

Information Sharing and the Bullwhip Effect Reduction

A New Perspective Through the Lens of Blockchain Technology

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Quality Technology and Logistics

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I DEDICATE THIS HUMBLE WORK

*To my beloved brother, friend, and soulmate, **Mahmoud**
To your pure soul. To your lovely heart
Thank you for everything you did and are doing
We have been waiting for such moment
Till we meet again... Goodbye*

ABSTRACT

Globalization and the surge of competition across industries forced companies to improve their supply chain capabilities to serve their customers efficiently and effectively. Due to this fact, businesses are no longer capable of handling all supply chain operations without collaboration and coordination with other firms. One of the key obstacles to coordination is the lack of information sharing and trust between firms since they view information as a sensitive asset. Digital technologies like blockchain, with its inherited features, have the capability to facilitate real-time information sharing, solve trust issues, and improve end-to-end visibility across the supply chain. This licentiate thesis highlights the impact of multiple aspects of information sharing on the bullwhip effect mitigation and explores the potential of blockchain technology as a new coordination mechanism for reducing information distortions, enhancing trust, and orchestrating decision making. Three research papers have been produced within this context and are appended to the thesis. *Paper A* presents an information sharing-based blockchain architecture to mitigate the bullwhip effect in service supply chains. *Paper B* explores the literature in terms of using multiple aspects of information sharing to lessen the bullwhip effect. Finally, *Paper C* introduces an agent-based modeling and simulation approach for two aspects of information sharing: “what to share” and “how to share.” The results show that blockchain technology does provide a significant solution to trust-based issues and information sharing visibility considering the bullwhip effect mitigation. The results also provide a guide for supply chain managers to achieve better coordination and serve as a roadmap for supply chain researchers.

Appended Papers

Al-Sukhni, M., Migdalas, A. (2022). "Blockchain Technology for Information Sharing and Coordination to Mitigate Bullwhip Effect in Service Supply Chains. In: Karim, R., Ahmadi, A., Soleimanmeigouni, I., Kour, R., Rao, R. (eds) *International Congress and Workshop on Industrial AI 2021. IAI 2021. Lecture Notes in Mechanical Engineering. Springer*, pp. 202-211.

Al-Sukhni, M., Migdalas, A. (2022). "The Impact of Information Sharing Aspects on the Bullwhip Effect Mitigation: A Systematic Literature Review. *Submitted to International journal of Physical Distribution & logistics management*.

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TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Background.....	1
1.2	Problem Statement.....	2
1.3	Research questions.....	6
1.3.1	Developments of research questions	6
1.3.2	The relationships between the research questions and the research gaps.....	7
2	RESEARCH METHODOLOGY.....	8
2.1	Study 1: A conceptual framework-based blockchain.....	8
2.2	Study 2: A Systematic Literature review	8
2.3	Study 3: Agent Based Modeling and Simulation.....	9
2.4	Research Aims.....	9
3	LITERATURE REVIEW	11
3.1	Supply Chain Coordination	11
3.2	The Bullwhip Effect	11
3.2.1	The negative impact of BWE on SCP	12
3.2.2	Causes of BWE	13
3.2.3	Measuring of BWE.....	15
3.2.4	Information sharing a remedy to mitigate the BWE.....	16
3.2.5	BWE in Service Supply Chain	17
3.3	Information Sharing.....	17
3.4	Types of Information Sharing.....	18
3.5	How to Share Information?.....	19
3.6	Benefits of Information Sharing	20
3.7	Blockchain Technology	20
3.7.1	Blockchain and supply chain management	21
3.7.2	Categories of blockchain technology	22

4	SUMMARY OF THE PAPERS	24
5	CONCLUSION AND LIMITATIONS	26
	REFERENCES	28

List of Tables

Table 1. The Connection of the appended papers to the research questions...10

Table 2. Types of the Shared Information Sharing.....19

Table 3. Information Sharing tructures.....20

Table 4. The three categories of Blockchain technology.....23

List of Figures

Figure 1. The Cycle of Sales and Operations Planning.....2

Figure 2. Relationships between Research Questions and Research Gaps7

Figure 3. Orders Amplification in the Supply Chain.....12

Figure 4. The Operational and Behavioral Causes of the BWE.....15

Figure 5. The Working Mechanism of Blockchian Technology.....21

ABBREVIATIONS

Bullwhip Effect	BWE
Information Sharing	IS
Information Sharing Aspects	ISFs
Blockchain	BC
Agent-based Modeling	ABM
Enterprise Resource Planning	ERP
Electronic Data Interchange	EDI
Vendor Managed Inventory	VMI
Collaborative Planning, Forecasting and Replenishment	CPFR
Quick Response	QR
Smart Contracts	SCs
Information and Communication Systems	ICTs
Internet of Things	IoT
Artificial Intelligence	AI
Just-In-Time	JIT
Order up to policy	OUT
Supply Chain Performance	SCP
Manufacturing Supply chain	MSC
Service Supply Chain	SSC

1 INTRODUCTION

1.1 Background

The emergence of the internet and the global business environment trigger the necessity for firms to develop their capabilities and improve their operations to fulfill the considerable customer demand and stay competitive in today's dynamic markets. Nowadays, the performance of companies' supply chains is regarded as a competitive advantage (Hugos *et al.*, 2019). Operation is a crucial part of organizations and a core function for producing products and services. Particularly, sales and operations planning (S&OP) as a cross-business process and data-driven function have a significant impact in terms of managing the supply chain effectively and efficiently (Thomace Wlaace, 2000). The core objective of S&OP is to align supply with customer demand and achieve integrated functional alignment (Chopra and Meindl, 2016). To this end, S&OP tracks demand and the supply of resources on a regular basis and continually adjust current operating procedures to account for future uncertainty. S&OP is conducted on a weekly, daily, and hourly basis, allowing all parts of the business, including the chief executive, to engage effectively. Therefore, successful S&OP brings numerous benefits for the supply chain, such as stable production and service rates, shorter lead times, low inventory levels, low holding costs, higher trust, transparency, and openness, and synergic decision making (Sanders, 2014; Srivathsan and Kamath, 2018).

Accordingly, business leaders recognize the importance of integrating the S&OP process by incorporating both customers and suppliers through coordination (Srivathsan and Kamath, 2018). However, it has been argued that the availability of clean, accurate, and reliable data is crucial for achieving coordination within S&OP (Sanders, 2014; Palmatier and Crum, 2003). For example, Chen *et al.*, (2019) report that achieving a coordinated supply chain is among the primary priorities of Hewlett-Packard, IBM, and Procter & Gamble.

Coordination strategies such as vendor managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR), and just-in-time purchasing (JIT) are useful for supply chain echelons. The benefits of upstream echelons are in terms of customer demand visibility which in turn could reduce the demand uncertainty, and downstream echelons might benefit by having higher profit margin and higher customer satisfaction (Chopra and Meindl, 2016). Among various coordination approaches, information sharing (IS) is regarded as the cornerstone of many coordination methods, and it is found to have a considerable value and advantages in terms of supply chain performance (SCP)

improvement (Ramayah and Omar, 2010). Moreover, IS plays the role of glow that material and financial flows rely on. Figure 1. depicts the cycle of S&OP process, which is adjusted continuously considering demand fluctuations to fulfill the potential sales.

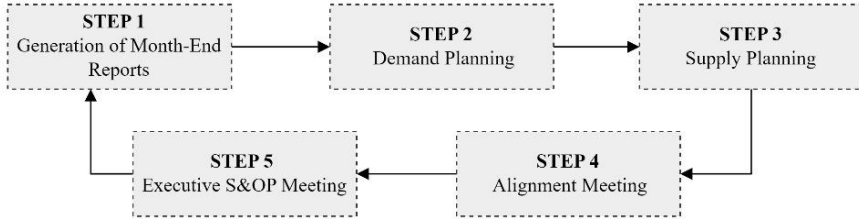


Figure 1. *The Cycle of S&OP (Sanders, 2014)*

1.2 Problem Statement

Globalization has had a big impact on how supply chain management has changed over time. Nowadays, the companies serve customers in many countries and regions which made the supply chain more complex. This has led to the emergence of new trends and strategies in managing supply chain, including the use of information and communication systems (ICTs), sustainability practices, risk management, and resilience measures (Gligor and Esmark, 2015; Helo and Hao, 2019). According to Sharma and Kumar (2017), the supply chain is a network of organizations that collaborate and share information to produce and deliver products and services to the ultimate consumer at the right time, place, quality, and price. To achieve this goal, sharing accurate, real-time, reliable, and transparent information among supply chain partners is required (Wang and Disney, 2016). On the other hand, coordination is defined as a combination of techniques and methods that manage the interrelationships among supply chain partners (Xu and Beamon, 2006). Similarly, Benavids *et al.*, (2012) stated that coordination is a collaborative effort that extends beyond regular daily operations with the aim of achieving substantial and sustainable benefits in the long run. It is also claimed that coordination is inevitable to achieve higher profits and higher levels of customer service (Srivathsan and Kamath, 2018). Thus, the primary purpose of coordination is to create a mutually beneficial scenario, i.e., a win-win strategy in which each supply chain echelon can receive a fair share of the overall surplus and maximize their profits.

Coordination can take many forms, such as supply chain contracts, VMI, CPFR, quick response (QR), and IS. However, IS is inherently the backbone of many coordination methods, and it is necessary to be shared among supply chain partners in order to improve its efficiency (Ramayah and Omar, 2010). However, different aspects of IS should be considered since they constitute a challenge for effective IS in the supply chain. Such aspects in turn affect the value of the information, i.e., “what type of information to share?” “how to share information?” “why to share information” (Kembro *et al.*, 2015), “how much to share information?” and “with whom to share information?” (Deghadi, 2014). Other challenges are associated with the fragmented, delayed, and distorted information flow, the lack of trust, and the opportunistic behavior among supply chain echelons (Ebrahim-Khanjari *et al.*, 2012). Similarly, misaligned decisions, incentives, and silo mindsets result in local optimization i.e., decisions made by individual supply chain actors prioritize their own profit rather than the overall profit of the entire supply chain (Chopra and Meindl, 2016). Therefore, coordination requires each partner to share his information and consider the impact of such decisions on the operations of other partners. As a result, any behavior that results in local optimization, information latency, information distortion, and uncertainty across the supply chain can be seen as an obstacle to coordination (Chopra and Meindl, 2016; Ebrahim-Khanjari *et al.*, 2012).

The bullwhip effect (BWE) is a result of a lack of supply chain coordination in which small swings in demand information propagate the order quantity dramatically as they move up the supply chain. According to Jay Forrester (1961), who first noticed the BWE, he conducted a system dynamics simulation (SD) approach to investigate the impact of information distortion on the SCP. He stated that demand information gets distorted as it goes further upstream in the supply chain, which increases fluctuations in the customer demand (Wang and Disney, 2016). Moreover, Forrester (1961) stated that demand information was distorted within the supply chain, when each echelon performs a different estimate of what demand looks like, i.e., every echelon uses orders to forecast future demand. In fact, both forecasting and inventory processes become more difficult when the demand is variable, i.e., variability tends to imply uncertainty, higher inventory, and/or lower service levels (Ha and Tang, 2017). In other words, this phenomenon affects the incoming orders to the upstream echelons, where they have a larger variance than the incoming customer demand to the downstream echelons.

Sterman (1989) established, the "Beer Game," a simulation experiment for decision-making behavior in supply chains. He attributed the demand amplification to the managers' irrational behavior in making decisions regarding their inventory. That's to say, the managers tend to place their replenishment orders ignoring the inventory-in-transit, i.e., the orders that they have not yet received. Lee *et al.*, (1997) seminal work paved the way for clearly understanding the operational causes of the BWE where supply chain echelons are assumed to be fully rational. They suggested four main causes: demand signal processing, batch ordering, price fluctuations, rationing and shortage gaming. The BWE harms both downstream and upstream echelons. However, it is more severe on upstream echelons since they don't have access to the actual demand information. The BWE negative consequences are associated with setting up and shutting down machines, idling and overtime in high workload, workforce hiring and firing, excessive inventory levels, difficulty in forecasting and scheduling, system nervousness, and poor service level, amongst other consequences (Wang and Disney, 2016).

Plenty of studies which investigated the BWE stated that to overcome such phenomena, distorted information needs to be avoided, and partners need to share demand information in a better way (Bray and Mendelson, 2012; Van Engelenburg *et al.*, 2018). Hence, IS attracted great attention in the literature as a crucial mechanism for reducing the negative impacts of the BWE which enables the supply chain partners to synchronize and integrate their operations (Trapero *et al.*, 2012).

However, the supply chain echelons may not have the willingness to share their information with other partners due to several reasons: a lack of trust, the need to maintain a competitive position, and the desire to achieve higher customer satisfaction. Consequently, the upstream echelons estimate their demand forecasting relying on the available information, i.e., the orders information that is transferred by the downstream and not the actual demand information (Deghedi, 2014). Although, the downstream echelons may exaggerate their orders to get incentives by affecting the receiver's decisions and retain their competitive position (Deghedi, 2014). To incentivize truthful IS, the literature has come up with a variety of solutions to mitigate the BWE including revenue-sharing contracts (Kong *et al.*, 2013), market-based contracts (Shin and Tunca, 2010), and costly actions by retailers (Shamir, 2012). Additionally, variety of methodological approaches are presented to overcome the BWE: analytical models (Cachon and Fisher, 2000; Chen *et al.*, 2000; Dejonckheere *et al.*, 2004; Gilbert and Troitzsch, 2005; Chen and Lee, 2012) empirical analyses

(Anderson *et al.*, 2000; Cachon *et al.*, 2007; Bray and Mendelson, 2012), simulation modelling (Cannella *et al.*, 2015; Pamulety *et al.*, 2016; Dominguez *et al.*, 2017; Dominguez *et al.*, 2018; Cannella *et al.*, 2018; Jeong and Hong, 2019; Ojha *et al.*, 2019; Jin, 2019; Shaban *et al.*, 2019; Shaban *et al.*, 2020) and behavioral experiments (Croson and Donohue, 2006; Cantor and Katok, 2012).

The technological advancement made the balance between supply and demand more achievable, and the supply chain more profitable (Chopra and Meindl, 2016). Disruptive technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain (BC) have the potential to transform supply chain operations and logistics and provide remedies for information asymmetry. (Treiblmaier, 2018; Winkelhaus and Grosse, 2019). Nakamoto (2008) was the first to use BC in the cryptocurrency context of Bitcoin. BC is known as a shared database and peer-to-peer network that enable storing and sharing different kinds of data instead of only transactions (Pournader *et al.*, 2019). The implementation of BC has expanded into different industries: health care, market monitoring, copyright protection, and supply chain management (Khan and Salah, 2018; Scott *et al.*, 2017; Kim and Laskowski, 2018; Savelyev, 2018; Queiroz *et al.*, 2018). Recent literature on BC within the supply chain context shows an increasing interest in adopting such a promising technology (Pawczuk *et al.*, 2018), such as improving SCP and partnership efficiency (Kim and Laskowski, 2018), transforming supply chain operations (Sabeti *et al.*, 2018), enabling real time traceability (Kshetri, 2017), facilitating information sharing (Van Engelenburg *et al.*, 2019), and enhancing sustainable supply chains (Kouhizadeh and Sarkis, 2018). Moreover, few conceptual framework-based studies use BC to mitigate the BWE (van Engelenburg *et al.*, 2018; Ghode *et al.*, 2021; and Sarfaraz *et al.*, 2021). However, these studies haven't emphasized the importance of considering multiple aspects of IS.

To the authors' knowledge, no study has thus far considered the BC technology as an enabler to mitigate the BWE using multiple aspects of IS. Due to the above, it is required to study the effect of multiple IS factors on the mitigation of the BWE using BC technology with respect to end-to-end visibility among SC members. Finally, an information sharing-based BC could be a paradigm shift for the BWE mitigation.

1.3 Research questions

This section links the licentiate research questions with the identified gaps in the literature. Relevant research avenues are recognized, which leads to the development of three research questions. In the end of the section, we provide an explanation of how the research questions are linked to the research problem.

1.3.1 Developments of research questions

The purpose of this licentiate thesis is to review the literature on the aspects of IS and explore how such aspects could mitigate the BWE through the lens of BC. The aspects that were identified in previous research are “why to share,” “how to share,” “what to share,” “with whom to share,” and “how much to share.” However, it is not fully explained how these aspects influence the mitigation of BWE. Most researchers investigated “what to share,” “why to share,” and “how to share” (Jeong and Hong, 2019; Dominguez *et al.*, 2017; Dominguez *et al.*, 2018; Kembro *et al.*, 2015). However, few researchers explain “what to share” and “how to share” considering BC technology. As information sharing is crucial to mitigate the BWE, it is also important to understand how multiple aspects of IS impact the mitigation of BWE (Gustavsson and Jonsson, 2008). Thus, while ISFs have not been fully explored in terms of BWE in previous research, the distinct characteristics of BC should have a direct influence on mitigating the BWE and driving benefits to supply chain efficiency. Three research Questions are generated:

RQ 1: *To what extent does the literature consider the impact of multiple ISFs on BWE mitigation?*

RQ 2: *How could blockchain technology mitigate the BWE among supply chain partners considering “what to share” and “how to share” IS aspects?*

RQ 3: *How could blockchain technology mitigate the BWE in service supply chain?*

1.3.2 The relationships between the research questions and the research gaps

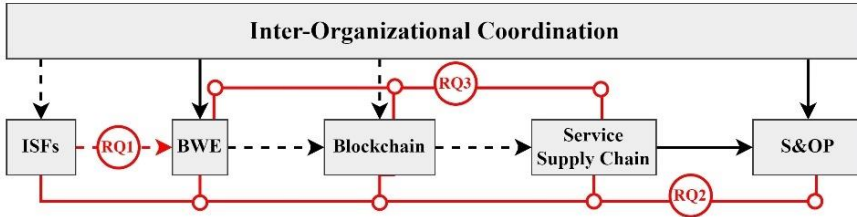


Figure 2. Relationships between the research questions and the research gaps

Figure 2 depicts how the research questions are related to each other as well as to the gaps identified in the literature. The solid lines are intensively studied, and the dotted lines are partially studied. As can be seen in Figure 2, the relationship between inter-organizational coordination and the BWE, S&OP, and supply chain is intensively studied. However, the relationship between inter-organizational coordination and multiple aspects of IS has been partially investigated. Particularly, *the first RQ*, the impact of multiple ISFs on the BWE mitigation, is partially exposed. Likewise, *the second RQ*, investigating the impact of multiple ISFs on the BWE mitigation through the lens of BC technology is not fully investigated. Finally, *the third RQ*, investigating the role of BC in terms of service BWE mitigation, is also partially exposed. Consequently, there is a need to investigate thoroughly the relationships that have been partially investigated and pave the way for future research.

2 RESEARCH METHODOLOGY

This section describes the overall research process, the research design, and the presentation of the research results.

2.1 Study 1: A conceptual framework-based blockchain

In the first paper, we construct a BC architecture to illustrate how service supply chain echelons could share real-time backlog information and thus mitigate the negative impacts of the BWE. For this purpose, we use a conceptual framework approach, a qualitative method, to describe the processes, partners, and interactions among service supply chain echelons using BC technology (Böhme *et al.*, 2015). Using conceptual framework method helps to understand the various components and processes of a SC-blockchain system, identify potential challenges, and improve its implementation and management (Crosby *et al.*, 2016). The proposed architecture emphasizes the potential benefits of using distributed ledger and cryptography in terms of sharing real-time backlog information. The BC simplifies the complexity of IS by using a set of new features, including cryptography, distributed ledger technology, smart contracts (SCs), and consensus algorithm to orchestrate the heterogeneous decisions made by different service supply chain echelons. These components include the consensus mechanism, smart contracts, governance structure, and network topology.

2.2 Study 2: A Systematic Literature review

Giiunipero *et al.*, (2008) stated that literature reviews are a good way to find and map out new research paths. In addition, it is useful in identifying research gaps and future research directions. Particularly, the systematic literature review is used to conduct an unbiased and comprehensive review of the existing literature and increase objectivity during the review process (Tranfield *et al.*, 2003). The systematic literature review methodology was first introduced by Chalmers *et al.*, (1977) in the field of health sciences and has since been widely used in various fields, such as the social sciences, engineering, and computer science. A systematic literature review is a structured and comprehensive method of reviewing existing research studies on a particular research question or topic. This method involves identifying a research question or topic of interest, searching relevant literature databases and sources in a systematic manner, applying predefined inclusion and exclusion criteria to select relevant studies, extracting and analyzing data from selected studies, synthesizing the results of selected studies using appropriate statistical or qualitative methods,

and evaluating the quality and validity of the selected studies. The systematic literature review that was conducted as part of this licentiate thesis builds on the guidelines provided by Tranfield *et al.*, (2003). The study expands on prior literature reviews (Kembro *et al.*, 2015; Huang *et al.*, 2003) to find current research published between 2015 and 2021 in peer-reviewed journals. This study reviewed the literature that investigates the impact of multiple IS aspects on the BWE mitigation. The results show that “how to share,” “what type to share” and “in which direction to share” have the least attention in the literature.

