). This study considers that SCI has an intermediary role in bridging blockchain visibility through the synchronisation of internal functions and external supply chain partners to enhance SCP.

It is also worthy to note that limited studies have systematically assessed blockchain as a technological advance feature having the potential to achieve many of the metrics of SCP. Consequently, this study aims to bridge the knowledge gap highlighted in the literature review by revealing the value that blockchain visibility can facilitate SCP and explore SCI as the prevailing factor. In summary, this study principally examines the influence of blockchain visibility on SCP measured by cost, flexibility and delivery. Specifically, the elements of blockchain visibility are assessed, namely: business intelligence (BI) gathering, information exchange (IE), information technology (IT) and knowledge asset (KA) status. Previous studies highlighted that SCI plays a key role in linking blockchain and SCP; thus, the following research questions have been formulated:

RQ1. Does blockchain visibility support SCI?

RQ2. What is the effect of SCI on SCP?

RQ3. Does SCI have a mediating effect in connecting blockchain visibility and SCP?

The use and application of theories in operations management (OM) research have been increasingly underscored in recent years. Two key theories, namely Resource-Based Theory (RBT) and Network Theory offer various interesting and helpful perspectives to address the above research questions. RBT posits that a firm's capabilities are crucial to derive desired operations performance outcomes from its resource base (Nandi *et al.*, 2020). Further, the RBT offers the theoretical skeleton of understanding when resources reinforce the competitive advantages of organisation. That is to say, it is SCP, where the resources are valuable, rare, inimitable and non-substitutable. RBT has become a significant paradigm in the field of critical analysis in OM (Hitt *et al.*, 2015). Based on this background, this study builds upon SCM literature that utilises the RBT and Network Theory in the supply chain network (SCN) to identify blockchain visibility in supporting SCI. Under the SCN, the network theory has resorted to SCI's basic concepts to explain the exchange of information, goods and services within an organisation.

On the other hand, the network theory focuses on developing long-term, trust-based relationships between supply chain members. Thus, the partners' coordination and collaboration within the SCN is always complex. As such, these two theories are appropriate to gain greater insight into blockchain visibility in the SCN. This paper continues in discussing the literature review and development of hypotheses. The following sections outline the research methodology and findings, concluding with a discussion on the implications of this study.

2. Theoretical background

2.1 Resourced-based theory (RBT)

RBT has remained a key strategic management model, gaining in popularity in adjacent and complementary fields such as OM. The OM field focuses on more strategic and macro issues like supply chains. Consequently, RBT has been identified as having unique complementarity to many of the important foci in OM (Pilkington and Meredith, 2009). RBT investigates the efficiency-based differences of organisations' performances based on their resources (Peteraf and Barney, 2003), which represent the strengths that facilitate in creating the competitiveness of the organisation and help to execute strategies to achieve its vision, mission and organisational goals (Porter, 1981). By efficiently absorbing and utilising resources, an organisation can gain a sustainable competitive advantage (Barney and Clark, 2007).

Moreover, the different efficiency levels in utilising resources will create a different performance level in an organisation. For instance, an organisation having superior resources will perform better than those with inferior resources. In addition, an efficient organisation will create higher value with lower costs than inefficient organisations, and this efficiency is measured regarding net benefits once excluding the firms' costs (Miles, 2012). The theory explains how organisations can be special or unique and sustainable in competitive environments (Hoopes *et al.*, 2003). Hitt *et al.* (2015) countered that RBT provides a unique way of evaluating the supply chain to investigate the supply chain's activities individually and collectively. Integrating blockchain technology will improve supply chain efficiency and effectiveness, helping companies reduce operational costs (Helo and Hao, 2019). Therefore, by applying the RBT in this present study, the resources identified and analysed will help the companies gain and sustain a competitive advantage.

2.2 Network theory

Network theory seeks to understand the dynamics of inter-organisational relationships and focuses on personal relationships between and building mutual trust through cooperative relationship and process exchanges (Halldorsson *et al.*, 2007). Companies need to establish relationships to gain external access to resources external to the company. This will help create stable and ever-changing networks with several types of interactions: exchange processes and adaption processes among supply chain partners, helping to link the companies in a stable manner (Johanson and Mattsson, 1987). Although network theory in operation management literature has been widely adopted, topics such as long-term relationship development, intra-firm coordination, information sharing and administrative adaption are repeatedly and implicitly considered in relation to the supply chain.

In a prior study, network theory was referred to in analysing and developing manufacturing strategies based on horizontal and vertical technologies and processes in production systems (Karlsson and Sköld, 2007). Indeed, the network theory has been cited as a robust theoretical framework for the supply chain. This is because it can explain behaviour by agents from the perspective of their position in a network and, consequently, trust and power in buyer-supplier relationships in the context of OM (Dekkers *et al.*, 2020). Network theory deals with dyadic relationships in which the networks are firmly embedded (Halldorsson *et al.*, 2015). By applying network theory, blockchain's promise to create a "trustless trust network" (Werbach, 2018) can be explored.

Furthermore, through blockchain integration, data transparency will help enhance trust between personal contacts and provide a relational perspective basis to evaluate the role and importance of companies' inter-organisational networks. However, inter-organisational relationships' overall importance and qualities may decline when trust in supply chains is no longer a concern (Werbach, 2018). There are numerous connected issues and direct effects from a network theory viewpoint regarding blockchain visibility, including ties between organisations, trust, dedication and information sharing.

3. Literature review and hypotheses development

3.1 Supply chain performance

The interest in SCP measurements has grown over recent years, albeit not well articulated, given that researchers have different operation management disciplines, information management and various other definitions for SCP (Sezen, 2008). Traditionally, SCP assessment has been connected with internal procurement and buying management or customer relationship management (Bai *et al.*, 2021). In research prior to the 1990s', most of SCP was measured from a traditional cost perspective or was combined with customer responsiveness. This was because (1) changes in cost performances were easier to be measured and compared with readily available accounting data, and (2) the result was easier to interpret and understand. The economists also failed to agree with the accounting data to measure performance, ignoring the opportunity cost and time value of money (Tan, 2002).

