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Supply Chain Visibility: A Theoretical Framework

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Abstract

The concept of supply chain visibility has provided a great number of pivotal contributions to supply chains such as dealing with crises more comfortably, exceptional appraising risks in disruptions, raising flexibility and performance, creating more resilient supply chains and enabling sustainability; hence, it is accepted as a dynamic competence that critically affects the achievement of supply chain management in the digital transformation era. Although supply chain visibility is crucial to enable and enhance visibility, there is no universally accepted definition. It has been defined by different researchers, emphasising its various features. Therefore, understanding, measuring and improving it is quite difficult. This study aims to create a broad theoretical framework for the supply chain visibility concept. In this direction, its definitions were gathered under a single roof and their dimensionality in the literature was presented. The study guided for companies and supply chains aiming to ensure and enhance their visibility. Additionally, it uncovered the contributions of the Fourth Industrial Revolution technologies to visibility. Companies and their supply chains can have superior visibility by utilising them. The study ended with the appraisal of the findings.

Keywords: Supply chain visibility, The Fourth Industrial Revolution, Technology

1. Introduction

Supply chain management (SCM) is a notion that came out at the end of the 1980s, was extensively used in the 1990s, and has become more crucial recently (Hugos, 2018). Nowadays, competition does not occur among companies, but among the supply chains (SCs) of which they are members (Bowersox, 1997; Christopher & Towill, 2001). The most appropriate approaches and solutions for SCM have altered in line with the prevailing era and situation (Christopher, 2021). The concept of supply chain visibility (SCV) has attracted more attention from practitioners and researchers in recent years (Catalayud et al., 2019), and is a critical issue for SCM (Francis, 2008, p. 181). It is accepted as a dynamic capability for today's contemporary SCs (Lambourdière et al., 2022, p. 420).

The COVID-19 pandemic has demonstrated that enabling end-to-end visibility of SCs contributes to dealing with possible disruptions or risks in the SC more flexibly and efficiently (Ivanov, 2022, p. 455). The higher the visibility, the easier it is to monitor the operational status of the SCs. Moreover, SCs have become more efficient and effective thanks to higher visibility. The importance of SCV has become better comprehended, especially in the last four years, with this pandemic (KPMG, 2020, p. 9). SCV provides a better assessment of risks in the event of a disruption, quicker response, enhanced SC resilience and easier coping with future crises (Barriball et al., 2020; Finkenstadt & Handfield, 2021, p. 1; Hendricks & Singhal, 2012, p. 2).

The benefits of visibility to SCs are not limited to the benefits it provides in a disruption. End-to-end visibility ensures timely, accurate, and complete access to information, events, and data in the SCs. Moreover, it contributes to the efficient planning and conducting of SC operations (Pagano & Liotine, 2020, p. 9). It reduces the bullwhip effect in the SC by enabling complete and timely sharing of information (Lee et al., 1997, p. 546). It also lessens uncertainty and enhances coordination and customer satisfaction (Roy, 2021, p. 943). Moreover, it improves prediction and optimization ability as well as raises critical decision-making accuracy (Busse et al., 2017, p. 19; Modgil et al., 2022, p. 1248). It allows them to respond flexibly and quickly to alterations in the industry (Lummus et al., 2005, p. 2688). It simplifies SCM (Li et al., 2017, p. 377) and it ensures that higher supply chain performance (SCP) is achieved thanks to all these contributions (Kähkönen et al., 2023, p. 2697).

SCV has been described in various ways by different researchers, emphasising various characteristics of the information and process until today; therefore, it does not have a generally accepted definition (Özkanlısoy & Bulutlar, 2023, p. 386). According to the definition of Barratt & Oke (2007), it is the degree to which SC members share or access information that they deem crucial and that they think will be reciprocally beneficial. According to Wei & Wang (2007), it is the grade to which SC members have knowledge with regard to demand and supply to plan. Goh et al. (2009) defined the notion as the capability to see or reach convenient data or information. According to Williams et al. (2013), it is to achieve superior quality information over both supply and demand. When the descriptions in the prevailing literature are examined, it is obvious that the notion of SCV is explained by highlighting its various properties of SCV (Özkanlısoy & Bulutlar, 2022, p. 386).