2.3 Study 3: Agent Based Modeling and Simulation

The two first studies, i.e., the conceptual framework and the systematic literature review, paved the way for the design of the this study, which is a quantitative method. Due to the complexity of supply chain systems nowadays, agent-based modeling and simulation (ABM) methodology is considered useful to model complex systems, including various interacting agents, i.e., supply chain echelons. The concept of ABM was first introduced by Craig Reynolds in the 1987 as "boids," a model of flocking behavior in birds. ABM is a bottom-up approach where the simulation starts by modeling the behaviors and decision-making rules of the agents and the interactions between them in the specific environment. The fundamental components of ABM are agents' identification, what rules and properties they have, simulating the model, and evaluating the results. In this study, we identify four agents: retailer, wholesale, producer, and supplier. We assigned heterogeneous operational configurations for each of them in terms of lead time, target inventory level, and exponential smoothing factors. We simulate how they act and behave toward each other with respect to sharing different types of information, and we assess the results in terms of the BWE and inventory level mitigation. Table1. depicts the connections between the study methodologies and the three papers.

2.4 Research Aims

Accordingly, the research problem was formulated by identifying the following aims:

- Providing insights about the impact of multiple ISFs on the BWE mitigation.
- Developing a new coordination mechanism to mitigate the BWE and improve end-to-end visibility in both the service and manufacturing supply chains using blockchain technology.
- Investigating the impact of multiple ISFs on the BWE mitigation.

Table 1. *The Connection of the appended articles to the research questions*

	<i>Research Questions</i>	<i>Conceptual Framework</i>	<i>Literature Review</i>	<i>Simulation</i>
1	To what extent does the literature consider the impact of multiple ISFs on the BWE mitigation?		X	X
2	How could blockchain technology mitigate the BWE among supply chain partners through ISFs in sales and operations planning processes?	X		X
3	How could blockchain technology mitigate the BWE in service supply chain?	X		

3 LITERATURE REVIEW

3.1 Supply Chain Coordination

Coordination is an important problem to consider in modern supply chains, especially with the existence of different ownerships and decision-making misalignment (Chopra and Meindl, 2016). Coordination, as described by Larsen (2000), is the sharing of risks and rewards in accordance with collaborative and planned joint activities, as well as the interchange of information within an integrated information system. According to McClellan (2003), coordination is a win-win technique in which it benefits all parties involved. Inter-organizational coordination could be achieved if all supply chain echelons worked together to boost the overall surplus. Each echelon should coordinate with the other by disseminating relevant information and considering how their actions will affect the other echelons' decisions (Chopra and Meindl, 2016). In addition, inter-organizational coordination allows firms to access and acquire the required resources, such as money, competencies, and information, which is considered a major driver of supply chain efficiency (Dyer and Singh 1998). Managing inter-organizational coordination, especially in the presence of conflicting incentives, is regarded as a considerable challenge since it causes deficiencies in supply chain operations and propagates production, inventory, and transportation costs (Ambilikumarck, 2015). Moreover, local optimization, silo mindsets, and information sharing obstacles are some of the important issues of supply chain coordination. Coordination might take place in a variety of ways. They may be divided into two main categories: 1) vertical coordination, in which supply chain echelons coordinate within each other; and 2) horizontal coordination, in which supply chain echelons coordinate with rivals (Bartlett, 2007).

3.2 The Bullwhip Effect

The BWE is one of the most investigated problems in supply chain management (Ma *et al.*, 2013); it is also considered a forecasting-driven phenomenon related to information asymmetry (Rahman *et al.*, 2014). BWE was first noticed by Jay Forrester in 1961; it refers to the amplification of order variance far from the actual customer demand as it increases further across the supply chain echelons (see Figure 3). The BWE is a well-known concept in the operations' research field. It is referring to the fact that small swings in customer demand create large swings in order quantity from the retailer and end up at the supplier

(Wang and Disney 2016). It is also known as the "demand amplification," the "variance amplification," or the "Forrester effect."

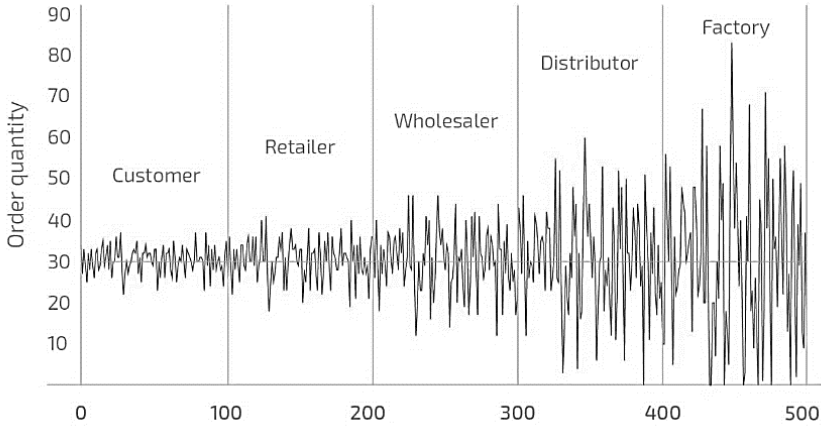


Figure 3. Orders amplification in the supply chain

Sterman (1989) conducted the famous simulation, "Beer Game," to investigate the BWE occurrence in the supply chain. He revealed that the presence of the BWE was due to the reaction of the players regarding the work-in-progress inventory which is known as "irrational behavior." Furthermore, the seminal work of Lee *et al.* (1997) attributed the BWE occurrence into four main causes: demand signal processing, batch ordering, price fluctuation, and shortage gaming. The literature on BWE can be categorized into three main sections. i.e., the research which investigated the existence of the BWE in the supply chain (Sodhi and Tang, 2011; Bray and Mendelson, 2012), the research which examined the causes of the BWE (Streaman, 1989; Lee *et al.*, 1997) and the research which focused on measuring and providing remedies to mitigate the BWE (Bray and Mendelson, 2012; Chen and Lee, 2012; Wang and Disney, 2016).

3.2.1 The negative impact of BWE on SCP

The BWE harms the SCP by increasing the costs of manufacturing, transportation, and inventory. Moreover, the increased costs erode the supply chain surplus and increase the possibility of a stock-out scenario, which results in customers leaking to other competitors (Chopra and Meindl, 2016). Particularly, erratic demand patterns, which are hard to forecast, induce upstream echelons to either increase their capacity or keep more inventory. Additionally, the costs of the BWE are affecting each echelon in the supply

chain. For instance, the producer is affected by having excess production capacity, the wholesaler is affected by having excess inventory levels, and the retailer is affected by losing customers and having excess inventory levels (Hugos et al., 2019). In addition, the BWE costs can affect the forecasting accuracy through the difficulty of scheduling orders aligned with a poor strategic relationship between the customers and the suppliers (Wang and Disney 2016).

3.2.2 Causes of BWE

The presence of the BWE is related to two types of causes: operational and behavioral causes. Different combinations of these causes could interact with each other and trigger the BWE.

Operational Causes

One of the seminal works on the causes of the BWE was published by Lee *et al.* (1997). The authors identified four operational causes of the BWE, including demand forecast updating, order batching, rationing and shortage game, and price fluctuations. On the other hand, Starman (2005) identified several operational causes which are related to demand planning, inventory management, production time delays, and delivery transportation lead times (see Figure 4).

Demand single processing

Demand forecast updating is one of the operational causes of the BWE. When demand forecasts are updated frequently and without proper coordination between different entities in the supply chain, it can lead to increased variability and uncertainty in the demand signal (Chopra and Meindl, 2016). Each supply chain echelon may interpret the updated demand forecast differently, leading to over or underordering of inventory and further amplification of demand variability (Hugos *et al.*, 2019). Clearly, one way to counteract this distortion in demand forecasts is motivating the IS among all supply chain echelons.

Order batching

Ordering in batches is a strategy where the orders are placed within an interval, once a day, for example. It describes the companies that accumulate their orders and place them at one time instead of placing them many times to benefit from the economics of scale (Ha and Tang 2017). As a result, the BWE is triggered due to the propagation of the order variance, which is larger than the demand variance.

Rationing and shortage game

This operational causes describes the buyer's behavior when they observe that the supplier is having a shortage in production. Therefore, they intend to exaggerate their orders and replenish their inventories. With such irrational behaviors, the amplitude of BWE increases (Bhattacharya and Bandyopadhyay, 2010).

Price fluctuations

Price fluctuations occur due to the promotional campaigns that trigger forward buying by customers. Such promotions and discounts affect the order pattern to the point where it becomes larger than the needed quantity. As a result, all supply chain echelons will be affected by such swings, which in turn induce the BWE (Disney and Labrecht, 2008).

Behavioral Causes

Sterman (1989) observed a systematic pattern of demand variation amplification in the beer game that is attributed to the manager's misperceptions of demand swings. Croson and Donohue (2006) demonstrated that there could also be additional behavioral causes, i.e., the supply chain echelons deny the work-in-progress inventory when they place their orders.

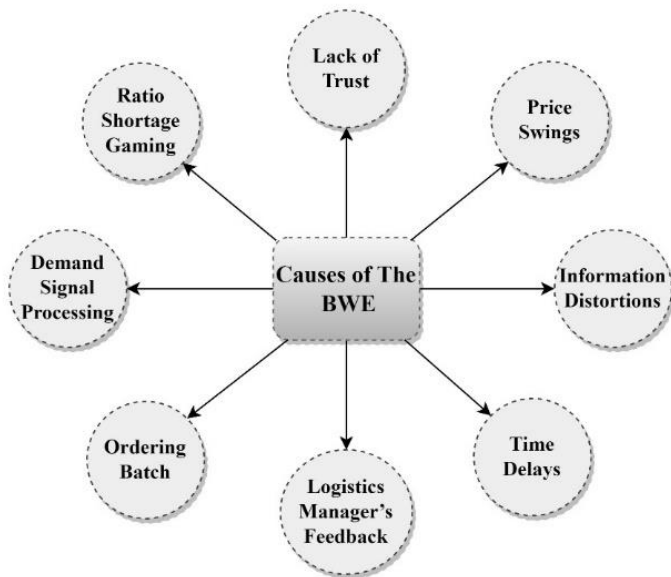


Figure 4. The operational and behavioral causes of the BWE

On the other hand, Corson *et al.*, (2014) define the behavioral causes as a sub-optimal decision made by the logistics managers about production planning and capacity adjustments. The ultimate results of such causes are the lack of efficient SCP due to large fluctuations in customer demand (see Figure 4).

3.2.3 Measuring of BWE

The BWE could be measured based on information flow (the differences between orders and demand) or material flow (shipments from the upstream and sales in the downstream) (Chen *et al.*, 2000). The BWE is an increase in order variability across the whole supply chain. In this thesis, we use the BWE information flow metrics. BWE can also be detected by comparing the variance of the outgoing orders with the variance of the incoming demand, which is defined as the order variance ratio (Cannella *et al.*, 2015). In addition, by comparing the variance of orders with the variance of actual demand (Wang and Disney, 2015), the BWE can be detected.

Tang *et al.*, (2020) stated that the incoming demand signal is stationary with considerable noise; this could be a result of the orders signal amplification at each echelon. Therefore, the order swings at the upstream echelons are attributed to the amplified noise at each echelon. Simply put, the BWE is measured by comparing the quantity and rate of orders received from the downstream echelons with the quantity and rate of orders placed in the upstream echelons (Hugos *et al.*, 2019). Such comparison can be made by either a ratio or a difference, where amplification (smoothing) is indicated by a ratio larger (smaller) than one or a difference greater (less) than zero (Cachon *et al.*, 2007). The BWE can be measured statistically as follows:

$$BWE = \frac{V[Orders](VO_i)}{V[Deman](VD_i)} \quad (1)$$

$$OVR = \frac{V[O_i]}{V[\sigma^2]} \quad (2)$$

The first equation calculates the BWE for each echelon in supply chain where (VO_i) is the orders placed by an echelon i to its upstream partner, and (VD_i) is the variance of its customer demand. Similarly, the second equation measure the BWE for each echelon, however it considers the demand as the final customer demand not the immediate downstream demand where $[O_i]$ is the order placed by an echelon i and $[\sigma^2]$ is the final customer demand.

3.2.4 Information sharing a remedy to mitigate the BWE.

There is an intensive literature on IS as one of the effective remedies to reduce BWE in the supply chain. Particularly, Croson and Donahue (2003) examined the impact of sharing point-of-sale (POS) data with the upstream supply chain parties. They found that POS data sharing reduces the BWE and improves the performance of inventory and stockouts. Dejonckheere *et al.*, (2004) investigated the impact of sharing customer demand information with two replenishment policies: an order-up-to policy (OUT) and a smoothing policy using control system engineering. They conclude that the order variance ratio is reduced when the end-customer demand information is shared. Kim *et al.*, (2006) conducted an analytical study to quantify the variance amplification using the customer demand information sharing with the order-up-to policy. They conclude that the BWE dampens when customer demand is shared with upstream echelons and exacerbates when there is no sharing.

Other studies claimed that the benefits of information sharing are greater when the demand is highly correlated or highly variable (Babai *et al.*, 2015) and when the lead time is long (Lee *et al.*, 2000). Further research used VMI policy, which requires sharing demand and inventory information, and they stated that VMI is found to be beneficial for all supply chain echelons in terms of reducing distorted information and stock-out scenarios (Xu *et al.*, 2001; Disney and Towill, 2003; Cannella *et al.*, 2015). Costantino *et al.* (2014) analyzed the BWE and inventory stability using simulation by comparing the effectiveness of information sharing and OUT to reduce the BWE. The results show that the lack of IS is the key root cause of demand amplification, followed by high safety stock levels and poor forecasting. Cannella *et al.*, (2015) stated that the coordination achieved by sharing inventory, demand, and order information with the upstream members can significantly help to avoid the occurrence of the BWE. On the other side, Barlas and Gunduz (2011) revealed that sharing customer demand information across all echelons with different ordering policies mitigate the BWE. Chatfield *et al.*, (2004) examined the importance of sharing customer demand information and information quality with stochastic lead times and OUT to mitigate the BWE using simulation under four scenarios. They proved that the variability of lead times increases the occurrence of the BWE; however, the transmission of customer demand information to the upstream levels and the quality of the information are significant enough to dampen the BWE. Finally, Huang *et al.* (2003) concentrated on showing the importance of sharing production information to reduce inventory levels and order variation.

3.2.5 BWE in Service Supply Chain

The occurrence of the BWE in the service supply chain (SSC) can take different forms due to the inherited features it possesses compared to the manufacturing supply chain. Therefore, the BWE can be attributed to different kinds of causes. Unlike the manufacturing supply chain (MSC), the service supply chain (SSC) has no inventory due to the immediate and simultaneous management of demand and supply (Shahin, 2010). The main differences between the SSC and the MSC are in terms of capacity, perishability, intangibility, and the customer-supplier co-production relationship (Shahin, 2010). Therefore, the causes of BWE are manifested, for example, by the fluctuations of backlogs, capacity, and workload (Anderson and Morrice, 2000; Anderson *et al.*, 2005). To clarify, the BWE in SSC appears as delays in order fulfillment rates, which cause sequential amplification in backlog levels and lead to a surge in workload rate affecting capacity adjustment decisions (Anderson and Morrice, 2000; Akkermans and Vos, 2003; Haughton, 2009; Akkermans and Voss, 2013). Particularly, Akkermans and Vos (2003) investigated the BWE in a US telecommunications company. They conclude that the workload amplification is a result of the poor service quality level when serving customers. In addition, the sales campaigns lead to a greater amplification of the workload rate. Anderson *et al.*, (2005) notice that the BWE appears in a backlog variance amplification, and it raises the capacity costs because of the hiring, training, and firing costs. Further research by Haughton (2009) investigated the BWE in logistics carriers' services and found that the BWE appears in terms of increasing capacity costs for carriers who have no flexible capacity. Akkermans and Voss (2013) examined the BWE in two case studies: consumer broadband services and another of glass fiber network services. They noticed an amplification in backlog variability, which can be reduced by service automation and the visibility of backlog information.

3.3 Information Sharing

IS has been defined in several contexts in the literature; Monczka *et al.*, (1998) defined IS as the level of shared information among supply chain parties. In another context, IS is the sharing of valuable and meaningful information internally with organizational units and externally with other organizations (Lotfi *et al.*, 2013). According to Olorunniwo and Li (2010), IS corresponded to which information is accessible to other firms through a joint exchange infrastructure. For this study, BWE adopted the definition presented by Cao *et al.*, (2010, p. 6617), which is "*the extent to which a firm shares a variety of relevant, accurate, complete, and confidential ideas, plans, and procedures*

with its supply chain partners in a timely manner.". Particularly, IS is the main driver of the SCP and the backbone for many coordination mechanisms (Min, 2009) an effective remedy to mitigate the BWE among supply chain echelons (Chopra and Meindl, 2016). In addition, the power of IS steamed from the advancement of information technology systems that can collect, store, process, and exchange the information.

3.4 Types of Information Sharing

Numerous types of information can be shared based on the organizational level: strategic, tactical, and operational (Deghedi, 2014). In addition, information related to designing, processing, producing, pricing, planning, inventory, demand forecasting, ordering, customer demand, and a production schedule can be shared (Yu *et al.*, 2001; Zhang *et al.*, 2006; Ramayah and Omar, 2010). Huang *et al.*, (2003) also suggested six categories of production information that can be shared: product, process, inventory, resource, order, and planning information (see Table 2).

Table 2. *Types of the shared information in literature*


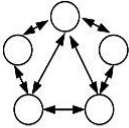
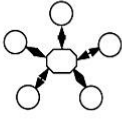
Literature	Shared Information Type
Chen <i>et al.</i> , (2000); Chatfield <i>et al.</i> , (2004); Asgari <i>et al.</i> , (2016); Argilagueta <i>et al.</i> , (2017)	Demand
Croson and Donohue (2003); Croson and Donohue (2005); Hassanzadeh <i>et al.</i> , (2014)	Sales (POS).
Dominguez <i>et al.</i> , (2014); Dai <i>et al.</i> , (2016); Wang <i>et al.</i> , (2016)	Inventory.
Yu <i>et al.</i> , (2001)	Demand and order.
Ouyang (2007); Agrawal <i>et al.</i> , (2009)	Order and inventory.
Li <i>et al.</i> , (2016)	Order.
Jeong and Hong (2019)	Demand Forecast.
Ding <i>et al.</i> , (2011)	Ordered quantity.
Rached <i>et al.</i> , (2016)	Demand and lead-time.
Jiang and Ke (2018)	Demand Forecasting and lead-time.
Ojha <i>et al.</i> , (2019)	Demand and lead-time.

3.5 How to Share Information?

The literature includes various means and methodologies to share information among supply chain partners who depend on the supply chain structure, such as face to face contact, telephone, fax, web-enabled portals, email, electronic data interchange (EDI), enterprise resource planning (ERP), and warehouse data management (Lee, 2002; Hill and Scudder, 2002; Adewole, 2005). Regarding supply chain structure, Rong and Kumar (2003) categorize the IS structures as shown in Table 3.

- **Sequential information sharing:** In this structure, the output of one party's action will serve as the input for the other. EDI is an example of this structure since it links operations in a cooperative and sequential manner.
- **Reciprocal information sharing:** In this structure, the parties have a dual connection through which they can converse with several parties. This may generate several information flows, which in turn increase the rate of uncertainty and asymmetric information. The most effective collaboration technique that can be used in this structure is the integration of interactive processes.
- **Hub-and-spoke information sharing:** This structure includes a central hub that communicates with all parties. The hub stores and maintains all the information about each party.

Table 3. Information Sharing Structures (Rong and Kumar, 2003)

Information Sharing	Sequential	Reciprocal	Hub-and-Spoke
Structure			
Level of collaboration	Between neighboring partners only (one-way)	Two-way, multiple partners	Two-way, centralized
Coordination Mechanism	Information flow upstream, goods downstream	Multiple information flows	Intelligent hub
Technologies	EDI	Networking, email, videoconference	Web services
Examples	Traditional supply chain, 3PL	VMI	CPFR, Private Trading Exchanges, Consortia Trading Exchanges

3.6 Benefits of Information Sharing

IS is one of the most effective coordination mechanisms that have been extensively cited through the literature. Companies that don't share information are vulnerable to getting misled by the distorted information and, as a result, causing the BWE (Ramayah and Omar, 2010; Ha and Tang, 2017). Therefore, IS brings several benefits for supply chain echelons in terms of SCP improvement, efficient inventory management, and cost reduction (Lee *et al.*, 1997; Cachon and Fisher, 2000; Lee *et al.*, 2000; Sahin and Robinson, 2002; Zhao, 2002; Huang *et al.*, 2003; Patnayakuni *et al.*, 2006). Besides, many research studies use IS as a tool that mitigates BWE in the supply chain (Forrester, 1958; Sterman, 1989; Lee *et al.*, 2004; Dejonckheere, 2004; Chen and Lee, 2009; Nyaga *et al.*, 2010; Cannella and Ciancimino, 2010; Hussain and Drake, 2011; Bray and Mendelson, 2012; Lotfi *et al.*, 2013). However, other studies like those by Jonsson and Mattsson (2013) and Ketzenberg *et al.* (2007) claim that the value and benefits of IS are still unclear and inconsistent. Additionally, another debate revolved around the optimal level of sharing information, i.e., is it more beneficial to adopt and include all supply chain echelons in the IS process or it would be more beneficial to involve some supply chain echelons (full and partial IS) (Dominguez *et al.*, 2021; Jeong and Hong, 2019). The reason beyond such debates is based on the different aspects of IS as the type of information that could be shared (Jonsson and Mattsson, 2013).

3.7 Blockchain Technology

BC technology can be described as a shared digital database of transactions, records, and events that is distributed throughout a peer-to-peer network (Crosby *et al.*, 2016; Manupati *et al.*, 2019). BC includes a chain of blocks that are linked together with an encrypted hash (code); each subsequent block holds the hash of the previous block, which makes such a chain secure, immutable, and transparent. All participants (nodes) in the BC network possess the same copy of the digital ledger (Pournader *et al.*, 2019). There is no central authority controlling the network. In contrast, all the nodes can access and review the data in real time (Gupta, 2018). In other words, BC technology can make the data visible and transparent for all parties (Bai and Sarkis, 2020) and support real time communications (Saber *et al.*, 2018b). Figure 5 shows the working mechanism of BC technology.