SCM's increasing importance is mainly reflected across four dimensions of cost reduction, quality improvement, service improvement and inventory optimisation. The SCP measurements used in this study include improved flexibility, improved delivery and cost reduction, as suggested by Foo and Zailani (2012). A recent study by Pan *et al.* (2019) found that 50 blockchain technology enterprises in China implemented blockchain to achieve improved performance on sales costs and, ultimately, create a positive impact on SCP. This means that utilising blockchain technology will optimise supply chain processes in any field, providing many other advantages such as cost savings on purchases, increased inventory awareness due to empowered traceability and transparency to supply chain participants. As a result, SCP is enhanced.

3.2 Blockchain visibility

Blockchain has several valuable features that are considered crucial to enhance SCP, among which visibility is integral to reducing black swans of information sharing or accessing information among supply chain memeber (Barratt and Oke, 2007). Blockchain visibility is the degree to which actors in a supply chain can access or exchange knowledge considered critical or beneficial to their activities, believing it would help all. Likewise, the term "blockchain visibility" refers to the models by which an organisation interacts and reports its actions to its liaisons through the SCN to facilitate supply chain visibility across all levels. Furthermore, it enables a vivid picture of the upstream and downstream inventories, including demand and supply status. Data available in a timely and accurate manner is essential towards supply chain effectiveness. From the SCN perspective, blockchain visibility can improve supply chain partnerships' accountability (Lu and Xu, 2017). This study contended that supply chain visibility must have data readily available, accurate, timely and in a format that communicates all necessary information (Pettit, 2008). Blockchain visibility likewise has a similar feature. Therefore, based on this conjecture, this study articulates that blockchain visibility incorporates four dimensions, namely knowledge asset (KA) status, information technology (IT), information exchange (IE) and business intelligence (BI) gathering (Ahimbisibwe *et al.*, 2016).

Nevertheless, blockchain visibility is important for SCI, as ambiguous or unclear visibility from one end to the other end of a supply chain may cause enormous inefficiencies in customer service (Baharanchi, 2009). Moreover, limited or negligible information visibility along the supply chain is a problem for supply chain process integration (Cachon and Fisher, 2000). On the other hand, real-time visibility helps provide accurate information sharing among supply chain members, reduce the Bullwhip effect, achieve just-in-time workflow and minimise inventory costs and errors (Pisello, 2006). Blockchain visibility was shown to assist supermarkets in Kenya lower transport costs, lead times, obsolescence costs, administrative costs and improve purchasing decisions (Makori and Magutu, 2016). According to Silvera (2017), 87% of fast-moving consumer goods of small-medium sized enterprises (SMEs) in London used visibility tools to enhance their SCI. Wamba and Queiroz (2020) conducted a study in the context of the US and India, discovering that blockchain visibility drives SCP. Hence, blockchain visibility can be regarded as an important parameter to achieve high-quality SCP.

3.3 Knowledge asset status

Nonaka *et al.* (2000) explained knowledge asset (KA) as the base or foundation of the knowledge-development process, describing them as "firm-specific resources indispensable for the creation of value for a company". These researchers categorised KA into four categories: experiential knowledge assets, conceptual knowledge assets, routine knowledge assets and systemic knowledge assets. KA forms part of a company's intangible assets and signifies strategic resources and sources of value formation (Schiuma *et al.*, 2012). KA status generally refers to efficiency, particularly in disaster events; the status of assets, including facilities, inventory, equipment and personnel, is crucial towards effective decision-making (Pettit, 2008). However, transforming this status into knowledge requires dissemination to the right people, at the right time and in a form they can accept and use. Therefore, evaluation of KA is critical as workers recognise, define and quantify ideas referring to their KA status (Lerro *et al.*, 2012). As part of blockchain visibility, KA was also discovered to have a positive and significant relationship with SCI and the performance of Malaysian SMEs (Abu Hasan *et al.*, 2020). Thus, the following hypothesis is proposed:

H1. KA status has a positive effect on SCI.

3.4 Information technology

Given the technological advances in the field of IR 4.0, the relationship between blockchain technology and SCP has attracted the increasing interest of researchers. Using technology has allowed several sectors to boost production while using less resources and raw materials (Yeo *et al.*, 2021). Information technology (IT) portrays a vital role in the operations of the supply chain. IT has assisted companies in maximising the amount and complexity of information that needs to be transmitted to their trading partners. Likewise, multinational corporations (MNCs) introduce IT to exchange information and skills across strategic and corporate boundaries. Indeed, IT enables companies to provide real-time supply chain information, including inventory levels, distribution status, production preparation and scheduling, allowing them to monitor and regulate their supply chain activities. Because of blockchain, it is now able to acquire total information performance from the supply chain network and share it with other enterprises (Hong and Hales, 2021). Several researchers in the current literature emphasised that IT usage is a core element for SCI.

Information technology (IT) utilises computerised systems to integrate supply chain operations and provide visibility of internal procedures and processes. In this regard, IT facilitates core processes in the supply chains, including procurement and order execution (Swaminathan and Tayur, 2003). Internal integration involves cross-functional collaborations enabling the organisation to absorb and utilise information to enhance flexibilities. Pettit (2008) asserted that in today's age of electronic data interchange (EDI), radio frequency identification (RFI) and web presence, visibility can successfully stem from various forms of media. With a vast amount of data created in today's enterprises, electronic dissemination, filtering and monitoring can be both rapid and cost-effective.

Kim (2017) compiled surveys from manufacturers in Korea, finding that IT has a positive correlation with SCI and has concluded that IT plays a critical role in SCM. In their most recent paper, Buer *et al.* (2021) surveyed Norwegian manufacturing companies, concluding that both IT and SCI contribute positively towards SCP. Likewise, Vafaei-Zadeh *et al.* (2020) discovered a positive and significant influence between IT and SCI among Malaysian manufacturing companies. Therefore, the following hypothesis is proposed:

H2. IT has a positive effect on SCI.