From a general perspective, the key to survival depends on adapting to alteration. (Megginson, 1963) and this is also valid in the SC context. SCs must adapt to changes occurring in the business environment and beyond (Ruel et al., 2021, p.2). Ensuring and improving visibility is one of the current requirements of SCs. This study aims to examine elaborately the concept of SC, which is frequently handled today, to enable broader conceptual comprehension and a greater awareness of its contributions. Furthermore, another purpose of the study is to present the contributions of novel technologies called 4IR technologies to visibility and to ensure that SCs can achieve superior visibility by utilising the right technologies.

This study is composed of five main sections: Section 2 discussed the concept of SCV regarding its extant descriptions, contributions and dimensions. Section 3 investigated the effects of novel technologies on ensuring and enhancing SCV. The results are discussed in Section 4 and the study ends with the evolution of main insights.

2. Supply Chain Visibility (SCV)

2.1. Conceptual Framework

SCV is a complex issue involving information flow, processes, technology, and people. It is about the ability to collect and analyse distributed data, create custom recommendations, and match insights with strategy (Tohamy et al., 2003). The concept has been defined by various researchers by considering its various characteristics and there is no generally accepted definition in the literature. Some of the definitions in the extant literature are illustrated in Table 1 below:

Table 1: The Extant Definitions of SCV

Author(s)	Definition	Focus Point
Schoenthaler (2003)	"*Important information is readily available to those who need it, inside and outside the organisation, for monitoring, controlling, and changing SC strategy and operations, from service acquisitions to delivery.*" (p. 12)	Monitoring, controlling, and changing strategy and operations
Tohamy et al. (2003)	*"Capturing and analysing SC data that informs decision-making, mitigates risk, and improves processes."*	Collecting and analysing information that benefits the SC
McCrea (2005)	*"The ability to be alerted to exceptions in SC execution, and to enable action based on this information."* (p. 58)	Execution of the SC
Barratt & Oke (2007)	*"The degree to which SC members share or access information that they deem significant and that they think will be mutually beneficial."* (p. 1218)	The amount of useful information shared
Wei & Wang (2007)	*"The degree to which SC members have information regarding demand and supply in order to plan."* (p.1)	Degree of information
Francis (2008)	*"The identity, location and status of entities transiting the supply chain."* (p. 182)	Contents of information
Goh et al. (2009)	*"The capability to see or reach appropriate data or knowledge."* (p. 2546)	Availability and access to information
Williams et al. (2013)	*"To reach high-quality information about both demand and supply."* (p. 553)	Reaching high-quality information
Klueber & O'Keefe (2013)	*"The ability to provide and access information elements at a level chosen by the relevant supply chain stakeholders."* (p. 300)	Enabling and accessing of information elements
Baah et al. (2022)	*"The ability to access information within the supply chain and use this information in real-time."* (p. 435)	Access and use of real-time information

Source: Author.

2.2. The Main Contributions of SCV

The reason for the enhanced interest in SCV in recent years is undoubtedly not only the COVID-19 pandemic. The pandemic has only brought greater awareness of its growing significance and its numerous benefits to SCs (Kalaiarasan et al., 2022, p 2). The concept of SCV is recognized as a dynamic capability that vitally affects the success of SCM in the current era (Lambourdière et al., 2022, p. 420). Some of the main contributions of SCV to SCM are given in Table 2 below:

Table 2: The Main Contributions of SCV

Author(s)	Contribution of SCV
Hendricks & Singhal (2012)	Enabling better appraisement of risks and quicker response in the event of SC disruption
Finkenstadt & Handfield (2021)	Coping with future crises more easily

Barriball et al. (2020)	Boosting resilience and prohibiting disruptions in SCs
Roy (2021)	Lessening uncertainty, enhancing coordination and customer satisfaction
Holcomb et al. (2011)	Enabling effective and efficient control and management of SCM processes
Modgil et al. (2022)	Ensuring critical decision-making accuracy during special periods such as the pandemic
Lee et al. (1997)	Lessening the bullwhip effect by ensuring timely sharing of information
Lummus et al. (2005)	Enabling to respond more quickly and flexibly to alterations in the industry
Busse et al. (2017)	Improving the forecasting and optimization capability of the SC
Wei & Wang (2010), Li et al. (2017)	Enabling SC reconfigurability and facilitating SCM
Kähkönen et al., 2023, p. 2697; Kalaiarasan et al., 2023, p. 5228	Positive impact on supply chain performance.