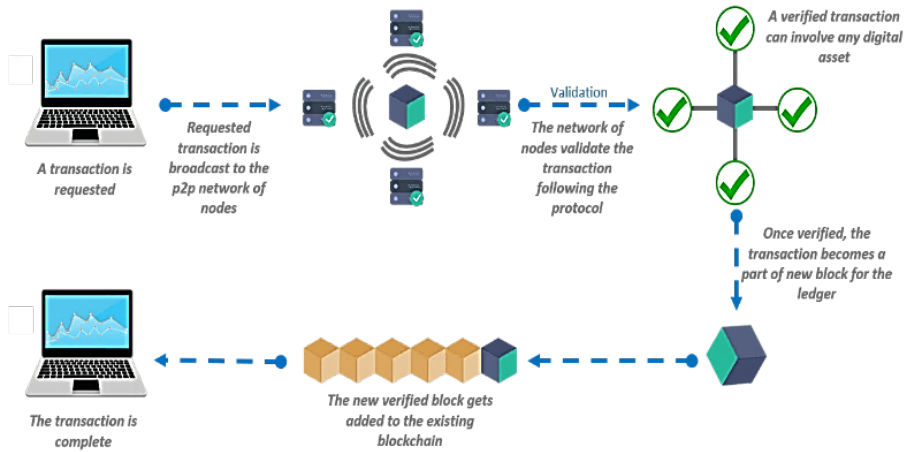


Figure 5. The working mechanism of BC technology

At first, BC technology was implemented in financial applications. i.e., cryptocurrencies (Nakamoto, 2008). Unlike other information technologies, the BC's distinct features expand the utilization of such technology to different businesses: E-government (Bhardwaj and Kaushik, 2017), healthcare (Bocek *et al.*, 2017; Mettler, 2016), energy (Munsing *et al.*, 2017), banking (Guo *et al.*, 2016), supply chain management (Pournader *et al.*, 2019; Kshetri, 2018; Kouhizadeh and Sarkis, 2018; Bai and Sarkis, 2020), sustainability (Saber *et al.*, 2019; Saber *et al.*, 2018); traceability (Lu *et al.*, 2017); supply chain resilience (Min, 2019); collaboration and coordination in maritime supply chains (Philipp *et al.*, 2019); trust sharing (Wang and Guo, 2019); information sharing (Longo *et al.*, 2019); transparency (Zheng *et al.*, 2019); Francisco and Swanson, 2018); product origins monitoring (Casado-Vara *et al.*, 2018); security improvement (Dorri *et al.*, 2017); smart-contract transactions (Sikorski, 2017); improvement of supply chain partnership efficiency (Kim and Shin, 2019); and the BWE mitigation (Van Engelenburg *et al.*, 2018).

3.7.1 Blockchain and supply chain management

Supply chains are getting more difficult, complex, diverse, and the organizations don't have a full visibility within the supply chain. BC offers transparency, traceability, and security for supply chain operations (Queiroz *et al.*, 2019; Saber *et al.* 2019; Schmidt and Wagner 2019). The trustworthiness, legitimacy, and smart contractual relationships facilitated by BC have the potential to disrupt the supply chain operations (Saber *et al.*, 2019). Therefore, by incorporating BC technology into the supply chain, the traceability, auditability,

and verifiability of each echelons' decisions can be improved. The BC structure can enhance workflow, transparency, traceability, visibility, and predictability, enabling the development of robust forecasts. Additionally, the shared data remains within the consortium's frame, providing a controlled environment (Queiroz *et al.*, 2019).

3.7.2 Categories of blockchain technology

According to Gourisetti *et al.* (2020), BC can be classified into three main categories: public, private, and consortium. The choice of BC type depends upon the information that needs to be shared. Public BC allow anyone to access and read the stored data, whereas private BC restrict access to authorized users only (Assaqtly *et al.* 2020). Consortium BC, on the other hand, allow certain users to have partial authorizations in specific areas (Qiao *et al.* 2018). These three types of BC offer different levels of privacy based upon the transactions and information recorded in the distributed ledger. An important feature of BC technology is the use of SCs, which are programs that can automate processes and perform calculations like a decentralized machine. SCs are activated when certain events occur and are agreements between network participants (Christidis and Devetsikiotis 2016). These capabilities have the potential to improve supply chain management in various stages and processes. The difference between these three categories is summarized in table 4.

Public: Anyone can read transactions, submit them (which will be accepted if they are valid), and take part in the consensus process. These platforms such as Ethereum, are secured by mechanisms such as proof of work or proof of stake.

Consortium: Consensus is controlled by a preselected set of nodes and rules for achieving consensus. The right to read the BC can be open for the public, and it can also be restricted to a set of known participants.

Private: permissions are kept centralized within a single organization. Reading permissions might be public or restricted to a set of known participants.

Table 4. The three categories of BC technology

<i>BC Feature</i>	<i>Public</i>	<i>Consortuim</i>	<i>Private</i>
<i>Consensus determination</i>	All nodes	Selected set of nodes	One node
<i>Immutability</i>	Almost completley tamper-proof	Potencial for tampering	Potencial for tampering
<i>Effeciency</i>	Low	High	High
<i>Centralized</i>	No	Partial	Yes
<i>Consesnsus Process</i>	Permissionless	Permissioned	Permissioned

4 SUMMARY OF THE PAPERS

The results of this research have both academic and managerial contributions. Theoretically, the result of the research fills some parts of the gap which is related to the relationship between the multiple aspects of IS and SCP. As the relationship between multiple aspects of IS and the BWE reduction is still far from completely understood, the findings of this research can also be used as a guidance for future research. Practically, the results of this research can help supply chain managers, both upstream and downstream, redesign their information sharing process by adopting BC technology to improve SC efficiency. Although understanding how inter-organizational coordination challenges arise, supply chain managers may consider adopting such disruptive technology in their supply chains. Further, the research can help suppliers and manufacturers to plan their operations in advance and assure their ability to use the shared information to fulfill the customer demand in a timely manner. Also, the results of the research can help customers, and suppliers develop a strategic relationship since BC technology supports secure and accurate IS. Moreover, the thesis results could motivate the will of supply chain managers to invest in BC. Consequently, by being aware of how such technology aligned with multiple aspects of IS impact the mitigation of BWE and inventory levels, customers and suppliers can both put in more effort to initiate coordination between them and together may get a win-win profit.

- **The First Paper** develops a conceptual architecture to illustrate how BC technology may reduce demand information distortion and thus mitigate BWE in the service supply chain. Intensive studies have been conducted to investigate the promises of BC technology holds in a manufacturing supply chain context. Regarding BWE, few studies have been dedicated to investigating such phenomena using BC. However, no study uses such technology to investigate the BWE in the service supply chain. Therefore, this study contributes to the field by paving the way for more future research regarding how the BWE is manifested in the service supply chain and if so, how such new disruptive technology could mitigate its negative consequences.
- **The Second Paper** has the aim is to shed light on the impact of multiple aspects of IS and to what extent the current literature covers such aspects in terms of BWE mitigation. By revisiting the study's results, most of the research papers consider the "why" aspect, i.e., "why to share information," which mainly focuses on the value and the importance of the information sharing. However, few studies devoted to investigating the other aspects

such as “what type to share,” “how to share,” with whom to share” and “how much to share.” Therefore, the study contribution is providing a new taxonomy of information sharing in terms of its aspects and their impact on the internal efficiency side of the supply chain, i.e., the BWE.

- **The Third Paper** develops a new coordination mechanism using BC an agent-based simulation model to share different types of information among the supply chain echelons and evaluate how they interact with each other in a heterogeneous environment. The ABM has been developed using NetLogo to represent the mathematical model that enables us to evaluate the impact of multiple aspects of IS on BWE reduction. Two main IS aspects have been considered in this study: “how to share information” and “what type of information to share”? In addition, we contribute to the literature that overlaps information systems (IS) and SCM on the adoption of emerging technologies (Faraj *et al.*, 2011; Gibson, 1979; Zammuto *et al.*, 2007), positioning our study in the overall literature on the adoption of supply chain technology, and we contribute to the supply chain inter-organizational coordination area via information sharing.

5 CONCLUSION AND LIMITATIONS

This thesis attempts to show how information sharing based on BC technology could be beneficial for the SCP with respect to the BWE mitigation. This thesis also investigates the potential benefits of using BC technology in service and manufacturing supply chain. In addition, this research identifies a set of IS aspects and explores how these aspects impact the mitigation of the BWE. In addition, the research also shows how inter-organizational coordination between supply chain echelons plays a focal role in improving SCP. This research shows how multiple aspects of IS can be used to improve the supply chain operational efficiency. The research also shows how using emerging technologies such as BC technology can have a direct impact on supply chain operations with respect to end-to-end demand visibility.

Furthermore, involving BC technology in the supply chain information sharing process will facilitate collaborative planning, improve demand forecasting accuracy, and mitigate inventory levels. This research addresses some of the gaps identified in previous research regarding the relationship between multiple aspects of IS and the BWE; however, the research does not cover all IS aspects. An alternative for future research is thus obviously to extend this research and explore this avenue. To address this linkage, a simulation study could be conducted to determine their impact on BWE mitigation. This research is limited to three research papers with simple assumptions. Thus, an alternative for future research is to include more sophisticated assumptions that better reflect the reality of the supply chain. For example, in the simulation study, we assume that all the echelons have unlimited capacity, but that is not always the case. Therefore, the model could enrich by considering capacity constraints in future research and investigate how such an assumption may affect the whole supply chain in terms of the BWE. Also, this research presents a conceptual framework that describes the use of BC technology in the service supply chain. Another relevant research avenue would be to conduct a case study in one of the service supply chains and investigate the existence of the BWE and use BC as a remedy to mitigate such phenomenon. This research takes a serial supply chain approach; however, demand-related information is shared between more actors in a supply chain than just adjacent ones. An alternative for future research is thus to extend this research to include more sophisticated supply chain structures such as divergent, convergent, and network supply chains and share related information between more than four echelons. The systematic literature review study is limited to the aspect of IS aspect and the BWE between 2015 and 2021, with a sample of 46 papers. Therefore, an alternative for future research is to

extend the research sample and interval to include more papers and different aspects of IS with a different performance metric. The research presented in this licentiate thesis could be extended to encompass a survey study regarding the willingness of supply chain echelons to implement the BC technology. Similarly, BC technology, like any ICT, has its costs. Therefore, another future research goal is to study the trade-off between the BC's benefits and costs in a supply chain context. Moreover, BC itself is a new database with distinct features; however, if it is used with IoT and AI, firms could make optimal use of it.

Many avenues of future research are considered but haven't been covered by this thesis. Therefore, we intend to conduct several studies using mathematical modeling, game theory, and simulation with other different assumptions. For example, in the third study, we used an agent-based simulation approach to model a serial supply chain. The intention is to develop the model assumptions to be more sophisticated and reflect the reality of complex supply chain systems. Moreover, we investigated two aspects of IS; however, a next study could shed light on bilateral information sharing using BC technology and how it affects BWE mitigation. Moreover, the BC in this study proved to be an effective remedy to facilitate the IS and thus mitigate the BWE. Therefore, a further research avenue could investigate the potential of BC technology in accessing two time series with a time lag. Furthermore, "when to share information" is rarely discussed in the literature. It would be a good idea to investigate how BC technology could help in this aspect.

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Paper A

Blockchain Technology for Information Sharing and Coordination to Mitigate Bullwhip Effect in Service Supply Chains.

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Blockchain Technology for Information Sharing and Coordination to Mitigate Bullwhip Effect in Service Supply Chains

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Abstract. Supply chain management experiences inefficiencies due to several reasons, such as the lack of information sharing and coordination among supply chain participants. Moreover, these participants may not share their information with other parties in the supply chain due to trust issues and considering such information as sensitive asset. This behavior may hinder the supply chain efficiency and motivate the occurrence of bullwhip effect (BWE). This phenomenon has been intensively investigated in manufacturing industries. In addition, information sharing has been considered the main remedy to eliminate BWE in literature. However, few attempts examined the effect of information sharing in reducing this phenomenon in service supply chain (SSC). Digitalization and computerization have the potential to convert and reshape the supply chains in all kind of businesses and improve the coordination among supply chain partners by exchanging real-time information. Blockchain as a disruptive technology has many distinct features like disintermediation and decentralization that provide integrity, visibility and security for the supply chain. To bridge this gap, this paper aims at proposing a blockchain architecture to mitigate BWE in SSC by improving end-to-end visibility among supply chain partners through sharing backlog information. The proposed supply chain-based blockchain enables SSC partners to share securely and transparent backlog information mitigating thus BWE.

Keywords: Digitalization · Blockchain technology · Information sharing · Bullwhip effect (BWE) · Demand amplification · Service supply chain (SSC)

1 Introduction

Supply chain management is developing dynamically over time. This is attributed to the growing of businesses and the pressure of the market and customers. Therefore, improvement of supply chain becomes an imperative need for businesses to keep a competitive advantage [1]. A supply chain includes a network of organizations that shares information and collaborates to produce and deliver products and services to the ultimate consumer [2]. Information transparency and coordination among supply chain partners are required to achieve this goal [3]. Hence, information sharing attracts a great attention in literature as a key tool giving supply chain collaborators the ability to plan, forecast, and produce [4]. Upstream parties, suppliers, conduct their demand forecasting relying on the available information that passed to them through the preceded party [5]. Supply chain parties, however, may not share their information with other parties, because they consider such information as a sensitive asset.

In addition, downstream parties, retailers, may share distorted information, particularly distorted demand information, in order to get advantages and thus affect the receiver's decisions [5]. These information distortions cause several problems in supply chain [6], mainly demand amplification. Jay Forrester [7] in 1961 firstly observed this amplification. This phenomenon has become known as bullwhip effect (BWE) [7], which refers to increasing fluctuations in demand as one moves up in the supply chain causing excessive inventory levels [3]. Plenty of studies investigating BWE state that to overcome this amplification, distorted information needs to be avoided and partners need to share demand information in a better way [8, 9]. Blockchain and other disruptive technologies; for instance, Internet of things (IoT) and artificial intelligence (AI) have the potential to transform supply chain [10] and logistics [11] and provide remedies for information asymmetric. Blockchain, which has been initially implemented in the context of cryptocurrency, Bitcoin, by Nakamoto in 2008 [12], is a shared database on a peer-to-peer network that stores and manages data. In addition, it has the ability to share different kinds of data instead of only financial transactions [13]. The implementation of blockchain technology has expanded into different industries, such as healthcare, market monitoring copyright protection, and supply chain management [14–18]. Recent literature on blockchain technology in the context of supply chain management shows an increasing interest to adopt and implement it [19]. Blockchain technology has been applied to improve supply chain performance and partnership efficiency [16] and used as a tool to transform supply chain management [20]. More importantly, it has been implemented for traceability [21], information sharing [22], green supply chain [23], and BWE mitigation in manufacturing supply chain [9]. Most of the works investigating BWE focused on manufacturing supply chains [6, 8, 24–26]. Nonetheless, Service Supply Chains (SSC) should also attract attention due to the increasing significance of services industry. To the authors' knowledge, no study has thus far considered blockchain technology to mitigate BWE in SSCs. Therefore, this paper aims at proposing a blockchain architecture to mitigate BWE in SSC by supporting visibility and transparency of the information along the whole SSC stages.

This paper consists of additionally four sections. Section 2 presents the introduction of this paper. Related work on BWE and the implementation of blockchain technology are presented in Subsects. 2.1 and 2.2. Section 3 introduces conceptual framework for the specific application. Section 4 demonstrate the blockchain architectural realization. Conclusion and future research are given in Sect. 5.

2 Literature Review

2.1 Bullwhip Effect and Information Sharing

BWE is one of the most investigated problem in supply chain management [27]; it is also considered as a forecast driven phenomenon [28], and it is a problem of information asymmetry [27]. BWE first was noticed in 1961 [7]; it refers to the gradual amplification of customers demand far from the actual one as it moves further across the supply chain echelons [29]. BWE occurrence in manufacturing supply chain attributes to numerous causes: price fluctuations, order batching, single demand forecasting, shortage gaming [6], and the lack of information sharing and coordination among supply chain partners

[30]. However, due to the nature of SSC, namely perishability, intangibility, simultaneous management of demand and capacity, and the customer-supplier co-production [31], the main cause of BWE in SSC is summarized by the fluctuations of backlog level, its impact on workload level, and the adjustment of capacity [32]. To clarify, BWE existence in SSC appears as a backlog amplification, increases in workload and changes in current capacity due to the delays in noticing, making, and implementing decisions regarding backlog information swings [32–36]. The fact is that BWE causes rely on one key root, which is the poor coordination and collaboration among supply chain partners [30]. In literature, information sharing is noted as a significant remedy to eliminate BWE [29, 37–39]. The table below illustrates the types of information utilized to mitigate BWE in literature (Table 1).

Table 1. Types of information sharing used to mitigate BWE

Authors	The shared information type
[24, 43–45]	Demand information
[40]	Sales information, point of sales (POS)
[41, 48, 51, 55, 56]	Inventory information
[42]	Demand and order information
[25, 49]	Order and inventory information
[46]	Order information
[47]	Demand forecast information
[50]	Ordered quantity information
[52]	Demand and warehouse lead-time information
[53]	Demand forecasting and lead-time information
[54]	Demand and lead-time information

2.2 Blockchain Technology

Blockchain technology can be described as a shared digital database of transactions, records, and events distributed throughout the network and which gives access to such data to authorized participants [57, 58]. Blockchain includes a chain of blocks that are linked together with an encrypted hash (code); each subsequent block holds the hash of the previous block which makes the chain secure, immutable and transparent. All participants (nodes) in blockchain network possess the same copy of the digital ledger [13]. There is no central authority controlling the network. In contrast, all the nodes can access and review the data in the real time [59]. In other words, blockchain technology can make the data visible and transparent for all parties that are allowed to enter the network [60], and it supports real time communications among them [20].

At first, blockchain technology was implemented in financial applications (i.e., cryptocurrencies) [12]. Unlike other information technology, blockchain distinct features

expand the utilization of such technology to different businesses: E-government [61], healthcare [62, 63], energy [64], banking [65], and supply chain management [13, 23, 66]. Blockchain applications in supply chain are growing considerably [60]. Plenty of studies focused on blockchain applications in sustainable supply chain [20, 58, 67, 68], products origins traceability [69], enhancement of supply chain resilience [70], collaboration and coordination in maritime supply chain [71], trust sharing [72], information sharing [73, 74], transparency [75], product origins monitoring [76], improvement supply chain partnership efficiency and performance [77], and BWE mitigation in manufacturing supply chain [9]. Few studies have been dedicated to track BWE in SSC [30, 32–35]. Additionally, only one single study has used blockchain technology to mitigate BWE in manufacturing supply chain [9]. As a result, this paper aims to propose an architecture applying blockchain technology to eliminate BWE in SSC.

3 Conceptual Framework

In this paper, we propose a blockchain architecture that focuses on sharing the accumulative number of unfulfilled orders (backlog data) among SSC partners to mitigate BWE [36]. The SSC structure is based on the model by Ellram et al. [78]. Also, our study considers the key stages of SSC service producer, service provider, customer, and other service partners. The focus of the proposed architecture is in supporting the visibility and transparency of the whole SSC by sharing the backlog data among service partners in order to maintain appropriate level of backlog and deliver the right service to the ultimate customer in the right time. Therefore, we consider the service provider as a vital stage that collects and monitors the backlog data in order to eliminate BWE. Sharing real-time backlog data with the upstream stages helps to avoid the occurrence of any management delays and other related consequences. Moreover, we use the hybrid blockchain system (consortium), which applies both permissionless (public) and permissioned (private) ledgers to secure certain information and limit participating in such network by central company (service provider) and share service information with the end customers.

4 Blockchain Architecture

Nakamoto [12] defines 6 steps for running a blockchain network. Some of these steps can be neglected based on the type of transactions are shared: distributed ledger, transaction, block creation, nodes, consensus algorithm, and adding new block [70]. Blockchain network gives access to all nodes, namely, all participants have the same copy of real-time backlog information, which is stored in a chain of blocks. Once the backlog information is added to a new block, the nodes (SSC parties) ensure that the added information is authenticated throughout a consensus algorithm [12]. Then, the new block is distributed through the whole network and linked with the previous blocks after the validation process [12].

Figure 1 illustrates the proposed framework to mitigate BWE through blockchain technology. The Proposed architecture is built based on the work of Akkhhmans and Voss [36], who investigated the occurrence of BWE in two SSC's: the installation of

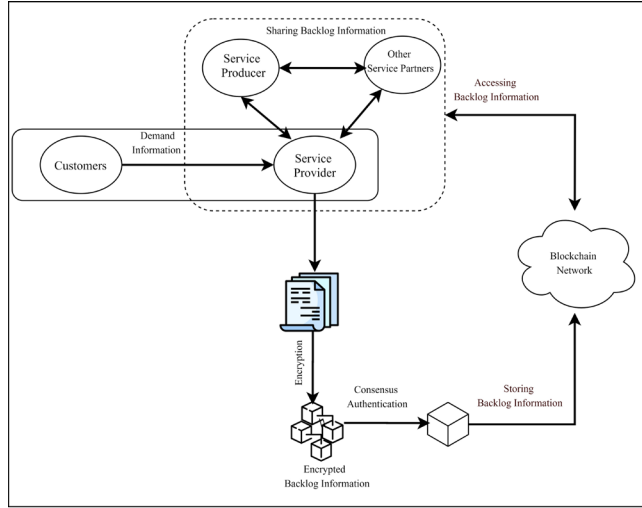


Fig. 1. Blockchain architecture to mitigate BWE via sharing backlog data.

customer broadband services and the installation of glass fibre network services. They found that BWE manifests itself in SSC in the form of variabilities in backlog information across SSC partners. In addition, they found that sudden increases of sales rate happen in customer's calls and complains. This in turn rises the workload for processing such backlogs, which leads to more burden on the companies' resources because it must be fulfilled by people not computers [36]. Additionally, they proposed five root causes of the occurrence of service bullwhip effect (SBWE).