3.5 Information exchange

Information exchange (IE) is defined as the extent to which information is communicated between the partners in the chain (Vilko, 2012). In facilitating dynamic actions and decision-making, the exchange of adequately high-quality information is critical in the coordination of operations within the supply chain. The study of SCM has directed much attention to knowledge sharing and, more recently, to supply chain exposure. Furthermore, increased access to information improves the capacity of companies to effectively adapt to changes in their business environment (William and Roy, 2013). Information sharing is crucial in maintaining the supply chain's accountability (Panahifar *et al.*, 2018). Moreover, information sharing is seen as the glue that holds together the activities and resources along the supply chain, from the procurement of raw materials to customer services (Holcomb *et al.*, 2011). Ramayah and Omar (2010) asserted that information sharing is a way of increasing approximately 50% SCP. One of the main elements in improving blockchain visibility is via sharing information and knowledge exchange among supply chain affiliates.

Gunasekaran *et al.* (2017) asserted that to share quality and relevant information, organisations should focus on IE and knowledge exchange in order to enhance visibility. Another study reported that information sharing was positive and significant in relation to SCI and SCP of Indonesia's apparel and textile industry (Maulina and Natakusumah, 2020). Likewise, IE was discovered to be relatively significant towards SCI in the automobile sector in Indonesia (Hasibuan *et al.*, 2020). Sharing information significantly increases its power since information reduces uncertainty and buffer to maintain sufficient inventory levels. Therefore, the third hypothesis of this study is proposed to investigate the relationship between IE and SCI:

H3. IE has a positive effect on SCI.

3.6 Business intelligence gathering

Business intelligence (BI) can be viewed as both a process and a product that extends beyond the boundaries of the supply chain. The aim is to incorporate leading indicators of potential developments and to forecast the actions of rivals, manufacturers, consumers, technology, investments, economies, goods and services and the general business climate with a level of certainty (Pettit, 2008). BI can also link the demand for finished goods with the demand for raw materials to lessen the effect of fragmentation created by a lack of correlation between the marketing and manufacturing industries, particularly the actions of rivals or competitors (Liu, 2010). A vast amount of data is generated within the supply chain, which needs to be processed; the greater the volume of data, the greater the level of rivalry. Expectations for quicker execution and decision-making are strong.

In this sense, BI offers organisations the means to achieve success and maintain their supply chain more effectively (Langlois and Chauvel, 2017). Notably, MNCs need to have a greater profile with respect to market intelligence as it encourages quick and efficient decision-making to sustain routine activities, particularly in turbulent times or crises. Based on an extended literature search, it is worth highlighting that little has been studied on the relationship between BI and blockchain visibility and SCI. Consequently, there is a need to undertake further research to acquire further insights into how this area can be enhanced concerning the SCP of semiconductor companies in Malaysia. Therefore, the following hypothesis is proposed:

H4. BI gathering has a positive effect on SCI.

3.7 Supply chain integration

The SCI is a long-term plan for supply chain members; however, each member of the supply chain has distinct objectives due to their corporate goals, competitive policies, business procedures and contingencies within their respective business environments (Wang *et al.*, 2016). SCI is mainly concerned with designing more efficient solutions to remove inefficiencies due to supply chain fragmentation and underscores connecting each organisation with logistics and information communications (Evangelista *et al.*, 2012). Supply chain integration (SCI) has gotten a lot of attention from academics and practitioners in recent years, and it's been identified as a powerful tool for improving performance (Zhang *et al.*, 2019). Many studies previously have typically shown that close and cohesive supply chain alliances are a way of achieving improved organisational and operational performance (Vafaei-Zadeh *et al.*, 2020). According to Kim (2006), in order to measure the construct, the following can be measured: the level of the company's integration with suppliers, the level of cross-functional integration within a company and the level of its integration with customers. Although, the literature in this field suggests that the relationship between SCI and SCP is not always constant and relies on the organisational structure of interconnected components.

SCI functions at a strategic level for the interactive relationship between corporates and draws benefits to SCP from the perspectives of cost, quality, flexibility and delivery performance (Kim, 2006). According to Chen *et al.* (2009), SCI improves supply chain capabilities and brings improvements to SCP. Similarly, as suggested by Silvera (2017), the integration of the supply chain can enhance SCP, such as on-time delivery for fast-moving consumer goods (MMCGs) of SMEs in London. Likewise, Kumar *et al.* (2017a) indicated that improving SCI is positively linked to the SCP of UK manufacturers in the food industry. Similarly, Delic *et al.* (2019) contended that SCI has a positive and statistically significant influence on the automotive industry's SCP of automotive manufacturers in the European Union (EU). Therefore, the following hypothesis is proposed:

H5. SCI has a positive effect on SCP.

3.8 Supply chain integration as a mediator

Today's competitive semiconductor business has encouraged companies to increase their performance by integrating the supply chain. SCI is viewed as a process of redefining and connecting supply chain members through coordinating or sharing information and resources (Katunzi, 2011). Moreover, proper guidance and strategies for managing information and sharing the data can significantly enhance the overall performance levels. Previous studies have proven that SCI has a mediating effect in connecting an organisation's blockchain visibility with organisational performance (Imran Hanif *et al.*, 2018). Another study by Hasibuan *et al.* (2020) reported that SCI mediates the relationship between blockchain visibility incorporating IE and SCP in Indonesia's automotive sector.

Furthermore, SCI has a mediating role between blockchain visibility and SCP in the Iranian pistachio industry (Imran Hanif *et al.*, 2018). According to Wei and Wang's (2010) study, blockchain visibility is vital for integrating supply chain processes to achieving greater SCP. Similarly, Silvera (2017) asserted that SCI internally and externally through one of blockchain visibility features, IE, could improve SCP. Blockchain visibility features inspire organisations to develop their supply chain structure to enhance their SCI, while improving SCP (Jajja *et al.*, 2018). Hence, this study preconceives SCI as coordinating inter and intra-organisational activities to acquire efficient and effective information flow, services, products, funds and decisions to swiftly bring out the best value for customers at the lowest costs. As such, SCI's mediating role in the relationship between blockchain visibility (comprising KA status, IT, IE, BI gathering) and SCP is anticipated.