Source: Author.

The aforementioned contributions are the most highlighted contributions of SCV in the extant literature. As a sub-contribution of them, SCV has also significant contributions to lessening distribution costs, inventory holding costs and total cost, improving service level and delivery performance, and enhancing product availability and quality (Caridi et al., 2010, p. 596; Vilko et al., 2019, p. 471). Conversely, having a low SCV can result in estimation errors, a bullwhip effect, incorrect stock information, and having to work with incomplete, inaccurate, or outdated information. Moreover, there may be delays in deliveries, resulting in reduced productivity and revenue (Yu & Goh, 2014, p. 126).

SCV is also explained as the ability to perform forward and reverse monitoring of raw materials, sub-assemblies, or ultimate goods throughout the SC (Mubarik et al., 2021, p. 2). It is important for ensuring SC resilience as it enables the ability to respond quickly to alteration and disruptions, better understand SC relationships, and lessen the complexity of SC relationships (Dubey et al., 2020, p. 3382). There has been a significant enhancement in the number of studies on SC traceability due to its recovery after crises, improvement of SCP and possible benefits to SCs in recent years (Razak et al., 2023, p. 1114). SC traceability and SCV are concepts that are often confused with each other. From a general point of view, while the concept of visibility refers to the state of being able to see and be seen, the concept of traceability can be expressed as the visibility of the movement of developments (Roy, 2021, p. 3). On the other hand, SC traceability is an enabler of SCV. To illustrate, one of the contributions of SC traceability is improved monitoring of events and risk identification. This contributes to SC resilience by enhancing SCV (Razak et al., 2023, p. 1128). Additionally, one of the essential elements to enable SCV is timely information sharing (Christopher & Lee 2004, p. 389). In this regard, correct information must be followed (Scholten & Schilder, 2015, p. 472). Accordingly, SC traceability must be ensured to perform SCV (Roy, 2021, pp. 30-31):

The concept of SC transparency is another concept that is confused with the concept of SCV. This is because neither concept has a widely accepted standard definition. Efforts to collect downstream and

upstream information about SC operations are associated with the concept of SCV. On the other hand, SC transparency is "a company disclosing information to the public, including consumers and investors, about upstream operations and about the products it sells to consumers" (Sodhi & Tang, 2019, p. 1). While SCV meets the needs of SC members, transparency covers a wide range of external stakeholders such as consumers, consumer advocacy groups, investors, and non-governmental organisations (Akerlof & Schiller, 2015, pp. 1–11). Moreover, SC transparency is defined as having detailed and accurate information about operations and products (Bai & Sarkis, 2020, p. 2143). It is the capability of a company to proactively communicate with stakeholders to enable SC traceability and visibility across its downstream and upstream SC operations (Morgan et al., 2018, p. 959). The crucial point which should be highlighted is that SCV must be enabled to ensure SC transparency (Handfield, 2017). To sum up, the scopes of these concepts are different. SC transparency also considers the external stakeholder group, and SCV is a prerequisite for ensuring SC transparency.

2.3. Dimensions of SCV

There are many characteristics of SCV in the existing literature. They are only for the SC of which it is a member, thus they do not cover competitor SCs (McIntire, 2016, p. 11). Although SCV is highly correlated with knowledge sharing, it is a result of knowledge-sharing implementations (Moshood et al., 2021, p. 9). Quality of information is significant for it. The information shared must be accurate, reliable, up-to-date, useful, and usable (Barratt & Oke, 2007, p. 1218; Titze & Barger, 2015). Real-time information sharing and improving business processes are among its other characteristics (Auramo et al., 2002, p. 514; Somapa et al., 2018, p. 312). When the dimensions of SCV are investigated in the literature, it is comprehended that it is grouped regarding these characteristics, but there is no universally accepted dimensioning of it. The SCV structure has been dimensioned by various authors from various perspectives. These dimensions discussed by the authors are summarised in Table 3 below:

Table 3: Dimensions of SCV

Author(s)	Categories/ Dimensions	Explanation
Wei & Wang (2010)	Visibility for learning	Use of innovative practices, novel technologies, and new processes.
	Visibility for sensing	Considering market trends, product quality and consumers' needs through information sharing.
	Visibility for coordinating	Identifying and managing risks and warnings among SC members through information sharing.
	Visibility for integrating	Enabling consensus-building information to achieve collaborative goals and create a collective SC identity.
	Availability	The availability of information accessed by whole eligible SC members. It is based on information sharing.
	Identity	It is the provision of credentials, and the level of detail varies depending on the demands of SC members.
	Position	It is the provision of location information of objects in the SC. The level of detail of the location information depends on the demands of the SC members. To illustrate,

Papert et al. (2016)		Global Positioning System (GPS) information about the object or which SC actor is currently responsible for which object.
	Status quo	It is the provision of information about the current status of objects in the SC such as transportation, handling and storage. This information also includes information about the environment in which the object is located.
Somapa et al. (2018)	Internal visibility	It is collecting, recording, and sharing data in business processes. It contains all the necessary elements to achieve it.
	External visibility	It is the goods and products outside the business enterprise that cover both aspects of the SC. It is more concerned with forecasting and dynamic status information of the supply network.
Roy (2021)	The technology-dominant view of visibility	It focuses on understanding the contributions of using technology to SCV.
	The SC-dominant view of visibility	It focuses on collaboration among SC members.
	Visibility and transparency requirements in products and processes	It focuses on revealing qualitative information about products and processes.
	Visibility for improving SCP	It focuses on SC challenges that need to be addressed to improve SCP.
Kalaiarasan et al. (2022)	People	It includes people-related factors for enabling SCV.
	Process	It includes process-related factors for enabling SCV.
	Technology	It includes technology-related factors for enabling SCV.
Swink et al. (2023)	Demand visibility	Visibility regarding orders, sales, demand forecast, customer data, promotions, etc.
	Supply visibility	Visibility regarding shipping schedule, inventory levels, etc.
	Process visibility	Visibility regarding key performance indicators, cost information, delivery time, order information, etc.
	Product visibility	Visibility regarding status, structure, quality of product, etc.
	Risk	Visibility regarding risk probability, risk source, risk impact, etc.

Source: Author.

As seen in Table 3 above, the concept of SCV has been dimensioned by considering its various aspects in line with the horizons of the researchers/authors.

3. Technological Viewpoint

Enabling visibility is remarkably related to the utilisation of SC technologies that enable real-time access to data on SC operations (Rogerson & Parry, 2020, p. 602). The capability to "vision" from one edge of

the SC to the other is essential to efficiently and effectively manage and control multi-firm global SC processes. Since SCV is based on data and information shared between members (Holcomb et al., 2011, pp. 32-33), The Fourth Industrial Revolution (4IR) technologies gain significance in terms of SCV because they are revolutionary technologies for today's SCs that transform SC activities and business processes (Luthra & Mangla, 2018, p. 7). The reason for this is that they enhance and facilitate data and information sharing (Delen et al., 2007, p. 613; Zhou, 2009, p. 252). In other words, utilisation of them provides real-time and proactive information exchange and therefore enhances SCV (Kot et al., 2020, p. 89).