As a result, this study sheds the lights upon the first root cause that concerns about delays and work backlogs, that represented in three main kinds of delays: 1) delays or failure in processing information, 2) delays in making further decisions regarding the sudden actions, 3) delays or failure in implementing adjustment decisions [36]. Therefore, we utilize blockchain technology as a remedy to mitigate the delays and failure of processing backlog information by improving the transparency among SSC parties in terms of sharing real time backlog information. The proposed architecture enables all SSC parties to access the same backlog information database (the database of unfulfilled orders). Additionally, it improves visibility among SSC parties by noticing the fluctuations of backlogs and taking further decisions regarding adjusting their resources in order to process these unfulfilled orders; for instance, adjusting the number of current employees or the current capacity and dividing the overload among SSC parties through outsourcing backlogs in order not to lose sales and maintain the customer satisfaction.

Here is a brief interpretation of the architecture flow: the service provider receives the demand information from customers. Unexpected demand fluctuations affects the service supplier's resources. Therefore, service providers face an accumulation of unfulfilled orders, called Backlogs. Blockchain technology can play a vital role to clear such unfulfilled orders and mitigate any amplification may occur to the service provider resources such hiring and firing employees. In this endeavour, service provider stores the unfulfilled orders information (backlog information) into blockchain network with a hash key. All

parties are involved in signing the backlog information. Then, the backlog information is distributed throughout the network. The service provider adds the backlog information to a block and the block is added to the chain. The new block having the backlog information is distributed throughout blockchain network and the SSC parties decrypt the backlog information and acquire the public key. The other parties in SSC check if the backlog information is signed by the authorized SSC parties. After that, the SSC parties get access to real-time backlog information following a validation process based on specific consensus algorithm and proceed to process the unfulfilled orders. This may mitigate the delays in processing the shared backlog information, which causes inefficiencies for the whole SSC parties.

5 Conclusion and Future Research

Blockchain technology has the potential to revolutionize SSC domain and introduce intelligent and efficient means to optimize its operations. Based on the work of Akkhmans and Voss [36], in this paper, we propose an architecture that takes advantage of such technology to mitigate the well-known BWE phenomenon in SSC. The architecture enables the SSC participants to share real time, secure and transparent backlog information. Backlog information sharing is the key pillar of the architecture as it eliminates the swings in service demand if it is stored and shared in real time. On the other hand, such architecture allows managers to notice the backlog variability in case sudden fluctuations hit service demand and enable them to take instant decisions towards any needed adjustments in order to fulfill the backlog levels before any amplification. Ultimately, the proposed architecture has the potential to improve the process of sharing timely backlog information through reducing delays and failures in SSC. Regarding future research, the proposed framework can be improved by applying the smart contracts technology among SSC participants. Further, the proposed architecture could be tested and validated by conducting an empirical study on service companies that would bring additional insights for researchers and practitioners.

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Paper B

The Impact of Information Sharing Aspects on Bullwhip Effect Mitigation: A Systematic Literature Review

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The Impact of Information Sharing Aspects on Bullwhip Effect Mitigation: A Systematic Literature Review

Abstract

Purpose: The purpose of this paper is to review, analyze and classify the research papers that uses information sharing as a remedy to mitigate the bullwhip effect for the period of 2015-2021, considering the different factors of information sharing such as why to share, what to share, how to share, with whom to share, how much to share, and in which direction to share.

Design-methodology and approach: Systematic Literature review was conducted. It produces reliable knowledge, performs an objective measure to analyze the literature of emerging topics quantitatively, and identifies gaps that can be addressed in future research.

Findings: The results show that “why, what, and how to share” are the most investigated factors, emphasizing thus the type and the value of sharing information. In contrast, only a few attempts have been made to investigate with whom to share, how much to share, and the sharing direction of the information flow. Concerning the supply chain structure, serial and dyadic supply chains are the most studied. Therefore, a lack of research tackling convergent and divergent supply chains and the importance of multiple factors of information sharing is needed.

Research Limitations -Implications: The used methodology presents how different information sharing factors affect the supply chain performance in terms of bullwhip effect mitigation and the use of emerging technologies to reduce the negative impact of such phenomenon.

Practical Implications: The impact of information sharing factors are highlighted to facilitate the inter-organizational coordination among supply chain partners. The need to improve information sharing structure among different entities emerge. New research paths that coming from the less investigated information sharing factors are presented.

Originality-Value: The novelty of the paper is the introduction of new classification and the investigation of the impact of multiple information sharing factors on mitigating the bullwhip effect.

Key words: Coordination, Information Sharing Factors, Information Sharing, Bullwhip effect, Information Systems, Emerging Technologies.

1. Introduction

Firms are facing new challenges due to the dynamics of the business environments and the competitiveness induced by globalization. The significance of supply chain management (SCM) has become more apparent as firms don't have alone the required capacity to fulfill the customer's demand. Companies need to cooperate and be part of a well-coordinated supply chain in order to achieve the goal of serving their customers efficiently and effectively (Holgado *et al.*, 2020)

SCM proposes a set of strategies and methods in order to consolidate and connect different parties (suppliers, manufacturers, distributors, and retailers) with the purpose to produce and transport the products to the end customers in the right quantities and qualities at the right time and the right price aligned with total costs reduction and high service level (Fu *et al.*, 2014; Mbhele and Phiri, 2016). Zhang *et al.*, (2019) state that SCM also concerns two essential objectives: global optimization and uncertainty reduction. Effective and efficient supply chain management appears to depend on trust, strong coordination, active communication, and business process collaboration (Mbhele and Phiri, 2016). However, trust and coordination seem to be difficult to realize among supply chain partners.

Lack of coordination and trust as well as focusing on local optimization without considering the impact of such decisions on upstream tiers leads to poor supply chain performance (SCP) (Disney and Lambrecht, 2008; Costantino, *et al.*, 2015). In particular, poor coordination among supply chain echelons increases the demand uncertainty due to forecasts based rather on orders received from the downstream tiers (Ali *et al.*, 2020). The existence of asymmetric information along the tiers amplifies the demand variance in the supply chain as one proceeds further upstream from the final tier. This amplification is known as the BWE (Babai *et al.*, 2015).

According to Forrester (1961), inventory levels and loss of efficiency upstream are exaggerated by small fluctuations in consumer demand downstream the supply chain. Forrester observed that such swings in customer demand produce massive increases in material orders as they move to the upstream parties. Moreover, Sterman (1989) demonstrated the BWE using the beer distribution game, which stresses the importance of information sharing (IS), and collaboration (Jiang and Ke 2019). The term BWE was coined by the seminal work of Lee *et al.* (1997). Lee *et*

al. (1997) presented four main causes of the BWE: demand signal processing, batch ordering, price fluctuation, and the shortage game. In addition, they stated that the distortion of demand information triggers the BWE in the supply chain resulting in negative impacts on its performance e.g., excessive inventory levels, poor customer service, increases in raw material costs (Cannella *et al.*, 2015), lost profits owing to shortages, and inconsistency in production planning and scheduling (Giard and Sali 2013; Mbhele and Phiri, 2016).

Several published research results conclude that the main cause of the BWE is the lack of coordination and information sharing among supply chain members, as well as the delays and distortions that occur when the information is transmitted upstream (Forrester, 1961; Sterman, 1989; Lee *et al.*, 1997; Zhang, 2004; Lampret and Potočan, 2015; Wood *et al.*, 2016; De Almeida *et al.*, 2017; Gonul Kochan *et al.*, 2018). Several other research papers (Sahin and Robinson, 2002; Dong *et al.*, 2014; Babai *et al.*, 2015; Gonul Kochan *et al.*, 2018) address the development of various remedies to reduce the BWE by implementing different types of coordination mechanisms to improve information visibility, such as quick response (QR), vendor managed inventory (VMI), collaborative planning, forecasting, and replenishment (CPFR), and efficient consumer response (ECR).

Information sharing (IS) is regarded as the essence of all coordination mechanisms within the supply chain (Deghedi, 2014). Therefore, IS has been intensively investigated in the literature as the most effective remedy to reduce the BWE (Costantino *et al.* 2015; Jeong and Hong, 2019; Tang *et al.*, 2020). Deghedi (2014) asserted the importance of IS in facilitating the decision-making process and its significant impact on the entire chain. IS ensures the reduction of information distortions and delays, which in turn reduces the BWE (Jiang, 2019). IS directly influences the production scheduling, inventory levels, and delivery plans, emerging thus as one of the most effective ways to improve supply chain efficiency and effectiveness (Cheng, Law *et al.*, 2010; Deng *et al.*, 2019; Pishdad-Bozorgi *et al.*, 2020).

To enable coordination based IS, Jeong and Hong (2019) emphasize the importance of identifying different factors of IS such as “what to share?”, “how to share?”, and “with whom to share?”, while Ojha *et al.* (2019) focus on “how much?” and “what type?” factors in order to improve coordination and supply chain performance.

Deghadi (2014) investigates the benefits and challenges of supply chain IS in terms of “what” “to whom”, and “how to be shared” in order to optimize competitiveness and profitability. Kembro and Näslund (2014) conducted a literature review on multi-echelon IS in terms of “why”, “what”, “how”, “barriers to share information”, and “IS driving costs”. Their study empirically evaluates the benefits of IS in the supply chain. Lee and Minner (2021) provides a review on IS for supply chain networks, including “what information to share”, “when to reveal it”, and “how to share it”. Their review focuses on a strategic framework when information is inconsistent and the impact of various sharing behaviors on supply chain performance. Giard and Sali (2013) analyzed 53 articles with respect to 13 coordinates: type of information shared, performance measures, demand models, impact analysis, causes of the BWE, supply chain features, inventory control model, and the method of modelling offering new insight on bullwhip. Regarding operational decisions, Frutos *et al.* (2020) classify them into three categories: information exchange, VMI, and synchronized supply chain. For each category, they identify different aspects such as the structure of the supply chain, forecasting models, replenishment policies, demand features, and the assumptions embodied in the examined research papers. Vosooghizaji *et al.* (2019) conducted a systematic review for the period 2000-2018 focusing on the coordination of supply chains in the presence of information asymmetry. The classification of the literature emphasizes the supply chain characteristics, the applied methods, the mechanisms of coordination, and the types of information asymmetry. Cannella *et al.* (2015) state that one of the most important challenges faced by the operations management community is developing strategies to reduce BWE.

It should be noted that most of the previous research review works have focused either only on empirical studying of some ISFs such as “what”, “how”, and “with whom to share” or on evaluating its benefits in the research field. , this paper contributes the following:

- 1) We propose a novel classification for the role of six ISFs in reducing the BWE. We also analyze the current status of the implemented ISFs in terms of BWE reduction in order to identify the effect of ISFs on SCP.
- 2) This paper investigates six ISFs in the form of the following questions: “Why to share information?”, “What information to be shared?”, “How to share

information?”, “With whom to share information?” and “How much information to share?” while previous reviews have only dealt with two or three factors of information sharing.

- 3) This study emphasizes the effect of ISFs on improving supply chain performance with respect to BWE mitigation exclusively.
- 4) This paper attempts to highlight new trends and gaps in the literature on ISFs by investigation *to what extent the papers reviewed have considered multiple ISFs and investigated their combined impact on the BWE.*

The rest of the paper is organized as follows: Section 2 describes the research method and section 3 presents the paper’s thematic analysis. Section 4 comprehensively introduces the research findings, while section 5 concludes with further research directions.

2. Methodology

A Systematic literature review (SLR) should produce reliable knowledge and should provide in-depth practices in the research field while it should also identify gaps that can be addressed in future research (Tranfield *et al.*, 2003). The research review attempts to analyze, organize, and categorize the relevant literature on information sharing factors (ISFs) with respect to BWE mitigation, to identify issues not covered, and thus reveal new research directions. To achieve this, the following steps have been followed: (1) identify data, (2) extract and synthesize data, and (3) analyze and disseminate data (Tranfield *et al.*, 2003). Figure 1. produces the schematic framework that was adopted. Each stage reflects the number of retrieved papers.

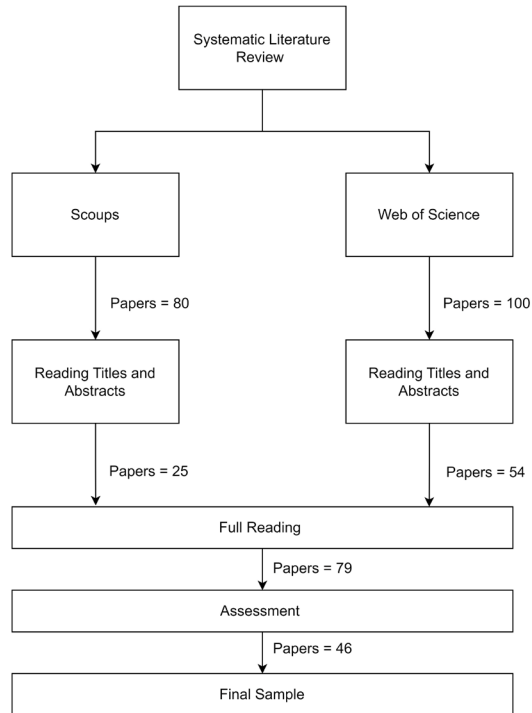


Figure 1. Schematic Representation of the SLR method
(Tells and Bonilla, 2018)

2.1 Data identification

This section provides information about the identification of search keywords, data sources, and literature selection used in the current study. We identified strings and keywords by examining several research papers, which included both review papers and research articles (Deghedi, 2014; Giard and Sali, 2013; Kembro and Näslund, 2014; Moll and Bekker, 2013; Wang and Disney, 2016). We subsequently constructed combinations of keywords that involve or relate to the following terms: IS, BWE mitigation, SCM, and coordination. Our search process went through two rounds. Table I shows the first keyword set that consists of specific strings.

Table I.
Keywords and search terms used in the systematic review (first set).

		[shar*] or		[bullwhip] or		[mitigat*] or [reduc*] or
		[flow] or		[demand amplification] or		
[Information]	AND	[exchange] or [transfer]	AND	[demand propagation]	AND	[dampen] or [lessen*]
Example of combination: “information” AND “share*” AND “bullwhip” AND “mitigat*						

The second set of keywords consists of more general strings in order not to miss related literature (see Table II).

Table II.
 Keywords and search terms used in the systematic review (second set).

[bullwhip]	AND	[mitigation] or	AND	[supply chain] or
		[reduction]		[coordination]
Example of combination: “bullwhip” AND “mitigation” AND “supply chain”				

To identify literature the search utilized the Web of Science, Scopus, and google scholar as primary databases for the time period from 2015 to 2021. 100 and 80 articles respectively were extracted in the first round, and 46 and 55 articles were extracted from Scopus and Web of Science databases in the second round respectively. After removing duplicated records, a total of 149 articles were left and after removing conference papers and non-English papers, a total number of 119 articles remained.

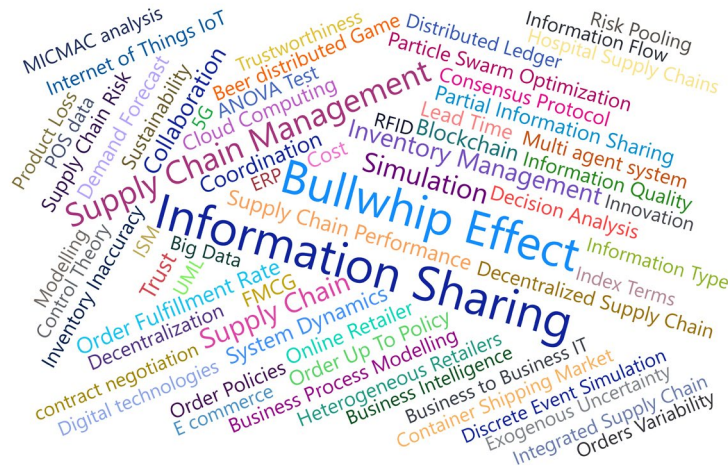
2.2 Data extraction and synthesis

We scanned and inspected the articles by title, abstract, and keywords to evaluate their relevance to the research objectives. This resulted in 57 articles being identified as irrelevant, leaving a sample of 62. Subsequently an in-depth examination of these articles excluded 16 leaving 46 articles which were organized in an Excel sheet that was developed for this purpose. The sheet stores two types of summaries for each paper: the general publication details (topic, the authors, publication year, and the journal), and the key aspects of the paper, namely supply chain structure, number of echelons, information type shared, ISF’s, coordination tool, supply chain performance metrics, and key findings.

2.3 Data analysis and dissemination

This section provides descriptive and thematic analysis of the research sample. We used Mendeley as reference management software to organize and manage the 46 articles and VOS viewer to visualize and identify the connection between keywords. In addition, we used Microsoft Excel to manage the articles and identify the categories and sub-categories. To analyze and visualize the articles, we imported them to Microsoft Power BI which is a powerful free software.

This subsection provides the descriptive findings of the research sample. Figure 2 illustrates the word cloud analysis of sample keywords. It indicates that the BWE and IS are the most frequent keywords. However, SCM, collaboration, coordination, and simulation come in the second group of appearance frequency.



The density and network diagrams analysis of key words co-occurrence is shown in Figure 3 and Figure 4. Based on this analysis, we have only kept the keywords that occurred at least three times. This resulted in having 24 out of 96 keywords which constitute the largest usable terms. The eight most occurring keywords are IS (41), BWE (39), Supply Chain Management (19), Simulation (12), Inventory Management (9), Collaboration (7), Trust (6), and Coordination (5).

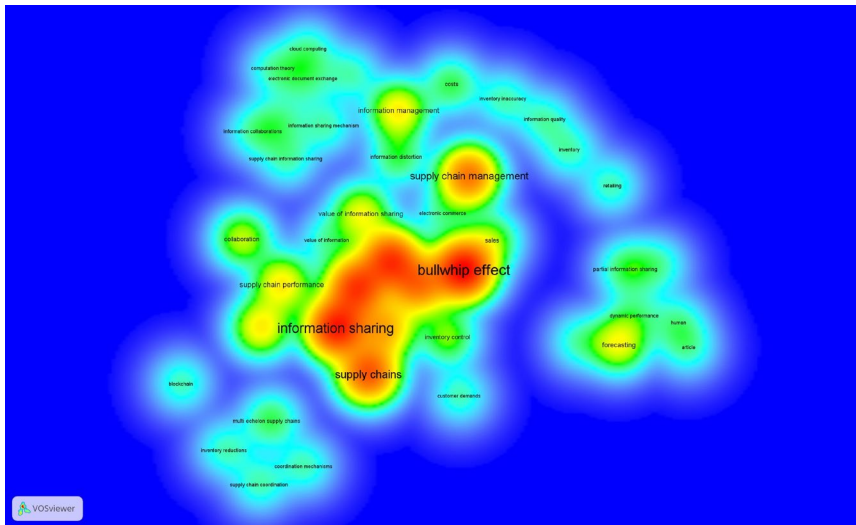


Figure 3. Density Diagram of the co-occurrence of Keywords

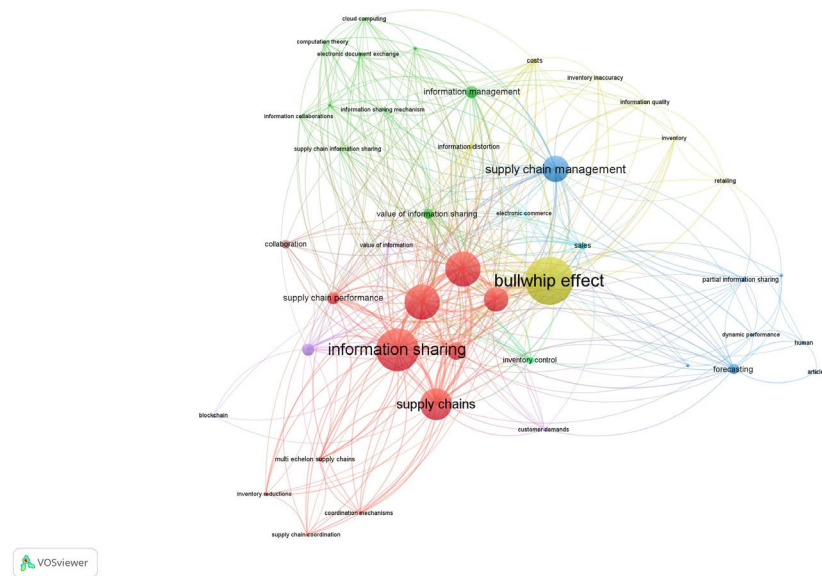


Figure 4. Network Diagram of the co-occurrence of Keywords

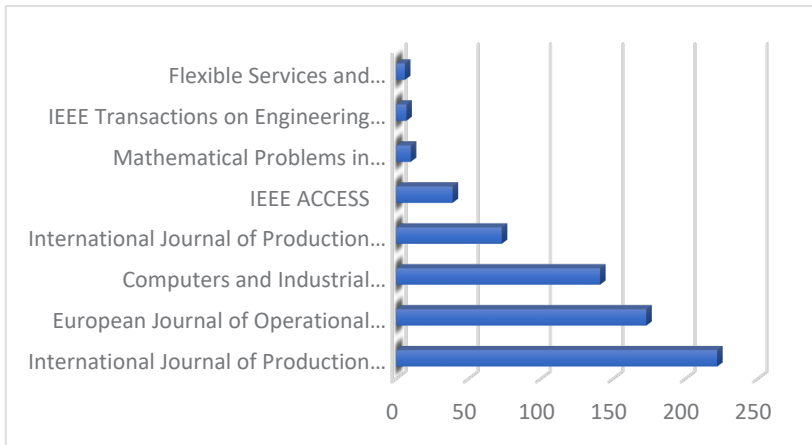


Figure 5. Citations of the selected articles per journal.