Therefore, the following hypotheses are proposed:

H6. SCI mediates the relationship between KA status and SCP.

H7. SCI mediates the relationship between IT and SCP.

H8. SCI mediates the relationship between IE and SCP.

H9. SCI mediates the relationship between BI gathering and SCP.

Figure 1 presents the research model used in this study based on the literature review and hypotheses developed.

4. Methodology

4.1 Research design

This study applied a non-probability convenience sampling technique. The questionnaire developed in this study was adapted from a previous study, making several amendments to suit the context of the current study. Several filtering questions were formulated specifically for respondents (operation manager/supply chain manager/manufacturing manager) who represented organisations that actively used blockchain technology or partially

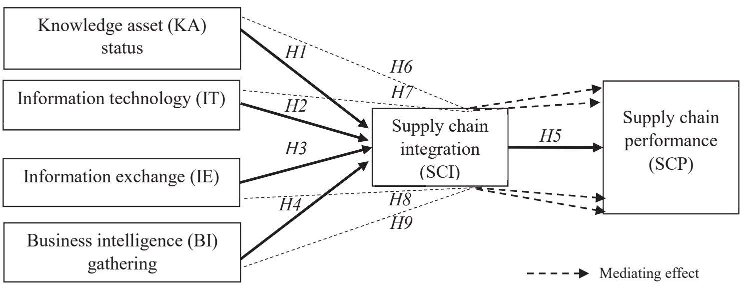

Figure 1.
Research model

incorporated blockchain functionality. The target respondents represented supply chain managers of blockchain adopted semiconductor companies in Malaysia. The Electrical and Electronics (E&E) industry in Malaysia is one of the most significant contributors to economic growth.

As positioned predominantly within the semiconductor industry, this sector is critical for cross-industry linkages and applications, thereby facilitating telecommunication technology development, medical devices development and Internet-capable industrial technologies. In order to design and validate the questionnaire, the study benefitted from undertaking the literature review to identify the measurement scale used in previous studies and some of the factors identified earlier. A total of 57 items were identified and utilised for this research. The four dimensions of blockchain visibility: knowledge asset (KA) status, information technology (IT), information exchange (IE) and business intelligence (BI) gathering were measured using 21 items adapted from Ahimbisibwe *et al.* (2016). Based on the work of Kim (2006), 21 items were also adapted for assessing the respondents' understanding of the integration level of the company with suppliers, the level of cross-functional integration within a company, and the level of integration with customers. All measurement items for blockchain visibility and SCI were based on a five-point Likert scale ranging from 1 = "Strongly Disagree" to 5 = "Strongly Disagree".

Additionally, the responses to the measurement of items for SCI were measured based on a well-established seven-point Likert-type scale ranging from 1 = "Extremely low" to 7 = "Extremely high". The measurement items are depicted in Table 1. The questionnaire was prepared in an electronic form, where the link to the e-form was emailed to the supply chain managers of the respective semiconductor companies. Hair *et al.* (2011) suggested using a rule of thumb for model evaluation. The sample size is determined as 10-fold the largest number of structural paths directed at a particular construct in the structural model. Thus, the minimum sample size required for this study was 40.

4.2 Statistical analysis technique

The data collected and compiled in this study were analysed using two statistical software applications. First, in analysing the demographic data, the Statistical Package for Social Science (SPSS) version 3.2.9 was used. Next, to analyse the convergence validity, discriminant validity, the relationship between the variables and the Importance-Performance Matrix Analysis (IPMA) Partial Least Square Structural Equation Modelling (PLS-SEM) version 3.2.9. was used.

5. Results

5.1 Demographic

The sample used in this study represented 71 valid responses received from the 96 companies who participated in this study, reflecting a response rate of 73.96%. Table 2 presents the companies' profile, and Table 3 summarises the demographic profile of the participating companies. Most companies were foreign-owned MNCs (90.10%), with 9.90% from the Sendirian Berhad (Sdn Bhd). Considering the number of employees in the companies, 50.7% of respondents were from a company having more than 500 employees. Of the 71 respondents, 52.1% were male and 47.9% were female. Only 21.13% of respondents had five (5) years or less working experience, with the majority (45.07%) having 10 years or above working experience. The current positions held by the respondents ranged from Section Head (57.7%) with 14.1% holding a position as a Manager.

Regarding non-bias responses, the sample consisting of blockchain visibility, SCI and SCP items between early and late responses were compared. The analysis showed that the mean