The extant literature has underlined that the most significant challenge encountered in enabling SCV is the lack of technology utilisation (Maghsoudi & Pazirandeh, 2016, p. 126). Accordingly, SCV needs to be enhanced to a sufficient level by taking advantage of the 4IR technologies of the current era (Nasir et al., 2022, p. 101; Pettit et al., 2022, p. 112). This study focused on the 4IR technologies, which are the novel disruptive technologies of the era, while investigating the contributions of technology utilisation to SCV. 4IR technologies, which are called novel disruptive technologies widely utilised in the SC context, consist of cyber-physical systems (CPSs), internet of things (IoT), artificial intelligence (AI), autonomous robots, big data analytics (BDA), blockchain, cloud computing, three-dimensional (3D) printers, augmented reality (AR), virtual reality (VR), autonomous (driverless) vehicles, digital twin, horizontal and vertical software integrations, simulation, cyber security and 5G technologies (Özkanlısoy & Bulutlar, 2022, p. 1336). Some of the studies in the literature on 4IR technologies and SCV are summarised below: Kim et al. (2015) developed an intelligent and integrated multi-monitoring system based on IoT technology. The study revealed that the monitoring systems enable SCV. What is more, the findings showed that they lessen location errors and enhance location accuracy for inventory, materials, and employees. Rogerson & Parry (2020) examined blockchain implementation for SCV through discovery case studies. The findings revealed that blockchain technology is a visibility enabler. However, there were also some difficulties. They consisted of trust in technology, swindling, human error and governance problems, difficulties in accessing client data and readiness to pay. Ahmed et al. (2021) carried out a structured literature review to investigate the contribution of IoT technology to SCV. The study revealed that IoT enables SCV. Moshood et al. (2021) conducted a literature review to investigate the impacts of digital twin technology on visibility in the logistics network. The findings of the study revealed that this technology positively impacts the organisational visibility factors identified in the study.

Dolgui & Ivanov (2022) conducted a study that relied on a literature review to conceptualise the role of 5G technology in digital SCs. The study revealed that 5G enhances SCV. Sahoo et al. (2022) examined the articles published in the Scopus database between 2016 and 2021 to specify the effects of blockchain on SCV. A detailed analysis was carried out by considering a total of 308 articles and bibliometric algorithms were utilised in the study. The findings revealed that blockchain enables transparency in food SCs, provides traceability thanks to its smart contracts, and contributes to sustainability thanks to its distributed ledger technology. This study is important in determining research patterns for further studies. Ivanov (2022) carried out a literature review to examine the role of 5G technology in SCs. The findings revealed that this technology boosts real-time process-level visibility in SCs in terms of visibility. Kaur et al. (2023) carried out a literature review based on content analysis to understand the impact of 4IR technologies in terms of visibility and operational efficiency in the food SC. The findings of the study revealed that IoT and blockchain among 4IR technologies have remarkable contributions in terms of efficiency and visibility. The study also revealed that AI and autonomous robot technologies have significant potential for food SCs if they can be implemented in a practical way.

Junaid et al. (2024) tested the role of SCV and circular economy practices in the sustainability impact of 4IR technologies utilising structural equation modelling. The findings of the study revealed that 4IR technologies have a significant positive impact on SCV ($\beta = 0.808$, $p = 0.000$). Trautmann et al. (2024) investigated SC issues and opportunities for utilising digital technology to overcome them. The study was conducted in pharmaceutical industry organisations and was based on expert group interviews with pharmaceutical SC members. The findings of the study uncovered that the utilisation of blockchain in conjunction with other technologies such as AI and IoT enhances efficiency and visibility in such SCs. As can be comprehended from the aforementioned studies summarised, the utilisation of 4IR technologies positively affects SCV. The usage of them is critical for the achievement of visibility, but it should not be forgotten that it is not the only factor (Saint McIntire, 2016).

4. Discussion

The COVID-19 pandemic has highlighted the necessity for a better comprehension of the SCV, its significance, and its provision and improvement (Dolgui et al., 2020, p. 4139; Ivanov & Das, 2020, p. 91) and uncovered the need to re-evaluate extant approaches and restructure SCs accordingly (Ivanov, 2020, p. 2). SCV is the determinant of decision-making, high speed, high accuracy and SC achievement to cope with altering realities in case of any crisis or SC disruption (Handfield & Linton, 2017, pp. 55-56). It contributes to managing disruptions in a global SC network and their sustainable and competitive business and SCP (Kalaiarasan et al., 2022, p. 1). Moreover, SCV contributes to SCs in terms of many issues such as enhancing resilience, realising effective risk management, improving performance, and contributing to sustainability (Busse et al., 2017, p.19; Saqib & Zhang, 2021, p. 1421). Moreover, it supports decision-making in SCs (Messina et al., 2022, p. 1). Therefore, identifying SCV factors and enabling superior visibility is a pivotal issue today. It is emphasised that enhancing SCV is a key component for enhancing SCP in the extant literature (Holcomb et al., 2011, p. 33, Baah et al., 2022, pp. 436-441; Bartlett et al., 2007, p. 295).