Figure 5. presents the citations of the selected sample is published per journal. The International Journal of Production Economies has the highest citation rate, followed by the European Journal of Operational Research as the next most-cited journal. More details are given in Table III.

Table III.

Journals names arranged according to the number of selected articles.

Journal name	Number of publications	Citations
International Journal of Production Economics	3	222
European Journal of Operational Research	3	173
Computers and Industrial Engineering	2	141
Flexible Services and Manufacturing Journal	2	6
IEEE ACCESS	2	39
IEEE Transactions on Engineering Management	2	7
International Journal of Production Research	2	73
Mathematical Problems in Engineering	2	10
Other	34	384

Table III reports the journals according to the number of published papers and its citations rate. Both International Journal of Production and European Journal of Operational Research are present with three articles in the selected sample and with 222 and 173 citations respectively. The other Journals have the same number of published papers, which is two articles. Moreover, the other 41 journals differ in citation rate which varies from 10 and 141.

Table IV.
The 10 most cited articles among the selected ones.

	Reference	Journal name	Publication n Year	Citation s
1	Gonul Kochan et al	International Journal of Production Economics	2018	132
2	Cannella et al	European Journal of Operational Research	2015	80
3	Costantino et al	Computers and Industrial Engineering	2015	79
4	Huang et al	Computers and Industrial Engineering	2017	62
5	Dominguez et al	Omega-International Journal of Management Science	2018	55
6	Dai et al	European Journal of Operational Research	2016	51
7	Ojha et al	International Journal of Production Economics	2019	51
8	Yang and Fan	International Journal of Production Research	2016	48
9	Teunter et al	European Journal of Operational Research	2018	45
10	Babai et al	Intenational Journal of Production Economics	2016	39

Table IV presents the most cited articles per journal. Gonul Kochan *et al.* (2018) is the most cited article in the research sample, followed by Cannella *et al.* (2015) as the second most cited article. The other articles approximately have the same citation rate, i.e., the variance is low.



*Figure 6. The geographic distribution based on the location of the first author
(Further details are given in Table V)*

Figure 6 shows a map of the authorship distribution of the sample articles. With respect to continents, Asia, with 8 countries, came first in terms of the number of published articles, followed by Europe with 7 countries and South America in the third place with two countries. North America, Australia, and Africa, which ranked

equally in the final position, each with only one representing country. The identified countries and their contributions are listed in Table V.

Table V.

First author's geographical location

Rank	Country	Articles	Percentage	Rank	Country	Articles	Percentage
1	China	14	30.43%	5	France	1	2.17%
2	India	4	8.70%	5	Greece	1	2.17%
2	Italy	4	8.70%	5	Iran	1	2.17%
3	Spain	3	6.52%	5	Japan	1	2.17%
3	USA	3	6.52%	5	Jordan	1	2.17%
4	Australia	2	4.35%	5	Malaysia	1	2.17%
4	Egypt	2	4.35%	5	Slovenia	1	2.17%
4	Netherlands	2	4.35%	5	South Africa	1	2.17%
5	Brazil	1	2.17%	5	South Korea	1	2.17%
5	Chile	1	2.17%	5	Taiwan	1	2.17%
Total		20 Countries				46	100 %

According to Table V, the sample consists of various authors from at least 20 different countries, with China at the top, followed by India and Italy in the second place, Spain and USA in the third, and three countries (Australia, Egypt, and the Netherlands) in the fourth place. All other listed countries contribute to the sample with one publication.

3. Thematic Analysis

The classification scheme of the ISFs in terms of BWE mitigation, six main themes have been categorized (Figure 6). However, we let the sample also guide us to generate trends and gaps in the literature and attempt to draw a roadmap for further research.

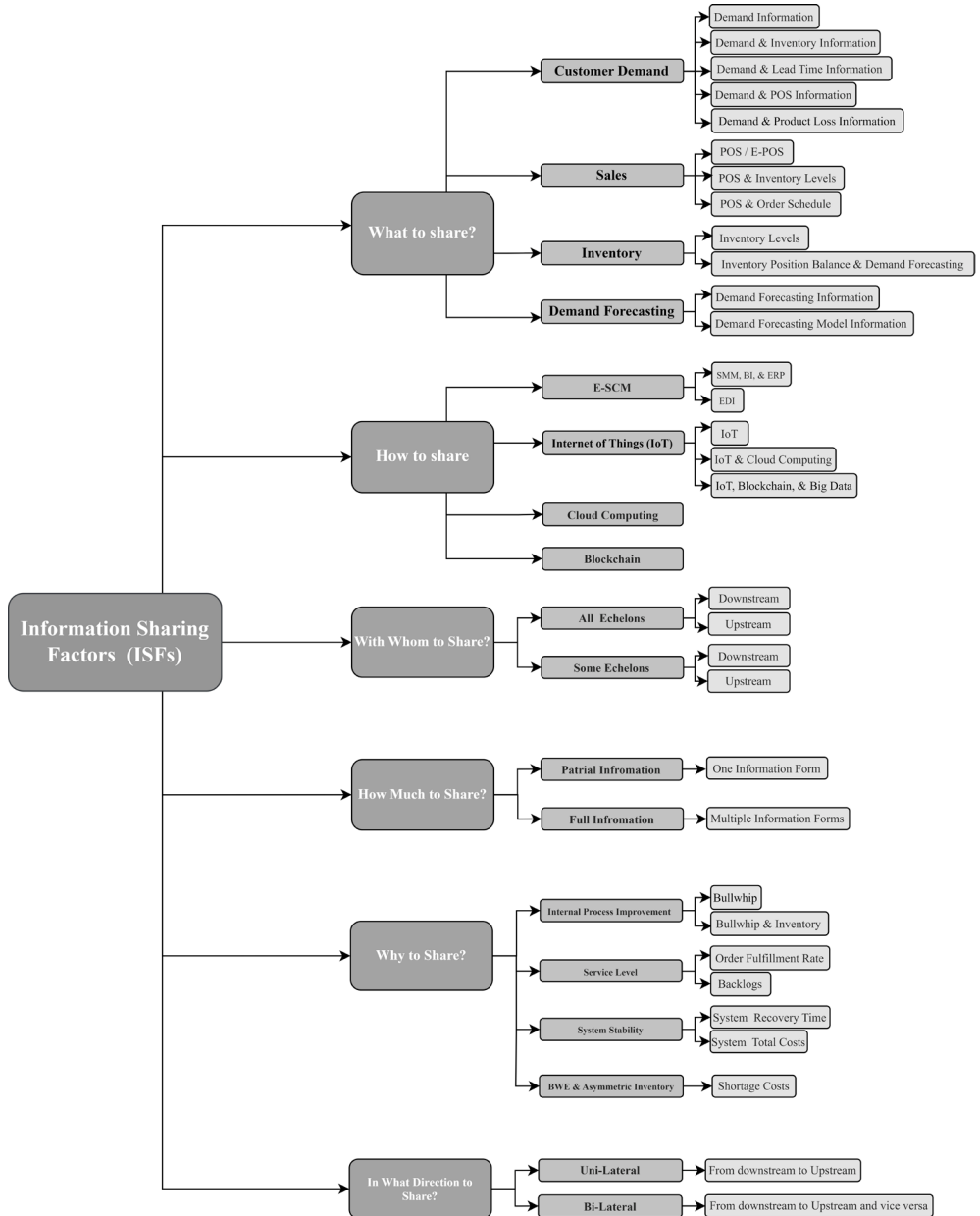


Figure 7. The Proposed Classification of ISFs.

The first aspect of the classification describes the types of shared information in the selected articles. The second aspect demonstrates the various methodologies (IS means and IT systems) which facilitate the sharing of information. The third aspect presents the need for the best partner to reveal the related information to guarantee mutual benefits and goals for sharing operational information and the direction of the information flow. The fourth aspect concerns the degree of IS in terms of how much the negative effect of BWE is reduced when transmitting and sharing information on time. The fifth aspect produces the direction of information flow; is it Uni-lateral or Bi-lateral information flow? Lastly, the sixth aspect shows the value of sharing information by improving different key performance indicators (KPI's) related to BWE reduction, service level improvement, and reducing the inventory levels and its holding costs.

Table VI.

The ISFs with SC design and the number of echelons.

IS Factors	Authors	SC Design	# of Echelons
What to Share?			
	Jeong and Hong., (2019)	Serial	4
	Jin., (2019)	Dyadic (M-R)	2
	Lopez-Campos <i>et al.</i> , (2017)	Serial	4
	Ojha <i>et al.</i> , (2019)	Serial	3
	Pamulety and Pillai, (2016)	Serial	4
	Wang <i>et al.</i> , (2016)	Dyadic (M-R)	2
How to Share?			
	Algharabat <i>et al.</i> , (2015)	Serial	4
	Ghode <i>et al.</i> , (2021)	Serial	4
	Gowda and Subramanya, (2017)	Serial	5
	Jiang and Ke, (2019)	Serial	3
	Jiang, (2019)	Serial	4
	Ran <i>et al.</i> , (2020)	Dyadic (S-R)	2
	Sarfaraz <i>et al.</i> , (2021)	Serial	4
	Teunter <i>et al.</i> , (2018)	Dyadic (M-R)	2
	Xue and Dou, (2020)	Serial	4
	Zhang and Gong, (2021)	Serial	5
With Whom to Share?			

	Dominguez <i>et al.</i> , (2017)	Divergent	
	Dominguez <i>et al.</i> , (2018)	Divergent	
	Dominguez <i>et al.</i> , (2020)	Serial	
	Gao <i>et al.</i> , (2020)	Serial	
How Much to Share?			
	Zhang <i>et al.</i> , (2019)	Serial	3
In Which Direction?			
	Sarfaraz <i>et al.</i> , (2021)	Serial	4
Why to Share?			
	Ali <i>et al.</i> , (2020)	Serial	5
	Babai <i>et al.</i> , (2015)	Dyadic (M-R)	2
	Cannella <i>et al.</i> , (2018)	Serial	4
	Cannella <i>et al.</i> , (2015a)	Serial	4
	Cannella <i>et al.</i> , (2015b)	Serial	4
	Costantino <i>et al.</i> , (2015)	Serial	4
	Dai <i>et al.</i> , (2016)	Dyadic (M-R)	2
	Drakaki and Tzionas, (2019)	Serial	4
	Ezaki <i>et al.</i> , (2021)	Serial	4
	Huang <i>et al.</i> , (2017)	Convergent (5S-1R)	6
	Li <i>et al.</i> , (2016)	Divergent	3
	Lu <i>et al.</i> , (2017)	Dyadic (M-R)	2
	Pamulety <i>et al.</i> , (2017)	Serial	5
	Seifbarghy <i>et al.</i> , (2017)	Network	6
	Shaban <i>et al.</i> , (2019)	Serial	6
	Shaban <i>et al.</i> , (2020)	Serial	6
	Tang <i>et al.</i> , (2020)	Serial	4
	Yang and Fan, (2016)	Dyadic (M-R)	2
	Zhao <i>et al.</i> , (2018)	Convergent (4S-1R)	5

We can notice from Table VI that 65% of the published research articles have investigated the different factors of IS in a serial linked supply chain while two-stage supply chain, divergent, convergent, and network supply chain correspond to 20%, 8%, 5%, and 2% respectively.

4. The Findings

In this section we present the results concerning several information sharing factors for the mitigation of the BWE in the research sample. As shown in table VII “why to share” is the most investigated aspect with 46% of research sample followed by “How to share” with 24% “What to share” with 14%, “With whom to share” with 10% and finally “In which direction to share” and “How much to share” with 2.5%.

Table VII.

The number of papers for each ISFs

ISFs	Number of Papers
What to Share	6
How to share	10
With whom to share	4
How much to share	1
In which direction to share	1
Why to share	19
Total	41

4.1 What information to share?

This section discusses the different types of information that the authors have used to mitigate the BWE in two-fold. Firstly, the papers that investigate the BWE mitigation considering information sharing type as part of their mathematical models (see Table VIII). Secondly, the papers that consider the information sharing type as a main aspect for BWE mitigation (see Table IX).

Table VIII.

Classification of the articles discussing “the type of information shared” in their models.

What to share	Authors
Demand Forecasting	Jeong and Hong, (2019)
Customer Demand	Lampert and Potočan, (2015) Pamulety and Pillai, (2016)
POS and Inventory levels	Lopez-Campos <i>et al.</i> , (2017)
Customer Demand and Inventory levels	Ojha <i>et al.</i> , (2019)
POS and Ordering Schedule	Wang <i>et al.</i> , (2016)
Customer demand and POS	Jin, (2019)

Table IX.

Classification of the articles that investigate “what to share” particularly.

What to share	Authors
Customer Demand	(Algharabat <i>et al.</i> , 2015; Babai <i>et al.</i> , 2015; Cannella <i>et al.</i> , 2015; Dominguez <i>et al.</i> , 2017; Lampret and Potočan, 2015; Pamulety and Pillai, 2016; Wood <i>et al.</i> , 2016; Yang and Fan, 2016; Cannella <i>et al.</i> , 2018; Gowda <i>et al.</i> , 2017; Jiang and Ke, 2019; Jiang, 2019; Pamulety <i>et al.</i> , 2017; Teunter <i>et al.</i> , 2018; Ali <i>et al.</i> , 2020; Ghode <i>et al.</i> , 2021; Jin, 2019; Ran <i>et al.</i> , 2020; Xue <i>et al.</i> , 2020; Li <i>et al.</i> , 2016).
POS \ E-POS	POS (Huang <i>et al.</i> , 2017; Seifbarghy <i>et al.</i> , 2017), E-POS (Tang <i>et al.</i> , 2020)
Inventory Levels	(Dai <i>et al.</i> , 2016; Zhang and Gong, 2021)
Demand Forecasting	(Dominguez <i>et al.</i> , 2021; Jeong and Hong, 2019; Zhao <i>et al.</i> , 2018)
Customer Demand & Inventory Levels	(Costantino <i>et al.</i> , 2015; Gonul Kochan <i>et al.</i> , 2018; Lopez-Campos <i>et al.</i> , 2017; Lu <i>et al.</i> , 2017; Van Engelenburg <i>et al.</i> , 2018; Drakaki and Tzionas, 2019; Ojha <i>et al.</i> , 2019)
Customer Demand & Lead Time	Sarfaraz <i>et al.</i> , (2021)
Customer Demand & Product Loss	Gao <i>et al.</i> , (2020)
POS & Inventory Levels	Cannella <i>et al.</i> , 2015; López-Campos <i>et al.</i> , (2015)
POS & Order Schedule	Wang <i>et al.</i> , (2016)
POS & Customer Demand	Jin, (2019)
Inventory Position Balance & Demand Forecasting	(Shaban <i>et al.</i> , 2019, 2020)

Table VIII shows that customer demand information is the most common form used to mitigate the BWE (41%) followed by customer demand and inventory levels (15%). The other forms vary between (2%-6%).

Table IX lists the papers that investigated the impact of different types of IS to mitigate the BWE reduction as focal unit of analysis. In the following, the articles are discussed in detail.

Lampert and Potočan (2015) investigate the impact of demand forecasting, inventory management, and production planning information on BWE reduction considering the role of organizational culture. The authors state that only sharing information is not enough to mitigate the BWE. However, it is more beneficial to share the proper type of information.

Wang *et al.* (2016) present an analytical solution in order to examine the value of sharing customer demand and order quantity information to mitigate inventory BWE. They assume that the retailer faces a price-dependent demand pattern that follows AR (1) process. Four different scenarios are applied (NIS, retailer's demand

with order price IS, DIS, and market price IS). They analyze four KPI's; the price correlation, demand shock error, price sensitivity and price shock error. Sharing both customer demand and order information is the most superior setting for both retailer and manufacturer.

Pamulety and Pillai (2016) discuss three types of demand information; periodic customer demand, historical customer demand, and customer demand distribution using game experiments and statistical analysis. The distribution of customer demand information shown to be the most valuable form with respect to BWE reduction

Lopez-Campos *et al.* (2017) present an IS process algorithm involving inventory levels (on-hand inventory, work in process, and inventory position) to determine which information must be shared to mitigate the BWE. Five KPI's are used; bullwhip slope, inventory instability slope, inventory variance ratio, order variance ratio and fill rate. The authors argue that to reduce the BWE, supply chain partners should share customer demand information, safety stock, lead time, on-hand inventory and work in process for all supply chain echelons. The inventory position, desired safety stock, and demand forecasting information are desired to achieve synchronized order quantity.

Ojha *et al.* (2019) simulate the impact of historical demand and supplier's delivery lead time, the previous plus lead time variance information, demand forecasting and demand variance information on BWE mitigation. BWE and order fulfillment rate (OFR) are selected as KPI's. The results show that Bi-lateral IS between manufacturer and supplier reduce the BWE thus improve the order fulfillment rate.

Jin (2019) investigates the impact of two IS type; customer demand information (CDIS), and retailer's POS information (RPOS). It is concluded that CDIS outperforms RPOS and reduces the BWE by 97.15% and RPOS reduces the BWE by 96.44%. Both information types have a significant impact on the reduction of BWE.

4.2 How to share

This Section discusses the technologies and IT tools that have been considered in SC coordination to facilitate information sharing process among partners to mitigate the BWE (see Table X).

Table X.

Classification of the articles on “how to share” with respect to IT tools

IT Tools	Authors
E-SCM	Mbhele and Phiri, (2016)
SMM, BI, and ERP	Algharabat <i>et al.</i> , (2015)
EDI	Lampret and Potočan, (2015) Seifbarghy <i>et al.</i> , (2017)
IoT	Jiang and Ke, (2019) Zhang and Gong (2021)
IoT and Cloud-Computing	Jiang, (2019)
IoT, Blockchain and Big Data	Ran <i>et al.</i> , (2020)
Cloud-Computing	Gounl Kochan <i>et al.</i> , (2018) Gowda and Subramanya, (2017)
Blockchain	Ghode <i>et al.</i> , (2021) Sarfaraz <i>et al.</i> , (2021) Van Engelenburg <i>et al.</i> , (2018) Xue and Dou, (2020)

We can notice from table X that blockchain technology and IoT are the most applied technologies followed by cloud computing implementation. The rest of the IT tools appear with smaller frequency in the sample.

4.2.1 Electronically enabled-supply chain (E-SCM)

Mbhele and Phiri (2016) investigate the impact of e-SCM on the mitigation of the BWE in FMCG industry. Factor analysis-based questionnaire with a sample of 460 respondents is analyzed. They consider four pre-formulated thematic evaluations, i.e., BWE, IS, inventory positioning, and optimization strategies. The results show that e-SCM system enable IS and integration among SC partners at processes level. Moreover, 75% of respondents state that IS and e-SCM have a positive impact on controlling the BWE by enhancing active connectivity, enabling responsiveness and agility for supply chain partners.

4.2.1.1 Social Media Monitoring (SMM), Business Intelligence (BI), and Enterprise Resource System (ERP)

Algharabat *et al.* (2015) empirically investigate the mitigation of BWE using ERP, BI, and SSM tools. They designed a questionnaire targeting marketing experts and implemented a structural equation model to evaluate 14 indicators. The results show

that a combination of SMM, BI, AND ERP systems ensures the quality and accuracy of customer demand information on Web and reduces the information distortions and delays, which in turn, mitigates the BWE.

4.2.1.2 Electronic Data Interchange (EDI)

Lampret and Potočan (2015) build an EDI system that is capable of recording POS data and demand information. They assume that coordination among SC echelons through the EDI system could improve the demand forecasting, inventory management, and production planning. They conclude that common goals, integrated functioning, proper information flow, information accessibility, and accuracy mitigate the BWE on upstream level and avoids excessive inventory.

Seifbarghy *et al.* (2017) propose an EDI system as enabler to share POS data in network supply chain structure considering a delay in products transportation. They prove that sharing POS data is significant to reduce the BWE.

4.2.2 Internet of things (IoT)

Jiang and Ke (2019) simulate the impact of IoT-based IS on the BWE reduction in three-tier tourism supply chain: travel agencies, tour operators, and service suppliers. They reveal that using IoT technology facilitate the exchange of tourist's demand information enabling them to forecast customer demand accurately and reduce the service lead time.

Zhang and Gong (2021) simulate the value of inventory IS on the BWE alleviation using IoT technology, Electronic Product Code (EPC). The findings indicate that 12% of operational costs are reduced by sharing inventory levels in each echelon in comparison with NIF scenario. The IoT-based platform allows the supply chain partners to achieve high coordination level reduces the inventory uncertainty and the BWE.

4.2.2.1 IoT and Cloud Computing

Jiang (2019) simulate the mitigation of BWE using IoT and cloud computing technologies with respect to information sharing. The results show that IoT can reduce the BWE through accessing updated and accurate demand information which reduces holding costs. They conclude that the reduction of demand distortions leads to a reduction excessive inventory probability reducing the BWE. In addition, constant auto-correlation coefficient with constant lead time is noticed to reduce the BWE to a smaller value.