Constructs	Indicators	Source
Knowledge asset (KA) status	SCVK1–Our firm has real-time data on the location and status of supplies, finished goods, equipment and employees SCVK2–Our firm has regular interchange of information among supplies, customers and other external sources SCVK3–Our firm has effective business intelligence gathering programs SCVK4–Our firm has detailed contingency plans and regularly conduct preparedness exercises and readiness inspections SCVK5–Our firm has order status tracking SCVK6–Our firm has knowledge of distribution centre stock levels SCVK7–Our firm has knowledge of product orders SCVK8–Our firm has inbound shipment from suppliers SCVK9–Our firm has knowledge of suppliers finished goods inventory SCVK10–Our firm has adequate ability to share information externally SCVK11–Our firm has adequate ability to share customised information externally	Ahimbisibwe *et al.* (2016)
Information technology (IT)	SCVT1–Our firm has information systems that accurately track all operations SCVT2–Our firm has knowledge of suppliers order status information SCVT3–Our firm has knowledge of customer demand forecasts SCVT4–The information available in our firm is accurate SCVT5–Our firm has adequate ability to share information externally with key suppliers	Ahimbisibwe *et al.* (2016)
Information exchange (IE)	SCVE1–Our firm effectively shares operational information between departments SCVE2–Our firm effectively share operational information externally with selected suppliers SCVE3–Logistics databases are integrated across applications within our firm	Ahimbisibwe *et al.* (2016)
Business intelligence (BI) gathering	SCVB1–Logistics information systems in our firm are being extended to include more integrated applications SCVB2–Our firm's logistics information systems capture and maintain timely data	Ahimbisibwe *et al.* (2016)
Supply chain integration (SCI)	SCI1–Information exchange with suppliers through IT SCI2–The level of a strategic partnership with suppliers SCI3–The participation level of suppliers in the design stage SCI4–The participation level of suppliers in the process of procurement and production SCI5–The establishment of a quick ordering system SCI6–Stable procurement through a network SCI7–Data integration among internal functions through a network SCI8–Systematic IS integration among internal functions SCI9–Real-time searching of the level of inventory SCI10–Real-time searching of logistics-related operating data SCI11–Data integration in the production process SCI12–Integrative inventory management SCI13–Systematic interaction system between production and sales SCI14–Periodic interdepartmental meetings among internal function SCI15–Follow-up with customers for feedback SCI16–The level of computerisation for customer ordering SCI17–The level of organic linkage with customers by network SCI18–The level of sharing on market information SCI19–The agility of the ordering process SCI20–The frequency of periodical contacts with customers SCI21–The level of communication with customers	Kim (2006)
Supply chain performance (SCP)	SCP1–Our firm improved product variety SCP2–Our firm improved the adjustment of the capacity SCP3–Our firm improved the volume changes SCP4–Our firm improved product features SCP5–Our firm improved product mix SCP6–Our firm improved the rapid design changes SCP7–Our firm improved the response time to demand changes SCP8–Our firm delivered the kind of products needed SCP9–Our firm improved speed of delivery relative to competitors SCP10–Our firm improved the accuracy of the predictability of delivery dates SCP11–Our firm reduced the unit cost of the product over the life cycle SCP12–Our firm reduced the production cost per unit SCP13–Our firm reduced inventory cost SCP14–Our firm improved labour productivity SCP15–Our firm improved capacity utilisation	Foo and Zailani (2012)

Table 1.
Measurement items of the study

levels for early responses were consistently lower than late responses, with differences ranging from a low of 0.10 to a high of 0.24. Overall, there was only a slight variation in BI gathering, IE, IT, KA status, SCI and SCP between the early and late responses. Therefore, the sample was representative of the population of interest. The slight difference regarding size may be statistically significant, having an impact on the inference.

5.2 Measurement model evaluation

The framework of this study includes four reflective constructs: BI gathering, IE, IT and KA status, SCI and SCP. In order to assess the measurement model, the reliability, convergent validity and discriminating validity of these reflective constructs were checked. Table 4 shows the assessment results of the measurement model, indicating adequate reliability. The average variance extracted (AVE) for all constructs was higher than 0.5, indicating acceptable convergent validity for the constructs (Hair *et al.*, 2019).

The reliability of the construct measurement was assessed by examining composite reliability, as suggested by Gefen *et al.* (2011). Table 4 shows that the composite reliability exceeded the benchmark value of 0.70, thus demonstrating construct reliability. Convergent validity was established for all the constructs since the AVE met the suggested threshold of 0.50. Next, discriminant validity was assessed based on heterotrait-monotrait (HTMT) (Henseler *et al.*, 2015). As proposed by scholars, the acceptable HTMT values (Table 5) should be lower than either 0.85 or 0.90 (Henseler *et al.*, 2015); this study adopted the more rigorous

Variable	Frequency	Percentage
Type of company		
Multinational corporations (MNCs) – foreign company	64	90.10%
Sendirian Berhad (Sdn Bhd) – local owned	7	9.90%
Number of employees in the company		
101–500	35	49.30%
>500	36	50.70%

Table 2. Companies' demographic profile

Respondent's demographic	Frequency	Percentage
Gender		
Male	37	52.10%
Female	34	47.90%
Education level		
Higher diploma/Bachelor's Degree	57	80.30%
Master's Degree	14	19.70%
Years of working experience		
5 years and below	15	21.13%
6–10 years	32	45.07%
10 years and above	24	33.80%
Current position level in the company		
Section head	41	57.70%
Manager	10	14.10%
Senior manager	16	22.50%
Director	4	5.60%

Table 3. Respondent's demographic profile ($n = 71$)

Variables	Label	Loadings	CR	Cronbach's alpha	rho_*A*	AVE
Knowledge asset (KA) status	SCVK03	0.717	0.886	0.85	0.852	0.528
	SCVK04	0.742				
	SCVK05	0.743				
	SCVK08	0.707				
	SCVK09	0.677				
	SCVK10	0.701				
	SCVK11	0.793				
Information technology (IT)	SCVT01	0.718	0.876	0.826	0.885	0.589
	SCVT02	0.839				
	SCVT03	0.676				
	SCVT04	0.708				
	SCVT05	0.877				
Information exchange (IE)	SCVE02	0.947	0.875	0.737	0.924	0.779
	SCVE03	0.814				
Business intelligence (BI) gathering	SCVB01	0.752	0.800	0.514	0.548	0.668
	SCVB02	0.879				
Supply chain integration (SCI)	SCI01	0.732	0.966	0.963	0.967	0.576
	SCI02	0.771				
	SCI03	0.664				
	SCI04	0.636				
	SCI05	0.682				
	SCI06	0.661				
	SCI07	0.786				
	SCI08	0.801				
	SCI09	0.849				
	SCI10	0.859				
	SCI11	0.821				
	SCI12	0.758				
	SCI13	0.746				
	SCI14	0.829				
	SCI15	0.708				
	SCI16	0.780				
	SCI17	0.669				
	SCI18	0.740				
	SCI19	0.743				
	SCI20	0.849				
	SCI21	0.802				
Supply chain performance (SCP)	SCP02	0.602	0.923	0.909	0.919	0.502
	SCP03	0.745				
	SCP04	0.692				
	SCP05	0.678				
	SCP06	0.677				
	SCP07	0.782				
	SCP08	0.654				
	SCP09	0.793				
	SCP10	0.783				
	SCP13	0.830				
	SCP14	0.572				
	SCP15	0.647				

Table 4. Measurement items of the study

HTMT 0.90. Together, these outcomes indicated that common method bias was not a threat to the current study. As in the measurement model (Figure 2), the R^2 in the model showed a high value of 0.602 for the endogenous constructs of SCP, suggesting that 60.2% of the variance in SCP for semiconductor companies in Malaysia.