SCV is a widely utilised notion today, it does not have a universally accepted definition; it has been defined by various authors by emphasising its various characteristics. This causes it to have a meaning that is open to interpretation. This is an especially significant challenge for companies and SCs seeking SCV capabilities and those trying to enhance SCV levels (Francis, 2008, p. 184). This study has gathered whole SCV definitions and their dimensions in the existing literature under one roof. In this way, researchers and managers will be able to look at the SCV concept from a broader perspective and have a better comprehension of its conceptual framework.

Visibility levels still lag these technological developments, despite the contributions of technological advances in the current era to SCV (Kalaiarasan et al., 2023, p. 5228). The main reason for this situation is the low level of technology usage or lack of digital transformation (Maghsoudi & Pazirandeh, 2016, p. 126). The technologies for real-time visibility need to be identified and utilised for enhancing SCV (Agrawal et al., 2022, p. 1). Accordingly, it is essential to leverage the technologies offered by the current era to enhance SCV and be able to build the SCs of tomorrow (Pettit et al., 2022, p. 120). This study addressed the contributions of 4IR technologies to SCV. The utilisation of these technologies is the key to improving visibility. Accordingly, this study contributes to managerial implications by presenting their contributions and providing companies and their SCs with the opportunity to enhance their SCV. According to the prevailing literature, BDA, blockchain, cloud computing, AI, digital twin and IoT technologies are significant technologies for visibility. They enable enormous amounts of understandable

data to be accessed in real-time at every node in the SC (Ivanov et al., 2019, p. 830; Rogerson & Parry, 2020, p. 602). In this way, they provide SC managers with a pivotal level of visibility across the SC and improve decision processes. Furthermore, it enhances customer satisfaction and customer acquisition and contributes to their retention (Modgil et al., 2022, p. 1247; Tortorella et al., 2022, p. 548). Additionally, it improves performance and contributes to sustainability in the SC (Messina, 2022, p. 1).

There are various studies in the extant literature investigating the relationship between using 4IR technologies and SCV. Kim et al. (2015) developed an intelligent and integrated multiple-tracking system based on IoT technology and examined its effect on SCV. The findings of the study revealed that it is an activator of SCV. What is more, the study demonstrated that systems based on IoT lessen location errors and enhance location accuracy for inventory, materials, and employees. Rogerson & Parry (2020) performed a study to determine the effects of blockchain on SCV in food industries through exploratory case studies. The study showed that the relevant technology ensures visibility. Dolgui & Ivanov (2022) carried out a study based on a literature review to conceptualise the role of 5G technology in digital SCs. The study found that utilisation of 5G boosts SCV.

The growing significance of SCV has encouraged companies to invest in improving this capability. However, enhancing visibility levels is quite a challenge (Holcomb et al., 2011, p. 39). Although the use of 4IR technologies in the current era has an extremely critical role in enabling and enhancing SCV (Cole et al., 2019, p. 470; Roy, 2021, p. 943), it is not enough alone. In addition to the utilisation of 4IR technologies, there are several other issues to consider in enhancing visibility. The lack of a common approach that measures SCV is an obstacle to enabling and enhancing it (Messina et al., 2022, p. 1; Somapa et al., 2018, p. 309). Additionally, there should be no lack of cooperation and coordination within the SC, and the systems utilised by SC members should be compatible with each other to enhance it (Messina et al., 2022, p. 1; Somapa et al., 2018, p. 309).

5. Conclusion

The interest in the SCV concept by both researchers and professionals has increased exponentially in recent years due to its numerous contributions to SCs. The COVID-19 pandemic has only underlined some of these contributions.

Although SCV is crucial to enable and enhance visibility, there is no universally accepted definition. It has been defined by different researchers, emphasising various features of information and processes. This makes it difficult to understand, measure and improve. This study contributes to both literature and managerial implications by gathering existing definitions of SCV under one roof and providing a better understanding of it. The study also presents its various dimensions in the extant literature. Moreover, this study presented the contributions of 4IR technologies to SCV. Therefore, it is a guide for companies and SCs that aim to boost their visibility by utilising them.

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