4.2.2.2 IoT, Big data Analytics, and Blockchain

Ran *et al.* (2020) examine the effect of IS-based digital technologies (DTs) on the reduction of BWE considering stochastic demand pattern. They propose a joint revenue-cost sharing contract using game theory in order to reduce order and production quantity. The BWE could be mitigated if the degree of DTs implementation equals 1; the application of a higher DTs degree could reduce the BWE, however, it makes the production cost higher. In addition, they argue that adopting a higher/lower level blindly could harm the whole SCP, namely, if the BWE exists to a small degree and the costs of implementing digital technologies is high, then the higher degree of implementation the worst the SCP is.

4.2.3 Cloud Computing

Gowda and Subramanya (2017) analyze the BWE mitigation with analytical hierarchy process (AHP) using cloud computing technology. They analyze four features of cloud computing technology: partnership and collaboration, demand forecasting, price of product or service, and infrastructure costs i.e., hardware and software costs. They conclude that SC-based cloud computing brings efficiency for all SC echelons in terms of BWE reduction at manufacturer with respect to inventory levels and holding costs. Furthermore, hardware and software costs decreased at manufacturer aligned with reduction of the inventory levels at the supplier.

Gounl Kochan *et al.* (2018) use system dynamics to investigate the impact of IS-based cloud computing on the mitigation of BWE. They analyze three KPIs; inventory control, service lead time, and order fulfillment rate. Cloud-based IS enable all SC partners to access patient forecast information, thus improving the visibility of patient's demand information. The BWE is significantly mitigated by reducing the inventory levels and demand forecasting accuracy. Furthermore, cloud-based-IS improves end-to-end visibility for demand and inventory information, reduces lead time and inventory variability, and reduces the patient service time.

4.2.4 Blockchain Technology

Van Engelenburg *et al.* (2018) propose a blockchain-based architecture solution for information sharing considering data accessibility and data security trade-off. They conclude that the validation of the proposed structure need orders, demand,

inventory levels, and work in progress information to be shared and only authorized partners in the same blockchain network can access such information. As a result, all SC partners access the same copy of different information enabling them to better forecast demand on mitigate the BWE.

Xue and Dou (2020) perform a system dynamics simulation to reconstruct the IS structure in terms of BWE mitigation using consortium blockchain architecture. They reveal that blockchain mitigate the BWE by involving all SC tiers in the network accessing the same demand information.

Ghode *et al.* (2021) build a blockchain architecture for sharing information. The results show that blockchain structure benefit the manufacturer in terms of accurate demand forecasting by accessing directly the retailer's order information, thus the manufacturer reduces the production costs in turn. Consequently, accessing actual demand information mitigates the BWE with respect to variance ratio by 1 comparing it to 1.99 before using blockchain.

Sarfaraz *et al.* (2021) investigate the impact of permissioned blockchain-based information sharing on BWE mitigation. Demand and order lead times were the shared types of information. Three KPI's have been utilized: the BWE ratio, inventory variance ratio, and system total cost. The authors propose a new consensus algorithm based on trust, i.e., the parties are selected based on their trust score. They simulate two scenarios: (1) NIS (traditional SC) and (2) demand and order lead time IS (BC-enabled IS). The results show that the second scenario has a significant impact on reducing the BWE by 99% at retailers, 98% at manufacturers, and 97% at suppliers.

4.3 With whom to share?

This section discusses papers that investigate the effect of choosing the ideal potential partner “to exchange information with” in order to mitigate the BWE. In other words, which partner should be involved in IS process? what is the optimal scenario? involving all SC tiers in IS or some of them? (see Table XI).

Table XI.

Classification of the articles on “with whom to share” with respect to echelon selection criteria.

Dominguez et al., (2017) utilize multi-agent simulation in divergent supply chain considering four retailers, one wholesaler, one manufacturer, and one supplier. They assume that retailers have different configurations in terms of demand variance, forecasting period, average lead time, and inventory policy. Three KPI's have been analyzed: BWE slope, inventory slope, and systematic inventory level. Five scenarios were simulated: NIS, the first retailer only shares demand information, the second retailer only shares demand information, and the third retailer shares his demand information, and all retailers share their demand information. The results show that the retailers with the same operational configuration have an equal impact on BWE mitigation; FIS is recommended in this case. However, considering heterogeneous retailers, it is more beneficial to implement PIS, particularly with retailers that have higher demand variance, lower forecasting period, and higher average lead time.

Dominguez et al., (2018) investigate the impact of DIS for heterogeneous retailers on the BWE mitigation using order variance prioritization (OVAP) approach to in a divergent supply chain. Multi-agent simulation is conducted considering two KPI's: the BWE and the average inventory. This strategy gives priority to sharing demand information with retailers that have the most variable orders among others. The results show that the retailer transmits most of the order variance to the upstream echelons is the most beneficial to involve in DIS; OVAP reduced the BWE by 27.2% and the average inventory by 7.8%.

Dominguez et al., (2021) investigate the impact of seven PIS scenarios on the BWE mitigation considering two levels: supply chain level and organizational level. They simulate a system dynamics approach in serial supply chain to analyze the BWE slope. They also conduct sensitivity analysis to test the benefits of involving new

Authors	Echolen	Selection Criteria
Dominguez <i>et al.</i> , (2017)	Retailers	Different operational configurations (demand variance, forecasting period, average lead time, and inventory policy)
Dominguez <i>et al.</i> , (2018)	Retailers	OVAP: the priority is to involve the retailer who has the most variability of orders among others in sharing demand information
Dominguez <i>et al.</i> , (2021)	The echelon which has the less lead time variability	Variability of the lead times

echelon based on their lead time capabilities. The results indicate that the BWE has a positive linear relationship with the supply chain echelons which means more value for IS strategy, so the more echelons participate in IS, the more the BWE reduces; each echelon has an impact of 20% in the reduction of BWE.

4.4 How much to share?

This section discussed papers that investigate the degree of IS among supply chain partners. That is, *we consider the aspect “how much to share” and represent the ISR level in terms of sharing different types of information*. To clarify, the examined papers consider two scenarios of ISR i.e., NIS which implies that the upstream echelons only receive the downstream order information and FIS which means that upstream echelons receive the customer demand information (Dejonckheere *et al.*, 2004). Table XII shows the classification of the papers with respect to this argument.

Table XII.

The articles that investigated “how much to share” with ISR of (0, 50%, 100%)

Authors	ISR
Jeong and Hong, (2019)	NIS (0), PIS (50%), and DIS (100%). (FIS is considered in terms of DIS).
Zhang <i>et al.</i> , (2019)	ISR is determined based on the costs of IS. The higher the costs the less the
Gao <i>et al.</i> , (2020)	FIS (upstream echelons build their forecasting based on order, demand, and product loss information). PIS, (upstream echelons build their forecasting based on ordering and product loss information)

Jeong, and Hong (2019) conduct a system dynamic simulating the impact of demand forecasting IS with two factors: the level of IS and the echelon’s position. Unlike previous works, they analyze three IS rates: NIS, PIS, FIS. The results reveal that the FIS have the most reduction magnitude regarding BWE mitigation i.e., three times less than the other scenarios: NIS and PIS. Regarding the echelon position, the impact of ISR decreases as one goes downstream.

Zhang *et al.* (2019) examine the impact of ISR on The BWE mitigation considering IS costs, SC structure, and SC performance. Notably, information costs include communication cost and information processing cost. The results indicate that supply chain structure complexity and communication costs have a linear relation; complex supply chain structures incur more communication and information processing costs. They conclude that there is a trade-off between information costs and the BWE reduction, i.e., it is useless to share approximate information and it is

prohibitively expensive to share precise information. Therefore, the BWE relies on sharing the right information at the right moment.

Gao *et al.* (2020) analyze the effect of PIS and FIS in terms of loss of products information sharing in e-commerce industry. They consider two KPI's: the BWE and inventory costs for near and far delivery distance. With FIS, the wholesaler can build his forecasting based on three pieces of information: ordering, demand, and loss information. However, PIS includes the ordering and product loss information. The BWE is mostly reduced when the delivery lead time is shorter than the replenishment lead time. Nonetheless, when the delivery lead time is longer than the replenishment lead time, the product loss IS is more beneficial since the wholesaler influenced by lower BWE. The findings of this paper contradict the previous findings regarding the value of DIS, i.e., DIS may cause larger BWE.

4.5 Why to share?

This section discusses the papers that investigate the value of information sharing and its benefits in terms of BWE reduction, inventory stability, service level, system stability and various costs.

4.5.1 Internal Process Improvement (IPI)

4.5.1.1 The BWE

This subsection discusses the articles that focus on the different performance indicators to measure the BWE (see Table XIII).

Table XIII.

Classification with respect to performance metrics measuring BWE reduction.

Performance Metrics	Authors
Order Variance Ratio (OVR)	Li <i>et al.</i> , (2016)
	Drakaki and Tzionas, (2019)
Root Mean Square Error (RMSE)	Seifbarghy <i>et al.</i> , (2017)
Order Standard Deviation Ratio (OSDR)	Ali <i>et al.</i> , (2020)
Inventory Variance Ratio (IVR)	Ezaki <i>et al.</i> , (2021)

4.5.1.1.1 OVR

Drakaki and Tzionas (2019) study the impact of sharing inventory recording errors information on the BWE reduction. They simulate RFID-based supply chain structure using colored Petri nets. A serial multi-stage structure is compared to a non-enabled RFID supply chain. The findings reveal that RFID technology could not mitigate the BWE in terms of OVR because inventory information has distortion errors when recorded. In addition, RFID technology would be viable

solution especially for upstream echelons when demand variance is small and inventory variance error is large.

Li, Chen, and Liao (2016) investigate the BWE mitigation in Shanghai and Hong Kong container shipping market incorporating both IS and risk pooling. Four different scenarios are conducted, i.e., DIS, NIS, and with/without risk pooling. The results confirm that the integration of risk pooling and IS reduces the BWE effectively more than implementing either method apart. The variability of the manufacturer's order quantity to the variances of the retailers' demands is considerably mitigated by 91% by decentralized IS and risk pooling.

4.5.1.1.2 RMSE

Seifbarghy *et al.* (2017) analyze the impact POS-IS and transportation delay on the BWE mitigation using expected root mean square errors amplification factor (RMSE). They use Frequency domain analysis (FDA) and Fourier Transform for this purpose. The analysis proves that sharing POS data along the supply chain network could mitigate the demand propagation (BWE) regardless of the exogenous uncertainty in the model.

4.5.1.1.3 OSDR

Ali *et al.* (2020) examine the effect of stochastic lead time and centralized /decentralized IS on the BWE mitigation in FMCG industry with three products using discrete event simulation. The results show that the BWE is caused by long lead time and its impact increases as the number of echelons get increased. The results show that the BWE is lowest under centralized information (DIS) and constant lead time. However, the retailer encounters higher BWE in the case of managing multi-product inventory levels.

4.5.1.1.4 IVR

Ezaki *et al.* (2021) investigate the impact of forecasting model sharing on the mitigation of inventory BWE. They assume that retaining the forecasting model for a long-term may trigger demand variability and the BWE. Therefore, they use the Gaussian distribution as the forecasting model. The results view that sharing retailer's forecasting model with upstream enables them to mitigate the BWE with respect to inventory levels due to visible demand variance and inventory levels information.

4.5.1.2 BWE and Inventory

This subsection is concerns with the metrics used to measure the BWE mitigation and the inventory levels stability (see Table XIV).

Table XIV.

Classification with respect to performance indicators measuring the BWE reduction and the inventory variability.

Performance Indicators	Authors
Order Variance Ratio (OVR)	Babai <i>et al.</i> , (2015) Costantino <i>et al.</i> , (2015) Zhao <i>et al.</i> , (2018) Shaban <i>et al.</i> , (2020)
Inventory Variance Ratio	Babai <i>et al.</i> , (2015) Costantino <i>et al.</i> , (2015)
Inventory Holding Cost (IHC)	Babai <i>et al.</i> , (2015)
BWE Slope	Cannella <i>et al.</i> , (2018)
Average inventory levels (AIL)	
Inventory slope (IS)	
Supplier's inventory level	Zhao <i>et al.</i> , (2018)
Net Stock Variance Ratio	Shaban <i>et al.</i> , (2020) Lu <i>et al.</i> , (2017)

Babai *et al.* (2015) analyze the value of DIS considering AR (1) demand process on the BWE in terms OVR and inventory holding costs. They assume that the value of DIS is small when the demand process follows high auto-correlated pattern. Furthermore, the DIS is highly valued when the demand parameters are not visible to the manufacturer, i.e., the BWE ratio and the percentage inventory reduction are likely to be reduced if the demand behavior is not auto-correlated.

Costantino *et al.* (2015) investigate the value of IS with respect to BWE comparing a slow IS strategy with a combination of two inventory policies: (R, S) and (R, D). The BWE reduction and inventory stability are selected as KPI's. The findings reveal that slow IS mitigate BWE and stabilize inventory levels more than the two combined inventory policies. These findings apply for three deterministic demand patterns and one stochastic demand pattern. Moreover, using the delayed IS method allows the upstream echelons to not be affected by the downstream echelon's inventory decisions, thus propagating the BWE.

Cannella *et al.* (2018) investigate the impact of transmitting inaccurate demand information considering four factors, i.e., demand delay, demand error, demand variability, and average lead time. They establish a collaborative simulation model using system dynamics. They conclude that when demand information is shared with error, the BWE and inventory levels are propagated, and the impact becomes higher when the error magnitude increases. Regarding the demand delay, its effect

depends on its length, i.e., longer delays have a positive impact on BWE and shorter delays harm BWE.

Zhao *et al.* (2018) examine the impact of DIS including customer's web clicks and product price at one online retailer and multiple suppliers in terms of BWE and inventory levels reduction. The results show that the retailer can accurately forecast the customer demand based on actual demand information plus the safety stock. Moreover, the BWE order variance proved to be 1 when the online retailer shares demand forecasting with the supplier. In addition, the supplier inventory percentage has been reduced when online retailers have shared their demand forecasting information.

Shaban *et al.* (2020) simulate the impact of generalized (R, S) policy on the BWE reduction in serial supply chain. Generalized (R, S) enables SC partners to exchange both demand forecasting and inventory balance information. The results of ANOVA analysis disclose that the information smoothing method has a significant impact on reducing the BWE i.e., as the smoothing parameter level decreased, the BWE becomes lower. Nonetheless, when the lead time is variable, the BWE increases. The IS-generalized (R, S) policy is an effective remedy to reduce the BWE as it is less sensitive to lead time variability, thus improving ordering and inventory performance at the retailer stage.

Lu *et al.* (2017) inspect the impact of demand information error on the inventory BWE in terms of net stock variance ratio considering a price-sensitive AR (1) demand process. They assume that the inventory BWE may increase or reduce count on four aspects: demand shock, information accuracy, timeliness, and whether the errors occurrence time during the replenishment process or before it. The findings reveal that the BWE at the manufacturer could be mitigated if the retailer's order and customer demand are lagged and if the manufacturer uses the historical order information to forecast the customer demand.

4.5.2 IPI and Service Level (SL)

This subsection discusses the metrics that are used to measure the BWE mitigation, inventory stability, and customer service level (see Table XV).

Table XV.

Classification of performance indicators with respect to measuring the BWE reduction, inventory variability, and customer service level

Performance Metrics	Authors
Order Variance Ratio	Cannella <i>et al.</i> , (2015a) Cannella <i>et al.</i> , (2015b) Huang <i>et al.</i> , (2017) Teunter <i>et al.</i> , (2018) Shaban <i>et al.</i> , (2019) Jin, (2019)
Net Stock Variance Ratio	Shaban <i>et al.</i> , (2019)
Inventory Variance Ratio	Cannella <i>et al.</i> , (2015a) Cannella <i>et al.</i> , (2015b) Tang <i>et al.</i> , (2020)
Inventory Levels	Huang <i>et al.</i> , (2017) Teunter <i>et al.</i> , (2018) Jin, (2019)
Inventory holding cost	Tang <i>et al.</i> , (2020)
Average Fill Rate	Cannella <i>et al.</i> , (2015a) Shaban <i>et al.</i> , (2019)
Order Fulfillment Rate	Teunter <i>et al.</i> , (2018) Tang <i>et al.</i> , (2020)
Order Backlog	Cannella <i>et al.</i> , (2015a)
Mean Backlog	Cannella <i>et al.</i> , (2015b)
Stock out Rate	Jin, (2019)
Shortage Cost	Huang <i>et al.</i> , (2017)

Cannella *et al.* (2015) simulate FIS structure in a decentralized SC of four partners when FIS across the stages is shared. The central theme of this study is sharing POS data and inventory information in conjunction with the implementation of a coordinated ordering strategy. The BWE is measured using order variance ratio and inventory variance ratio. The results reveal that sharing POS and inventory level mitigate the BWE by avoiding the penalty costs at the upstream and middle echelons' shortage scenario.

Another study by Cannella *et al.* (2015) use system dynamics to analyze the impact of sharing inventory shrinkage information on the BWE reduction, inventory stability, and service level improvement. The results show that once the error magnitude increases, the BWE and inventory stability increase, while the customer level decreases. In contrast, the performance of each stage is harmed and affected by the faulty recoded IS.

Teunter *et al.* (2018) examine the value of IS considering a slow response at retailer during demand fluctuations with two demand patterns: random walk and stationery.

The results show that the DIS has a positive impact on BWE mitigation when demand is correlated, and vice versa with random walk demand (no correlation). The overestimation of the quick response of retailer would harm the forecasting of upstream demand which in turn motivates the propagation BWE at the manufacturer due to forecasting error of unreliable IS.

Huang *et al.* (2017) explore the effect of sharing POS data including the retailer's promotions on the BWE effect with respect to inventory levels and shortage costs for five suppliers. The results show that sharing POS has a significant impact on reducing the supplier's inventory levels and shortage costs when successive demand is auto-correlated. Moreover, the value of IS is increased with higher demand correlation and greater demand variance.

Shaban *et al.* (2019) propose a new coordinated model, IS and OUP policy, using discrete-event simulation. They consider stress demand pattern with three non-stationary processes: upward shift, downward shift, and impulse. Three KPI's have been analyzed: BWE, net stock amplification, and average fill rate. The results show that the DIS strategy outperforms the new coordination strategy, IS-OUP, since upstream have the optimal forecasting parameter which mitigates the BWE. Nonetheless, IS-OUP performs similarly to DIF in terms of BWE reduction when the retailer is able to determine the optimal forecasting parameter. They conclude that increasing level of coordination by DIS improves the stability of orders and inventory for all forecasting parameters and lead-time combinations.

Jin (2019) investigates the benefit of DIS on the BWE reduction using system dynamics. The results are summarized in four main points: first, the BWE propagated as the ordering review period is raised. Second, constrained maximum ordering quantity reduces the coefficient of variance value, thus the BWE and inventory ratio are reduced. Third, DIS has a low impact on the BWE reduction when the retailer's replenishment order is lost and not backlogged. Lastly, the DIS outperforms the retailer's sales IS by reducing the BWE by 97.15% and 96.44% respectively.

Tang *et al.* (2020) explore the impact of four IS strategies (E-POS, emergency transshipment, VMI, and traditional supply chain) on the inventory BWE reduction and supply chain system robustness with stochastic demand and lead time and constrained production capacity assumptions. They use discrete event simulation

approach and weight signal-to-noise ratios to capture the system balance and robustness. Four KPI's are measured: inventory variance ratio, inventory holding, backlog costs, and customer service level. The findings are two fold: Firstly, both e-POS and VMI mitigate the BWE by decreasing the average value and inventory standard deviation among all echelons. Secondly, the emergency transshipment propagates the BWE at the distributor echelon because of receiving new orders from the retailer, however, it is improved the service level at the retailer echelon.

4.5.3 IPI, SL & System Stability (SS)

This subsection is concerned with the metrics measuring BWE mitigation, customer service level, and system stability (see Table XVI).

Table XVI.

Classification with respect to performance indicators measuring BWE reduction, customer service level, and system stability.

Performance Indicators	Authors
BWE Slope	Yang and Fan, (2016)
System Recovery Time	
Order Variance Ratio	Pamulety <i>et al.</i> , (2017)
Order Fulfillment Rate	
System Total Cost	

Yang and Fan (2016) use control theory and frequency response analysis to simulate the role of CPFR on the BWE mitigation using three KPI's: BWE, recovery time, and system stability. They consider a presence of demand disruptions. The results show that the FIS-CPFR-based supply chain is the best combination to reduce the BWE.

Pamulety *et al.* (2017) simulate the mitigation of BWE using periodic review-inventory policy with the comparison of four inventory policies: OUT, OUT smoothing, (s,S), and (s,Q). They use three KPI's: BWE, total cost, and fill rate and three demand patterns (constant seasonal, seasonal-increasing trend, seasonal-decreasing trend) with/without DIS in serial and divergent supply chain. The results show that OUT smoothing overpass the proposed policy with respect to BWE mitigation under DIS in all simulated scenarios except 8th scenario.

4.5.4 BWE and Inventory Asymmetric Information

This subsection considers the metrics used to measure the BWE mitigation and inventory levels (see Table XVII).

Dia et al. (2016) examine the impact of inventory on shrinkage on the BWE mitigation, holding and shortage costs. They consider two information quality levels, i.e., low-quality information (statistical inventory information) and high-quality information (real-time inventory information). They conclude that sharing real-time inventory information reduces BWE and the costs at the manufacturer, whereas sharing low-quality information is beneficial for the manufacturer in terms of costs, however, propagates the BWE.