Table 5.
Discriminant validity: HMTM

	SCVB	SCVE	SCVT	SCVK	SCI	SCP
SCVB						
SCVE	0.612					
SCVT	0.706	0.837				
SCVK	0.825	0.776	0.864			
SCI	0.793	0.656	0.595	0.842		
SCP	0.773	0.698	0.549	0.795	0.801	

Note(s): SCVB = Business Intelligence Gathering, SCVE = Information Exchange, SCVT = Information Technology, SCVK = Knowledge Asset Status, SCI = Supply Chain Integration, SCP = Supply Chain Performance

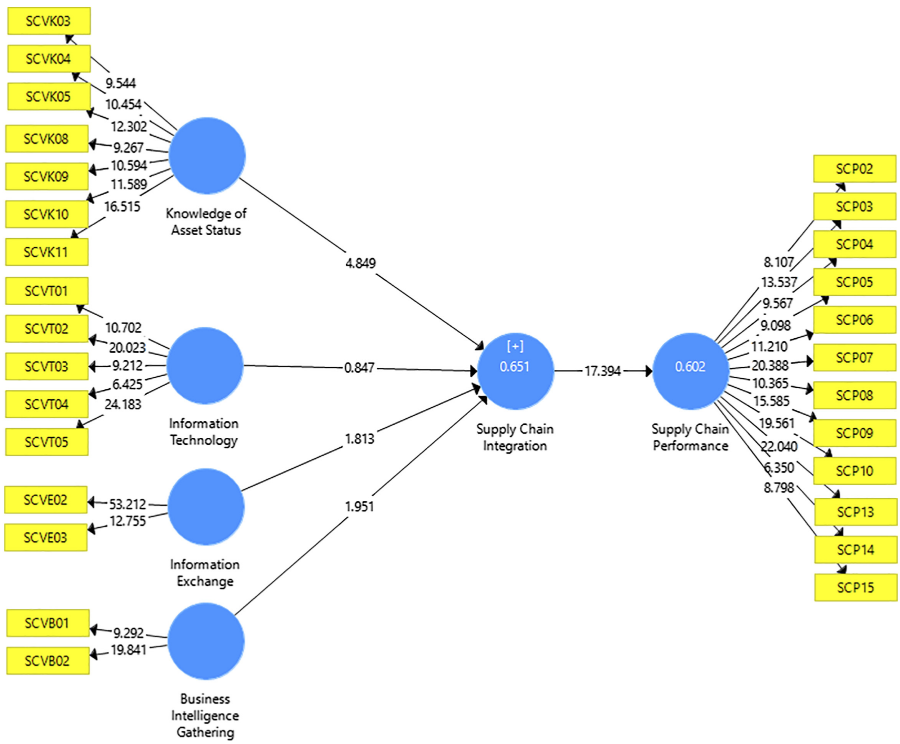

Figure 2.
Measurement model

5.3 Structural model evaluation

The structural model represents the relationships between the constructs or latent variables hypothesised in the research model. The bootstrapping analysis was performed on 5,000 subsamples to test the regression coefficients' significance, applied to determine if the proposed hypotheses were significant or otherwise. After computing the path estimates in the structural model, a bootstrap analysis was performed to assess the path coefficients' statistical significance. From the initial set of paths, three were significant at a 0.99 level (1%), four were significant at a 0.95 level (5%), and the remaining few were not significant (Table 6). Interestingly, the data revealed a significant correlation between the blockchain visibility of BI gathering, IE and KA status on SCI, and the statistical results rendering support for all the hypotheses; H1 ($\beta = 0.213, p < 0.05$), H2 ($\beta = 0.208, p < 0.05$), H4 ($\beta = 0.632, p < 0.01$) with BI gathering the strongest predictor of SCI. Furthermore, supply chain integration (H5: $\beta = 0.776$ and $t = 17.394$*) had a positive and significant effect on SCP, while SCI (H5: $\beta = 0.084$ and $t = 0.740$) did not mediate the relationship between IT and SCP.

5.4 The importance-performance matrix analysis (IPMA) results

The Importance-performance matrix analysis (IPMA) of the path modelling for SCP was next performed, considering each latent variable's performance against a scale ranging from 0 to 100. Here, the total effects of the relationships of all other constructs would indicate the importance of each latent variable. The IPMA results indicated the areas of the model that required improvement and further development (Hock *et al.*, 2010). The areas having relatively high importance and relatively low performance are where management should pay strict attention (Hair *et al.*, 2014). IPMA can likewise be explained using a four-quadrant diagram, as shown in Figure 3, with the horizontal axis signifying the importance level, while the vertical axis represents the performance. The four quadrants are separated as QI (Keep up the good work), QII (Possibly overkill), QIII (Low priority) and QIV (Concentrate here). The quadrants were used to measure the importance and performance of the latent exogenous variables of blockchain visibility (KA status, IT, IE, BI gathering) on the endogenous variables (SCI, SCP). The results are reflected in Table 7.

In presenting the findings of this study more precisely, IPMA was performed. The IPMA results for the endogenous variable of SCP are shown in Figure 4 below. Based on the IPMA map, the blockchain visibility elements, KA status appears more important than BI gathering, IE and IT for the SCP. It implies that with a one-point increase in KA status, the SCP is expected to increase by 0.500 of the total effect, while BI gathering will increase the performance of SCP with the value of 0.164. It was also observed that of all the blockchain visibility dimensions analysed, IT has the highest level of performance (81.207), although it has a low level of importance (−0.101). The results suggest that there could be due to lack of proper implementation of the IT system among the semiconductor companies in relevance to the supply chain performance in the era of digital transformation.

Hypotheses	Path	Std Beta	Std error	*t*-value	Confidence Interval (95%) bias corrected	Supported
H1	BI gathering → SCI	0.213	0.109	1.951*	[0.067, 0.412]	Yes
H2	IE → SCI	0.208	0.115	1.813*	[−0.014, 0.364]	Yes
H3	IT → SCI	−0.151	0.178	0.847	[−0.432, 0.161]	No
H4	KA status → SCI	0.632	0.130	4.849**	[0.438, 0.840]	Yes
H5	SCI → SCP	0.776	0.045	17.394**	[0.683, 0.834]	Yes
H6	KA status → SCI → SCP	0.490	0.107	4.573**	[0.311, 0.667]	Yes
H7	IT → SCI → SCP	−0.117	0.141	0.832	[−0.321, 0.132]	No
H8	IE → SCI → SCP	0.161	0.092	1.744*	[−0.011, 0.291]	Yes
H9	BI gathering → SCI → SCP	0.166	0.086	1.932*	[0.050, 0.325]	Yes

Note(s): ** $p < 0.01$; * $p < 0.05$

Table 6. Results of hypotheses testing

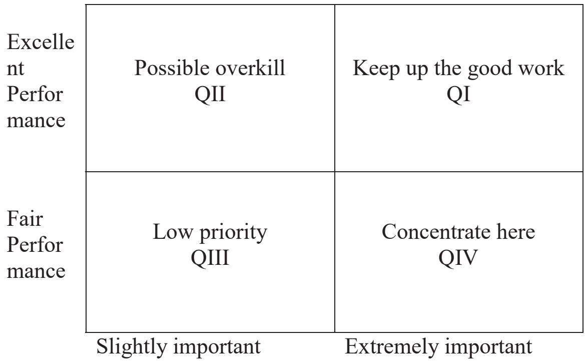

Figure 3.
IPMA four quadrants diagram

Table 7.
Importance-performance matrix analysis (IPMA) results for supply chain performance

Latent variable	Supply chain performance Direct effect (importance)	Index value (performance)
Business Intelligence gathering	0.164	51.372
Information exchange	0.128	70.231
Information Technology	−0.101	81.207
Knowledge asset status	0.500	73.456

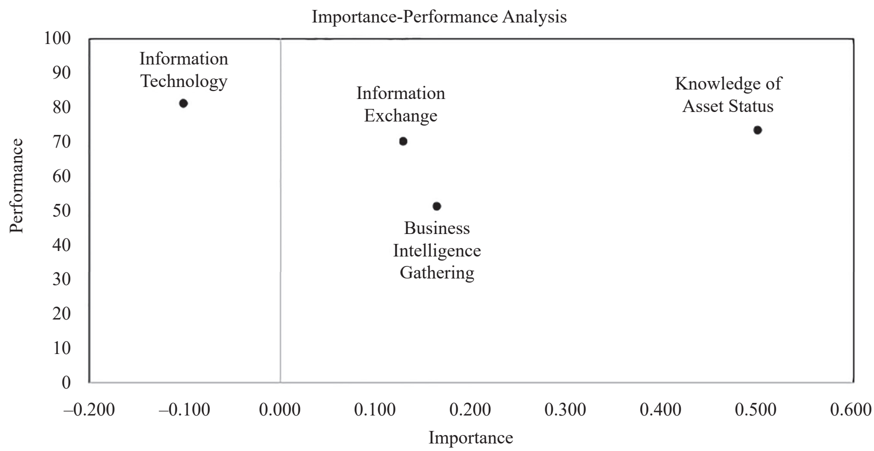

Figure 4.
IPMA for supply chain performance

6. Discussion

The R-square value of 0.602 indicated that the present model's factors could explain 60.2% of SCP variance. Thus, the research model demonstrated an appreciable explanatory power that could serve as a robust framework for investigating SCP in the subject area of blockchain visibility in the future. The following paragraphs discuss the implication of the findings of this study.

Three blockchain visibility elements show a high significance and positive influence on SCI and SCP, indicating that blockchain technology can significantly improve SCI. Therefore, blockchain adopters should highlight this since the IPMA model results also support that this area has the highest level of importance. This finding aligns with Makori and Magutu's (2016) study regarding the accuracy and real-time blockchain visibility to improve inventory forecasting, manage just-in-time workflow, eliminate high inventory costs and minimise inventory errors.

On the other hand, BI gathering appeared to be a potential factor leading to SCI. These results imply that the more extensive or widespread BI in semiconductor companies, the more extensive SCI and SCP can be attained. This finding is consistent with previous studies on SCM (Langlois and Chauvel, 2017). However, the main difference between this present study and past research is that the present study focused on the importance of BI gathering as a part of blockchain visibility for semiconductor companies in Malaysia. Though having said that BI gathering is not widely explored by many researchers nowadays. Accordingly, the findings of this study will offer further insight into how this area can further enhance the SCP of semiconductor companies in Malaysia. The extent of information exchange in the supply chain may be influenced by the confidentiality or privacy of the information. Our findings here echo more general observations by Maulina and Natakusumah (2020) that have shown that IE is a direct consequence of SCI. Similar result was obtained by Omar *et al.* (2010), who found that IE among supply chain partners may also have an effect on supply chain integration.

Notably, the results also revealed that KA status was significantly stronger than the other factors, demonstrating that KA status emerged as a crucial element of blockchain visibility in influencing SCI and achieving SCP. This finding is in line with Abu Hasan *et al.* (2020) that there is a positive and significant relationship between SCI and the performance of Malaysian SMEs. In the similar vein, Lin (2017) found a significant positive effect of KA status in influencing SCI. This result indicates that KA status has emerged as one of the key elements under blockchain visibility in enabling the companies to remain competitive in the SCN.