Table XVII.

Classification with respect to performance indicators measuring BWE reduction and inventory stability with quality problem.

Performance Indicators	Authors
Order Variance Ratio	Dai <i>et al.</i> , (2016)
Inventory Holding Costs	
Shortage Costs	
Order Variance Ratio	Pamulety <i>et al.</i> , (2017)
Order Fulfillment Rate	
System Total Cost	

4.6 In which Direction to Share

This section exhibits the direction in which the information is shared. Most of the reviewed papers investigate uni-lateral IS, transfer information from downstream to upstream 91% (39 papers). Only 9% adopt bi-lateral IS (4 papers) (see Table XVIII).

Table XVIII.

Classification with respect to "direction of information flow" across supply chain echelons

In which Direction to Share	Authors
Uni-Lateral	Algharabat <i>et al.</i> , (2015)
(From downstream to upstream)	Ali <i>et al.</i> , (2020)
	Babai <i>et al.</i> , (2015)
	Cannella <i>et al.</i> , (2018)
	Cannella <i>et al.</i> , (2015a)
	Cannella <i>et al.</i> , (2015b)
	Costantino <i>et al.</i> , (2015)
	Dai <i>et al.</i> , (2016)
	Dominguez <i>et al.</i> , (2017)
	Dominguez <i>et al.</i> , (2018)
	Dominguez <i>et al.</i> , (2020)
	Drakaki and Tzionas, (2019)
	Ezaki <i>et al.</i> , (2021)
	Gouni Kochan <i>et al.</i> , (2018)
	Gowda and Subramanya, (2017)
	Huang <i>et al.</i> , (2017)
	Jeong and Hong, (2019)
	Jiang and Ke, (2019)
	Jiang, (2019)
	Jin, (2019)

	Lampret and Potočan, (2015)
	Li <i>et al.</i> , (2016)
	Lopez-Campos <i>et al.</i> , (2017)
	Lu <i>et al.</i> , (2017)
	Pamulety and Pillai, (2016)
	Pamulety <i>et al.</i> , (2017)
	Ran <i>et al.</i> , (2020)
	Seifbarghy <i>et al.</i> , (2017)
	Shaban <i>et al.</i> , (2019)
	Shaban <i>et al.</i> , (2020)
	Tang <i>et al.</i> , (2020)
	Teunter <i>et al.</i> , (2018)
	Van Engelenburg <i>et al.</i> , (2018)
	Wang <i>et al.</i> , (2016)
	Wood <i>et al.</i> , (2016)
	Xue and Dou, (2020)
	Yang and Fan, (2016)
	Zhang and Gong, (2021)
	Zhao <i>et al.</i> , (2018)
	Algharabat <i>et al.</i> , (2015)
Bi-Lateral	Gao <i>et al.</i> , (2020)
(From downstream to upstream	Ghode <i>et al.</i> , (202)
and vice versa)	Ojha <i>et al.</i> , (2019)
	Sarfaraz <i>et al.</i> , (2021)

5. Conclusion and future research

We conducted a systematic literature review to answer the following research question: What are the predominant ISFs that are examined in literature and what is their role in the mitigation of BWE? For this purpose, we reviewed 46 journal articles published between 2015 and 2021 and we classified them with respect to different ISFs (what, why, how, with whom, how much, in which direction to share) in order to smooth the coordination among supply chain partners and improve supply chain performance. We conclude that most studies investigate the value of IS in both serial and dyadic supply chains which, however, does not reflect the complexity of supply chain reality. Also, although the majority of the papers do include discussion on why to share information and what information to share, few attempts are made to investigate any other factors, for instance, how much information to share, with whom to share it, how to share it, and in which direction to share it. The uni-lateral information flow direction is the most investigated sub-category. In addition, the papers that address information sharing within the framework of blockchain technology are still conceptual. Almost all selected papers assume that information is fully accurate before sharing it with upstream echelons except for a few studies that hypothesized otherwise.

Regarding the research methodologies, most reviewed articles utilize mathematical models, simulation, and numerical validation of the theoretical assumptions. Moreover, they base their analysis on the assumptions: customer demand follows an AR (1), all echelons apply OUT policy to manage their inventories, moving average or simple exponential smoothing is used for demand forecasting, and order variance ratio to measure the BWE. All reviewed papers deal with a single product except one study (Ali *et al.*, 2020). Similarly, the capacity is assumed to be unconstrained except one paper (Tang *et al.*, 2020).

Regarding coordination most papers implemented horizontal coordination among supply chain partners, one study implemented both horizontal and vertical coordination between multi-tiers for the same echelons (Sarfaraz *et al.*, 2021).

Given the above conclusions, several future research paths can be identified:

There is still a need to conduct empirical and theoretical research in order to investigate combination of multiple ISFs and their impact to BWE mitigation. In addition, more complex modelling should be considered in order incorporate

production limited capacity, multiple products, different lead times for production, replenishment, and delivery. Moreover, seasonal demand patterns need be investigated in terms of IS and BWE mitigation. Further studies are also needed in order to compare the impact of IS type and IS degree on the mitigation of BWE considering both backlog and lost sales scenarios. Partial information sharing (PIF) still needs more investigation in convergent and divergent SC. Regarding “how to share”, and “with whom to share”, these factors could be investigated by conducting case studies to validate the potential of new technologies such as blockchain, IoT, and AI in terms of BWE mitigation. The aspect of “when to share” in a supply chain network is rarely investigated in terms of BWE.

Empirically investigation of the value of IS in terms of BWE reduction using blockchain technology is also needed. Further studies should be made on the influence of various degrees of IS on the BWE effect and the supplier inventory level.

Current blockchain research is mostly based on qualitative methods, lacking reliable empirical analysis. Further research can mend limitations related to the operating performance and value creation of the supply chain based on blockchain technology. Multi-echelon SC system with blockchain technology as a coordination technology for information sharing, along with smoothening of order and financial transactions is another promising research topic. How to share bi-/multi-lateral information is also rarely studied in the reviewed papers.

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Paper C

Mitigating the Bullwhip Effect Using Information Sharing-based Blockchain Technology: An Agent-based Modeling and Simulation Approach

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ABSTRACT

Inefficient supply chains can lead to variety of problems like the bullwhip effect. Numerous research works devoted to investigate the impact of information sharing on bullwhip effect mitigation consider sharing demand information as the most beneficial tool to mitigate such an effect. However, a few works examine the impact of multiple aspects of information sharing, such as what to share and how to share using blockchain technology. Blockchain technology may prove to be a game changer and a paradigm shift for supply chain operations. Therefore, this paper investigates a new coordination mechanism based blockchain using agent-based modeling and simulation with respect to “which type of information to share” and “how information can be shared using blockchain technology”. A four-echelon supply chain is considered. Six scenarios of information sharing are investigated in order to compare the supply chain performance. The model stochasticity is considered in terms of production-distribution lead time, exponential smoothing factor, and safety stock factor. ANOVA- Kruskal-Wallis analysis is conducted in order to compare the bullwhip effect and inventory levels under the different scenarios. The results show that blockchain, enabling all partners to have access to the same information, is a significant coordination tool to mitigate the bullwhip.

KEY WORDS: Inter-organizational Coordination, Information sharing, Information Sharing Aspects, Blockchain, Agent-based modeling, Simulation, Bullwhip effect, Smart Contracts.

1. INTRODUCTION

Managing supply chain efficiently can be a challenge when experiencing high uncertainty and variability of customer demand (Ha and Tang, 2018). In addition, the lack of coordination and trust between supply chain echelons aligned with local optimization has negative consequences on the supply chain performance (SCP). The bullwhip effect (BWE) is the phenomenon in which the demand variance gets inflated when information is transferred from downstream to upstream echelons (Lee *et al.*, 1997, Chatfield *et al.*, 2004; Costantino *et al.*, 2015, and Jeong and Hong, 2019). Lee *et al.*, (1997) state that the BWE is a consequence of distorted demand information that leads to several inefficiencies in the supply chain. High inventory levels, poor customer service, higher costs production, transportation, and holding costs are some of the negative consequences of the BWE (Lee *et al.*, 1997; Costantino *et al.*, 2015). Forrester (1961), who first refers to such effect, analyzed it using System Dynamics (SD). Subsequently, many industries witnessed the BWE in their supply chains: Barilla SPA (Hammond (1994), Campell soup's (Cachon and Fisher, 1997), HP and Procter & Gamble (Lee *et al.*, 1997), and car manufacturing (Klug, 2013). A report by Bray and Mendelson (2012) reveals that about two-thirds of 4689 US firms have the BWE in their supply chain. Similarly, Shan et al. (2014) report that more than two-thirds of 1200 Chinese companies exhibit the BWE. Lee *et al.*, (1997) attribute the presence of the BWE in the supply chain on four main operational causes: demand signal processing (updating forecast information), rationing game, order batching, and price fluctuations. Cammarano *et al.*, (2022) stated that demand forecasting is the backbone for all supply chain planning process and one of the important factors that could trigger the BWE. Starman (1989) shed lights on causes which relate to the behavioral practices taken by logistics managers, i.e., managers' misinterpretation of demand fluctuations and delays in taking decisions.

To overcome the BWE, researchers proposed various coordination remedies such as supply chain contracts (Kocabasoglu and Prahinski, 2008; Cachon and Lariviere, 2005; Pagnozzi and Saral, 2021; and Rahmani and Mehdizadeh, 2021), joint decision making (Simatupang and Sridharan, 2002; Chen *et al.*, 2019; Gualandris *et al.*, 2021;

and Mardani *et al.*, 2021), and information sharing (IS) (Lee *et al.*, 1997; Chen *et al.*, 2000; Wang *et al.*, 2021; and Ma *et al.*, 2021). Apparently, IS found to be the most significant coordination mechanism to dampen the BWE (Wang and Disney, 2015). Towill *et al.*, (1992) argued that the more accurate and quicker information is shared, the higher the mitigation of the BWE would be.

The related literature in IS and the BWE mitigation has two streams of research. The first stream investigates the benefits of information sharing in terms of BWE reduction (Chen *et al.*, 2000; Dejonckheere and Disney, 2004; Hong and Goyal, 2011, Costantino *et al.*, 2014; Chaharsooghi *et al.*, 2019). The second stream is devoted to investigation of the value of IS considering various operational configurations: customer demand process, inventory management policy, forecasting technique, and supply chain structure (Costantino *et al.*, 2014; Babai *et al.*, 2015; Pamulety *et al.*, 2016; Costantino *et al.*, 2015; Cannella *et al.*, 2015a; Cannella *et al.*, 2015b; Li *et al.*, 2016; Wang *et al.*, 2016; Dai *et al.*, 2016; Huang *et al.*, 2017; Lu *et al.*, 2017; Dominguez *et al.*, 2018a, Dominguez *et al.*, 2018b; Kochan *et al.*, 2018; Cannella *et al.*, 2018; Teunter *et al.*, 2018; Zhao *et al.*, 2018; Drakaki and Tzionas, 2018; Jiang and Ke, 2018; Ojha *et al.*, 2019; Jin, 2019; Shaban *et al.*, 2019; Shaban *et al.*, 2020; Tang *et al.*, 2020; Gao *et al.*, 2020; Ali *et al.*, 2020; Zhang and Gong, 2021; Sarfaraz *et al.*, 2021; Ezaki *et al.*, 2021). Most of the previous research analyzed two scenarios: with and without information sharing. The first scenario, without information sharing (NIS), correspond to the traditional supply chain in which the SC echelons only shares their replenishment order quantity with each other. In contrast, in the second scenario, with information sharing (DIS), the SC echelons exchange the customer demand information with each other. However, the IS process appears to be more challenging in terms of inter-organizational coordination due to two reasons: lack of mutual trust among partners (Longo *et al.*, 2019) and unwillingness to share information with the other partners (Myers and Cheung, 2008)

In light of the above, information and communication technologies (ICTs) have improved the process of IS, reduced the information asymmetry and enabled data visibility (Hofmann, 2017). ICTs like web-based applications and Enterprise

Resource Planning (ERP) facilitate order transactions and reduce the communication costs (Omar *et al.*, 2021). However, despite such benefits, such systems don't have the ability to collect and analyze data (Yan *et al.*, 2022). Additionally, even if a company succeeded to develop a customized ICT, trust related issues with respect to IS may limit the optimal use of their information systems (Mendelson, 2000). Blockchain has the potential to significantly reduce the trust related issues and encourage more effective supply chain information sharing (Omar *et al.*, 2021). With blockchain technology, a common source of truth, shared and unified vision of reality can be achieved (Chen *et al.*, 2020). According to Cocco *et al.*, (2018) collaborative environments that are built on trust and information sharing can greatly benefit from blockchain technology as an intermediary. Due to the inherited features of blockchain such as decentralization, data validation, immutability, and transparent IS, supply chain operations become more resilient since there is no single point of failure, thus enhancing transaction confidence (Xu *et al.*, 2019).

Several studies adopted Ethereum, a blockchain-based platform, to build solutions and conceptual frameworks to investigate the BWE mitigation (Van Engelenburg *et al.*, 2018; Xue and Dou, 2020; Ghode *et al.*, 2021; Sarfaraz *et al.*, 2021). Other studies used a combination of agent-based simulation and blockchain. For example, Longo *et al.*, (2019) design a software connector to integrate an Ethereum-based blockchain with business's information systems to reduce the BWE. Likewise, Omar *et al.*, (2021) produces a blockchain-based inventory sharing method utilizing smart contracts and a private Ethereum network to connect suppliers and retailers. Cammarano *et al.*, (2022) used agent-based modeling to analyze three different scenarios of the Parmigiano Reggiano supply chain, considering blockchain, RFID and IoT technologies for redesigning the Vendor Managed Inventory (VMI) strategy. Another study by Adamashvili *et al.*, (2021) investigate the impact of blockchain technology on wine supply chain performance, using agent-based modeling (ABM).

Considering the above, we found that there is a need to investigate the impact of multiple aspects of IS on the BWE mitigation in a blockchain environment using ABM. Therefore, this research paper attempts to bridge this gap. Unlike previous

studies, this study applies an ABM approach within a blockchain environment in order to investigate the impact of two aspects of information sharing, what to share and how to share, on the mitigation of both the BWE and inventory levels. Thus, this paper attempts to answer the following question: *“How could blockchain mitigate the BWE effect, inventory levels and improve end-to-end visibility in terms of sharing different types of information?”* There are several contributions in this paper:

- We develop an agent-based simulation model to measure the impact of IS-based blockchain on the mitigation of demand variance for all echelons.
- We investigate the importance of sharing different types of information within a heterogeneous serial supply chain in a blockchain environment.
- We propose a blockchain architecture that uses smart contracts to facilitate sharing different types of information among supply chain echelons.
- We validate the proposed solution by conducting detailed testing of various scenarios and by applying Kruskal-Wallis -ANOVA statistical analysis.
- We extend the framework of blockchain to study the impact of multiple aspects of information sharing on the mitigation of BWE and inventory levels in a serial supply chain.

The rest of the paper is arranged as follows: the literature review is presented in the second section. The third section presents the simulation and modeling description. The results and analysis are introduced in the fourth section. Finally, conclusion and future research included in the fifth section.

2. LITERATURE REVIEW

In this section we review and categorize recent literature in terms of ABM, blockchain and the BWE.

2.1 ABM and supply chain management.

In this subsection we review the papers that explore the use of agent-based modeling in supply chain management with particular emphasis on information sharing and coordination mechanisms.

Several papers (Du and Jiang, 2019; Datta and Christopher, 2009; Longo *et al.*, 2019) investigate the importance of information sharing and coordination in managing supply chain uncertainties and improving overall performance. Particularly, Du and Jiang (2019) find that sharing retailer demand and inventory information can benefit the manufacturer under uncertain demand. Datta and Christopher (2009) suggest that centralized coordination and information exchange among supply chain echelons are crucial to manage supply networks efficiently under uncertainty. Longo *et al.*, (2019) demonstrate that adopting blockchain technology to share accurate information with suppliers can result in significant economic and operational benefits while minimizing negative consequences of information asymmetry.

Fu and Xing, 2021; Min and Bjornsson, 2008; Hsu *et al.*, 2016; and Tan *et al.*, 2019 focus on the use of agent-based modeling to address various challenges in supply chain management. For example, Fu and Xing (2021) propose a model combining an evolutionary algorithm and agent-based approach to resolve resource conflicts in a project-driven supply chain under decentralized decision-making and information asymmetry. Min and Bjornsson (2008) investigate the importance of real-time information sharing in construction supply chain using the agent-based simulation. Hsu *et al.*, (2016) introduce a new negotiation model using autonomous and interactive agents and fuzzified preference functions to achieve a mutually beneficial agreement. Tan *et al.*, (2019) proposed a game theory model to investigate the evolution process of information sharing in a supply chain network structure.

2.2 Blockchain technology

Blockchain technology is a distributed and decentralized database which securely store and transfer data through blocks that are chained together with cryptographic technology (Zachariadis *et al.*, 2019; Hughes *et al.*, 2019; Choi, 2019). The transactions are recorded in the blocks after getting validated by the network nodes through a consensus algorithm which prevent any change or alteration of the recorded data. Blockchain is tamper-proof and contain of three technologies: consensus algorithms, smart contracts, and cryptography. Consensus algorithms such as proof of work (POW), proof of stake (POS), and practical byzantine fault tolerance (PBFT) ensure the validity of each transaction and prove the ownership of all nodes (Feng *et al.*, 2020). On the other hand, smart contracts are self-executing contracts that are written in codes based on specific terms and conditions between two partners without the need of a central authority (Christidis and Devetsikiotis, 2016; Tanwar *et al.*, 2020). According to Abdullah *et al.*, (2020) smart contract is executed automatically once the contract conditions are met. Cryptography plays a crucial role in terms of creating encrypted public keys and hash function (Wang *et al.*, 2019). Public key cryptography, an asymmetrical encryption method, verifies the identities of participants within the blockchain network (Lopez and Farooq, 2020). The hash function converts incoming data into a compact output of fixed length, which support the consistency, authenticity, and unchangeable nature of the distributed ledger (Maesa and Mori, 2020). Blockchain technology can be divided into three main categories: public, private, and consortium (Gourisetti *et al.*, 2020). Public blockchains, such as Bitcoin and Ethereum, allow anyone to participate and allow for decentralized transactions (Nakamoto, 2008). On the other hand, private blockchains are exclusive and only accessible to authorized participants (Wüst and Gervais, 2017). Finally, consortium blockchains are a combination of public and private blockchains where certain users have the permission to participate in the network in certain areas (Qiao *et al.*, 2018).

2.3 Blockchain and ABM

Adopting blockchain technology in the supply chain area is becoming increasingly popular due to its ability to maintain the security and transparency of various transactions. It also helps to ensure the authenticity and traceability of information as it is transmitted among partners (Tijan *et al.*, 2019). These distinct features have a crucial impact on the supply chain's design, structure, and operations (Kamble *et al.*, 2021). Several researchers have been exploring the potential of blockchain in the supply chain, Wang *et al.*, (2019) conducted a study to understand how blockchain can bring value to supply chain management in four areas: visibility and traceability, digitalization, data security, and smart contracts. Philipp *et al.*, (2022) investigated the potential applications of smart contracts in multinational and multi-mode supply chains through expert interviews and case studies.

The ability to obtain timely data to improve procurement, production, transportation, and inventory management by blockchain is proposed by (Cole *et al.*, 2019). Liu and Li (2020) stated that the application of blockchain can be used to develop digital solutions and could enhance the ability to share transaction records in real time across the network to improve operational efficiency of the whole supply chain. In the light of the above, several companies have explored the impact of using the blockchain on their supply chains. For example, Walmart has implemented a traceability system for mangoes using blockchain, which has reduced the traceability time from seven days to just two seconds (Wong *et al.*, 2020). Meanwhile, Maersk and IBM are utilizing blockchain to improve information transparency and sharing among trading partners in cross-border supply chains (Chang *et al.*, 2022). Omar *et al.*, (2021) propose a blockchain solution as a facilitator for sharing inventory information using Ethereum smart contracts and analyze different security vulnerabilities that affect the transactions of supply chain stakeholders. Ghode *et al.*, (2021) propose a blockchain architecture for sharing customer demand information with upstream echelons. They conclude that the manufacturer BWE is reduced from 1.99 to 1 as consequence of reducing the production costs.

Xu *et al.*, (2021) use concurrent Practical Byzantine Fault Tolerance (PBFT) consensus algorithm to control scalability problem of supply chain partners. They conclude that blockchain helps in grouping the various peers in the supply chain into clusters based on their transaction history.

Two papers investigate the impact of blockchain on supply chain efficiency and resilience: Lohmer *et al.*, (2020) focus on the impact of different risk-based blockchain scenarios on supply chain resilience while Wang *et al.*, (2022) examine the impact of blockchain on the circulation efficiency and safety of agricultural products. Rubio *et al.*, (2019) investigate the regulation of an agent-based market agreement using blockchain smart contracts, with a focus on reducing greenhouse gas emissions. Pour *et al.*, (2018) use ABM to simulate a sand governance framework that leverages blockchain technology to regulate sand extraction and trade, highlighting the potential for cooperative outcomes using decentralized blockchain systems. Cammarano *et al.*, (2022) explore the impact of a combination of IoT, RFID and blockchain technology on the procurement and customer satisfaction improvement in the Parmigiano Reggiano supply chain. Adamashvili *et al.*, (2021) examine the impact of blockchain technology on the wine supply chain, highlighting its potential to improve traceability and protecting against fraud and contamination. In summary, the papers suggest that blockchain technology can have a positive impact on supply chain efficiency, resilience, and traceability, and can enable cooperative outcomes through decentralized systems.