Accordingly, the finding of this study aligns with that of Wade and Hulland (2004), where no or even a negative correlation was found between IT and SCP. On the other hand, the results of this differ from previous studies, such as Buer *et al.* (2021), concluding that both IT and SCI contribute positively towards SCP and that of Vafaei-Zadeh *et al.* (2020), where IT seems to be a crucial element to various aspects of SCM among SMEs. Importantly, this study found significant positive influences from SCI to SCP, which aligns with the study by Delic *et al.* (2019), stating that SCI would improve supply chain capabilities and bring improvements to SCP. The results also show that SCI mediates the relationship between blockchain visibility and SCP, which is consistent with Kumar *et al.* (2017a) study where visibility will ease integration and improve SCP.

7. Theoretical and managerial implications

7.1 Theoretical implications

From a theoretical perspective, the findings of this study extend the present literature on the semiconductor industry in Malaysia by examining the influence of blockchain visibility as the predecessor for SCI and the impact on SCP in the era of DT. Specifically, BI, IE and KA have, significantly, a positive effect on SCI. While this study examined the influence of blockchain visibility as the predecessor for SCI and its impact on SCP, it also tested the mediating effect of SCI between blockchain visibility and SCP. Resource-Based Theory (RBT) and Network Theory were applied as a theoretical lens to develop the research model. RBT dominated SCI while analysing the supply chain and examining the supply chain's activities collectively and individually (Williams *et al.*, 2002). Operation management activities within companies along the supply chain also require a unique set of resources and capabilities to accomplish the mission, creating a competitive advantage. However, the findings partially support the assumptions made in this study. It was observed that BI gathering, IE and KA status strongly influence SCI, which affect SCP. SCI was also shown to have an intervening effect on the relationships between BI gathering-SCP, IT-SCP and KA status-SCP. Surprisingly, the IT had no direct effect on SCI. Instead, the findings indicate that SCI does not mediate IT or the relationship with SCP. Overall, this research suggests a new conception of the anticipatory link among blockchain visibility, SCI and SCP. Indeed, the findings reveal an underlying issue regarding IT that should be considered in future. For instance, manufacturers are pressured or forced to make significant investments in IT, upgrading their current IT systems in order to remain competitive. Therefore, further research is required to understand better other blockchain features that may benefit the semiconductor industry in Malaysia.

7.2 Managerial implications

This research additionally provides valuable insights into challenges faced with blockchain visibility, particularly in Malaysia's semiconductor companies. By offering further insights and understanding on the relationship between blockchain visibility, SCI and SCP in the era of DT, this study helps managers to appreciate this critical feature in solving inherent problems that require effective decision-making in semiconductor companies. It also provides a better understanding of the strategies management may wish to introduce to improve SCP by introducing and implementing blockchain technology. On the other hand, this research demonstrates that IT, as one of the blockchain visibility features, may be the biggest challenge or barrier for semiconductor companies in achieving SCP. This could be due to the high complexity and compatibility issues of advanced IT commonly adopted in the semiconductor industry, dramatically challenging SCI. Therefore, companies should continuously support blockchain technology and its application in OSCM in the semiconductor industry.

Furthermore, based on the IMPA results, KA was the most important factor influencing SCP. It implies that with a one-point increase in KA status, SCP is expected to increase by 0.500 of the total effect. Therefore, this study suggests that semiconductor companies should have structured strategic resources and value formation sources to achieve a higher level of KA. Managers must understand the knowledge acquired within the company and manage this asset to support the success and competitiveness of the company. Moreover, for companies to safeguard the information flow and sharing of knowledge, they need to distinctly understand the nature and benefits of information sharing for operational processes. Although blockchain technology is not widely implemented within supply chains, those semiconductor companies looking to enhance end-to-end visibility should consider this form of technology. Blockchain visibility could empower SCI and provide managers with a window of opportunity into customer needs by gathering BI associated with products in possession of end-users. Companies should also extend their effort to upskill the knowledge assets to attain a better link between blockchain visibility, SCI and SCP.

8. Conclusion, limitations and directions for future research

This study examines the relationships between blockchain visibility, SCI and SCP in the era of DT in Malaysia's semiconductor industry to shed light on this emerging area. The result shows that BI gathering is the strongest predictor for SCI, thus leading to improvement of SCP. The commonly used RBT and Network Theory were proved to be suitable for examining blockchain visibility, SCI and SCP in the era of DT. The proposed model was evaluated using the PLS-SEM technique, and it adequately explained the SCP in Malaysia's semiconductor industry (60.2%). Additionally, current research reveals that the blockchain visibility of BI gathering, IE and KA status positively influence SCI, but not for IT. Furthermore, supply chain integration has a positive effect on SCP, while SCI did not mediate the relationship between IT and SCP.

Despite addressing the research questions in this study, several limitations were noted that could have resulted in a different outcome. First, the sample size was very small, and most respondents originated from large MNCs. Therefore, the findings cannot be generalised to all semiconductor companies since there are many SME companies in Malaysia. Second, the concept of integrating blockchain technology into SCM remains relatively limited and at an introductory stage; in fact, most of the middle-level managers in this study were not aware of it. Thus, their understanding may have been limited in answering the items presented in the questionnaire, thus resulting in an inaccurate analysis of the data combined with the low sample size issue, as noted above.

Third, this study was conducted based on data collected in a relatively short period, which means that the results may not be replicated if the study was undertaken over a more extended period. Thus, future research should identify more companies that have adopted blockchain technology in their SCM processes or expand the coverage area of the study, including the entire Southeast Asia semiconductor industry, to obtain a larger sample size. Future research could also investigate other application areas (such as fraud prevention, transaction automation) or include other variables (such as inventory performance, R&D performance). Lastly, the authors recommend that future research consider a qualitative study such as conducting interviews and focus groups where the outcomes could help triangulate and potentially provide further support and shed light on the findings from the SEM model.

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