2.4 Bullwhip effect and ABM

The papers reviewed in this section focus on the BWE mitigation in supply chains using ABM. The studies can be divided into several clusters based on their approaches and focus. Neghavi *et al.*, (2020), proposes a centralized decision-making approach where agents make decisions based on the final customer's demand to reduce the BWE. Ponte *et al.*, (2017) and Liang and Huang (2006) analyze different inventory policies and forecasting techniques using ABM to reduce the total cost of the supply chain and smoothen the curve of the orders variance. Moghadam and Zarandi (2022), proposes an automated negotiation solution based on Fuzzy logic to

reduce the BWE. Wu *et al.*, (2011), analyzes the BWE in a supply chain network structure, implementing the ABM simulation and the bee's algorithm. Fussone *et al.*, (2022), uses ABM to investigate how two manufacturers engage in a symbiotic exchange of waste, and the results suggest that an increase in the amount of waste exchanged between the manufacturers was associated with a decrease in the volume of orders placed and an increase in the variability of those orders. Scholz and Höhns (2003), proposes an agent-based simulation approach to collaborative supply net management, based on the SCOR-Model to reduce the BWE. Finally, Mahdavi *et al.*, (2008) proposes an e-based supply chain using Colored Petri Nets simulation approach to control and evaluate inventory policy at different echelons and minimize the total cost of the SC by sharing information and forecasting knowledge. In summary, the literature review reveals that several studies have utilized agent-based modeling to investigate the bullwhip effect in various supply chain settings. Most of the studies suggest that a centralized decision-making approach and coordinated inventory policies across the supply chain partners can help mitigate the bullwhip effect.

3. SUPPLY CHAIN MODEL

Considering the dynamics in terms of the heterogenous environment of a serial supply chain structure, this study proposes an agent-based simulation to evaluate the role of sharing different types of information using blockchain: actual demand, inventory levels and demand forecasting information. Different information sharing scenarios are considered, i.e., no information sharing and six blockchain based information sharing scenarios. The purpose of blockchain technology adoption is to support sharing multiple types of information sharing and redesign the process of sharing information among heterogeneous supply chain partners. Heterogeneity is considered in terms of delivery lead time (Ld), exponential smoothing factor (α), and safety stock factor (ε). Blockchain is used as a new remedy to mitigate the bullwhip effect to solve trust related issues. The bullwhip effect and inventory levels are considered to be the main performance metrics. To perform the mathematical formalization, we adopted the common assumptions that have been used in the

literature (Sterman, 1989; Dejonchheere *et al.*, 2004; Disney and Lambrecht, 2008; Boute, 2009; Ciancimino *et al.*, 2012; Chatfield *et al.*, 2013; Costantino *et al.*, 2014c; Cannella *et al.*, 2015; Costantino, *et al.*, 2016; Jeong and Hong, 2019; Shaban, 2020; Dominguez *et al.*, 2021)

The model represents a traditional four-echelon supply chain consisting of a customer, a retailer, a wholesaler, a producer and a supplier as for many previous studies in this field (Chatfield *et al.*, 2004; Chatfield, 2013; Ciancimino *et al.*, 2012) in which the retailer ($i = 1$) receives from customers ($i = 0$) demand and places an order with the wholesaler ($i = 2$), which places its orders with the producer ($i = 3$) and so on up the supply chain to the supplier ($i = 4$). Each echelon i in any time period t satisfies the incoming orders from its on-hand-inventory (I_t^i), then places order (O_t^i) to echelon ($i + 1$). The retailer observes and satisfies the customer demand (D_t^i) and places orders with the wholesaler. All the echelons employ a periodic review order-up-to (R, S) inventory policy in which the order-up-to level updates at the end of each review period (R), with $t = 1$, according to the forecasting of the future demand.

We use NetLogo 6.3.0 software (Wilensky, 1999), for the simulation with the following assumptions:

- A single product which is commonly used in supply chain analysis (Forrester, 1961; Sterman, 1989; Lee *et al.*, 1997) and each echelon in the system has a successor echelon and a predecessor echelon.
- The customer demand is assumed to be independent and identically distributed (*i.i.d*), meaning that the demand in each time period is independent of the demand in other time periods and follows a random normal distribution. This distribution is selected since it represents the independent behavior of the customers (Chatfield *et al.*, 2013).
- The agents in the supply chain use an order-up-to policy (OUT) to manage their inventory. OUT is used to simulate the flow of orders and inventory levels in the supply chain since the retailer replenish its inventory frequently and the upstream agents act according to the retailer's orders (Boute, 2009).

In addition, OUT is the most commonly policy used in modelling the BWE due to its easy implementation.

- The agents use exponential smoothing for forecasting the customer demand (Disney and Lambrecht, 2008).
- The safety stock factor is used to cover the ordering risk period. All echelons have different safety stock factors (Costantino, *et al.*, 2016).
- The delivery lead time is stochastic for all echelons. We randomize the lead time values for all agents.
- Backorder is allowed, which means the unfulfilled orders at any echelon are not lost but they become backlogs and they will be fulfilled once the on-hand inventory becomes available; thus, the inventory remains a positive or null value.
- Capacities have been kept unconstrained. However, supplier inventory replenishment has been kept unbound (the last upstream node), meaning that the supplier can deliver as much as needed to meet the demand. This assumption simplifies the model and allows us to focus on the impact of blockchain based information sharing adoption on the supply chain performance (Dominguez *et al.*, 2021)
- A nonnegative condition for order quantity is assumed, i.e., the products delivered to downstream echelons can't be returned to the supplier.

Table 1. The model notations for echelon i at time t

Variables	
I_t^i	On-hand-Inventory level
WiP_t^i	Upstream Work-in-progress or inventory in transit
SR_t^i	Shipment released to a downstream echelon from i^{th} echelon
C_t^i	Shipment received delivered from an upstream echelon to i^{th} echelon
B_t^i	Upstream Backlog of orders
D	Market demand
\hat{D}_t^i	Demand forecasted based on the simple exponential smoothing technique
O_t^i	Replenishment orders placed to an upstream echelon
$TWiP_t^i$	Target work-in-process level
TI_t^i	Target inventory level
Parameters	
Ld_t^i	Delivery lead time between immediate echelons
ε_i	The safety stock factor
i	Echelon index
K	Number of echelons in the supply chain
α_t^i	Forecast smoothing parameter
Statistics	
σ_{Ri}^2	Variance of order quantity rate in echelon i
σ_d^2	Variance of customer demand
σ_i^2	Variance of inventory in echelon i
μ_{Ri}	Mean of order quantity in echelon i
μ_d	Mean of market demand

The model equations describing the flow of information, material, and demand forecast are given in Table 2. The state variables at each echelon i are updated in every time period t (Costantino et al., 2014c; Costantino, et al., 2016; Cannella, 2014; Shaban, 2020; Dominguez et al., 2021):

Table 2. The Equations (1)- (11) define the different states at each echelon i in each period t .

On -hand inventory	$I_t^i = I_{t-1}^i + C_t^i - SR_t^i$	(1)
Work in progress	$WiP_t^i = WiP_{t-1}^i - C_t^i + O_t^i$	(2)
Orders delivered	$SR_t^i = C_t^{i-1} = \min \{ \{I_t^i\}, D_{t-L}^i + B_t^{i-1} \}$	(3)
	$O_t^i = D_t^{i+1}$	
Backlog	$B_t^i = B_{t-1}^i + O_{t-L}^i - C_t^i$	(4)
Demand Forecast	$\widehat{D}_{t+1}^i = \alpha D_t^i + (1 - \alpha) \widehat{D}_t^i \quad i = 1$	(5)
	$\widehat{D}_{t+1}^i = \alpha O_t^{i-1} + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1$	(5.1)
	$\widehat{D}_{t+1}^i = \alpha D_t^1 + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1$	(5.2)
	$\widehat{D}_{t+1}^i = \alpha \widehat{D}_{t+1}^{i-1} + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1$	(5.3)
	$\widehat{D}_{t+1}^i = \alpha \widehat{D}_{t+1}^{i-1} + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1,$	(5.4)
	$\widehat{D}_{t+1}^i = \alpha (D_{t-1}^1 + D_t^1) \frac{1}{2} + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1$	(5.5)
	$\widehat{D}_{t+1}^i = \alpha D_t^1 + (1 - \alpha) (\widehat{D}_{t+1}^1 - I_t^1),$	(5.6)
Target work in progress	$TWiP_t^i = L_{i+1} \widehat{D}_t^i$	(6)
Target inventory level	$TI_t^i = \varepsilon_i \widehat{D}_t^i$	(7)
Order quantity	$O_t^i = \widehat{D}_t^i + (TWiP_t^i - WiP_t^i) + (TI_t^i - I_t^i)$	(8)
Non negativity condition of order quantity	$O_t^i \geq 0$	(9)
Unlimited raw material supply condition	$SR_t^4 = O_t^{3i} \quad \text{for } i = 4$	(10)

On-hand inventory at each period t in echelon i , I_t^i , is increases by the orders quantity that is released from upstream echelon, C_t^i , and decreases due to the orders quantity that is delivered to downstream echelon, SR_t^i Eq (1). The work in progress WiP_t^i is determined by in-transit inventory (orders) plus that includes the orders in transit due

to lead time and backlog quantity at an upstream echelon. At every cycle, it decreases when a shipment is received, C_t^i and increased when an order is placed O_t^i Eq. (2). Eq. (3) expresses actual delivery orders between echelons and is constrained by the minimum value between the available inventory I_t^i , and the shipment required D_{t-L}^i (which is O_{t-L}^{i-1} including the backlogs at time t (B_t^{i-1+1}). The upstream backlog for any echelon i is presented as the initial backlog plus the difference of quantity due from upstream echelon O_{t-L}^i and the shipment received C_t^i is Eq. (4), Eq. (5) shows the simple exponential smoothing forecast for the retailer which uses the actual customer demand information to forecast the future demand. Eq. (5.1) to (5.6) show the forecast equations for echelons other than the retailer for six forecast scenarios based on blockchain information sharing. Eq. (6) and Eq. (7) define the target ($TWiP$) and target inventory level (TI), respectively. Since ($TWiP$), and (TI) use the demand forecast (\widehat{D}_t^i), they are also affected by the type of information sharing in each scenario at each echelon. Eq. (8) formalize the OUT. Eq. (9) and Eq. (10) models the incapacitated raw materials for upstream echelons.

3.1 The Study Scenarios

This subsection presents the equations that we have derived in order to model the different scenarios. We use the information shared as an input to an echelon's demand forecasting equation and formulate six different scenarios accordingly. The first scenario (NIF) is stated for the sake of comparison. For the other five scenarios we assume that all supply chain echelons exchange different types of information using blockchain technology through which they obtain real-time information and use it to update the demand forecast equation. The purpose is to explore whether using the information according to the different scenarios brings any beneficial results for all supply chain echelons.

3.1.1 No information sharing (NIS)

In this scenario, the farthest downstream is the only echelon that has access to the actual customer demand (see Eq.5.2) while upstream echelons receive only order information from respective downstream neighbor (see Eq. 5.1). The upstream echelons update their demand forecasting, generate their replenishment quantity, and

update their inventory relying only on local data and parameters of incoming orders (see Fig 2).

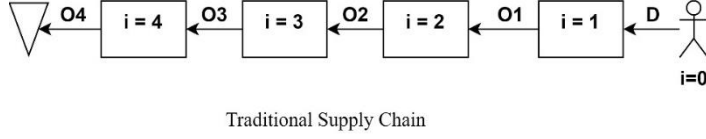


Fig 2. Sharing orders information in traditional supply chain.

3.1.2 Sharing the actual demand information (DIS)

In this scenario, all supply chain echelons are assumed to have access to actual demand information using blockchain technology according to the architecture in Fig 3. That's to say, all echelons update their demand forecasting and inventory parameters based on actual customer demand information instead of their local orders information. *This architecture is applicable to the other scenarios as well. However, the type of information shared differs for each scenario.*

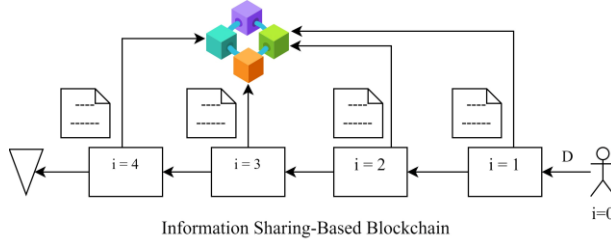


Fig 3. Sharing demand information sharing via blockchain technology.

3.1.3 Sharing demand forecast information of immediate downstream echelon (DFII)

In this scenario, all echelons have access to demand forecasting information for immediate downstream echelons:

$$\hat{D}_{t+1}^i = \alpha \hat{D}_{t+1}^{i-1} + (1 - \alpha) \hat{D}_t^i \text{ for } i > 1,$$

where \hat{D}_{t+1}^i is the future forecast, \hat{D}_t^{i-1} is the demand forecasted by the immediate downstream echelon and \hat{D}_t^i is the demand forecast by echelon i . for the immediately preceding period.

3.1.4 Sharing retailer's demand forecast information (RDFI)

The retailer, in this scenario, shares his demand forecasting information with the upstream echelons, and they set their replenishment orders based on this information:

$$\widehat{D}_{t+1}^i = \alpha \widehat{D}_{t+1}^{i=1} + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1,$$

where \widehat{D}_{t+1}^i is the future forecast, $\widehat{D}_{t+1}^{i=1}$ is the demand forecasted by the retailer and \widehat{D}_t^i is the demand forecast by echelon i .

3.1.5 The retailer shares historical demand information (RHDI)

In this scenario, the upstream echelons have access to the retailer's historical demand information. and they use the average demand over the two preceding periods in their own demand forecast function.

$$\widehat{D}_{t+1}^i = \alpha (D_{t-1}^1 + D_t^1)/2 + (1 - \alpha) \widehat{D}_t^i \text{ for } i > 1,$$

where \widehat{D}_{t+1}^i is the future forecast, $\widehat{D}_{t-1}^1, \widehat{D}_t^1$ are the retailer previous demands information and \widehat{D}_t^i is the demand forecast by echelon i .

3.1.6 The retailer shares demand information and inventory levels (RDHIL)

In this scenario, all echelons have access to the retailer's inventory level, the actual customer demand and his demand forecast information.

$$\widehat{D}_{t+1}^i = \alpha D_t^1 + (1 - \alpha) (\widehat{D}_{t+1}^1 - I_t^1),$$

where \widehat{D}_{t+1}^i is the future forecast, D_t^1 the customer actual demand, I_t^1 is the retailer on-hand inventory level and \widehat{D}_{t+1}^1 is the retailer's demand forecast.

3.2 Performance Metrics

We adopted two performance metrics for evaluating the internal efficiency of the supply chain with the aim to analyze the different versions of an IS-based blockchain in terms of the BWE mitigation and the inventory levels across the supply chain. These metrics are the order variance ratio and the inventory variance ratio.

3.2.1 The order variance ratio (OrVr)

The BWE ratio reflects the expansion of demand variability in the supply chain (Gunasekaran et al., 2004). OrVr is the most common metric to measure BWE

(Cannella, et al., 2015) and it is given by the variance of the orders divided by the orders mean over the demand variance divided by the demand mean.

$$OrVr = \frac{\sigma_R^2/\mu_R^i}{\sigma_d^2/\mu_d} \quad (11)$$

If the BWE = 1, this means that the order variance is equal to the demand variance, i.e., there is no variance amplification. However, if the BWE > 1 this indicates that the supply chain is experiencing the BWE, whereas if the BWE < 1 this implies that there the orders variance is less than the demand variance. i.e., the orders are smoothened or dampened.

3.2.2 Inventory Variance Ratio (*InvVrR*)

The ratio of inventory variation (*InvVrR*) was introduced to measure the degree of inventory instability (Disney and Towill, 2003; Cannella et al., 2015). This quantifies the net inventory variations relative to the fluctuations in the variability of demand. Higher (*InvVrR*) implies higher costs of holding and backlogs, i.e., increased total cost per inventory cycle. In addition, the variance of inventory has a significant impact on customer service i.e., the higher (*InvVrR*) is, the more safety stock is required.

$$InvVrR = \frac{\sigma_{Inv}^2/\mu_{Inv}^i}{\sigma_d^2/\mu_d} \quad (12)$$

3.3 Experiment and Simulation output

We designed three sets of experiments to analyze and quantify the impact of the information sharing on the BWE at each echelon. The three sets of parameters were generated as a random combination through an script written in R. The random heterogenous parameters were generated with the following bounds:

- The four echelons. Lead time: “lower” bound 1, “upper” bound 5 → 4 random lead times were generated for each of the four echelons.
- Smoothing factory, alpha: “lower” bound 0.1, “upper” bound, 0.8 → 3 random smoothing factors were generated for the three echelons (excluding the most upstream echelon “supplier” who has unbounded inventories and supply as per the model assumptions).

- Safety stock factor: “lower” bound 1, “upper” bound 5 → 3 random safety stock factors were generated for the three echelons.
- The three random parameter sets generated in R (see appendix A) with ten random experiments. One random combination has been chosen and we run it 100 random experiments for each of the six demand forecasting scenarios. A total of 180 experiments were run as such [10 x 3 x 6]. The sequence of demand, orders and supply was coded as follows:

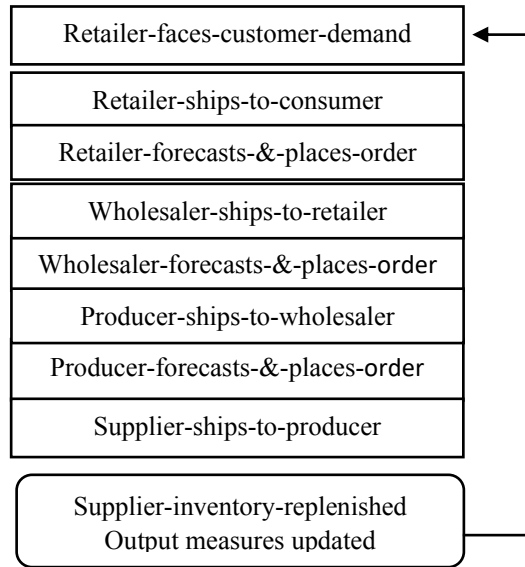


Figure 3. The sequence of demand, orders, and supply coding

Customer demand is generated as a random normal distribution (*i. d. d*) with a mean (μ) of 100 units and standard deviation (σ) of 20 units. The initial inventory values were set to 100, 200 and 300 units each for the retailer, wholesaler, and the producer respectively. Inventory for supplier were set unbounded as per the original simulation assumption. However, the impact of these initial state variables was even out in the warmup period (first 50 cycles) as the experiments were run for 300 cycles. At each step, relevant echelon inventories, work in processes, backlogs and target variables are updated as per the equations provided in Table 2. In the last step of the cycle, supplier inventory is replenished (as it is set unbound) and output measures are

updated. All the variables are updated with the heterogeneous parameters applicable to relevant echelon as set in the parameter combination. The experiments were run with the Behavior Space tool in NetLogo 6.3.0 (Wilensky, 1999). Each experiment was run for a simulation duration $T = 300$ cycles / time units that included warmup duration of 50-time units as per (Jeong and Hong, 2019). Thus, the effective simulation duration during which the statistical information is collected and updated is 250-time units.

4. THE RESULTS

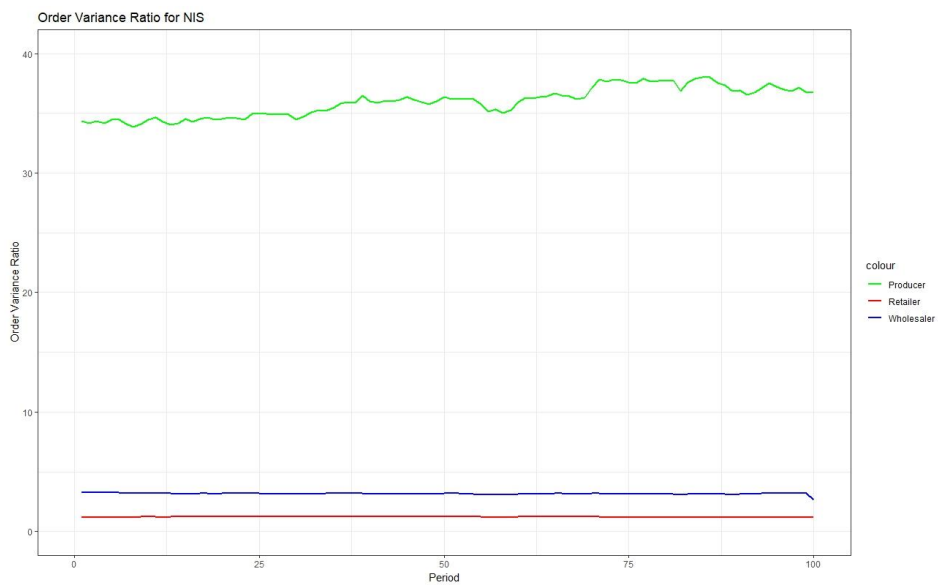
The findings are interpreted in terms of the impact of various types of IS on the BWE mitigation and inventory levels. For each performance metric, we use the ANOVA-Kruskal-Wallis rank sum test to statistically analyze the simulation results. The Kruskal-Wallis null hypothesis states that the means of the populations from which the samples were drawn are the same. The alternative hypothesis is that one population's mean differs from the others. We tested the significance of the BWE under different types of information and focused on the effect of the effect of two information sharing aspects "how to share information" and "what to share".

4.1 Impact of information sharing types on the BWE

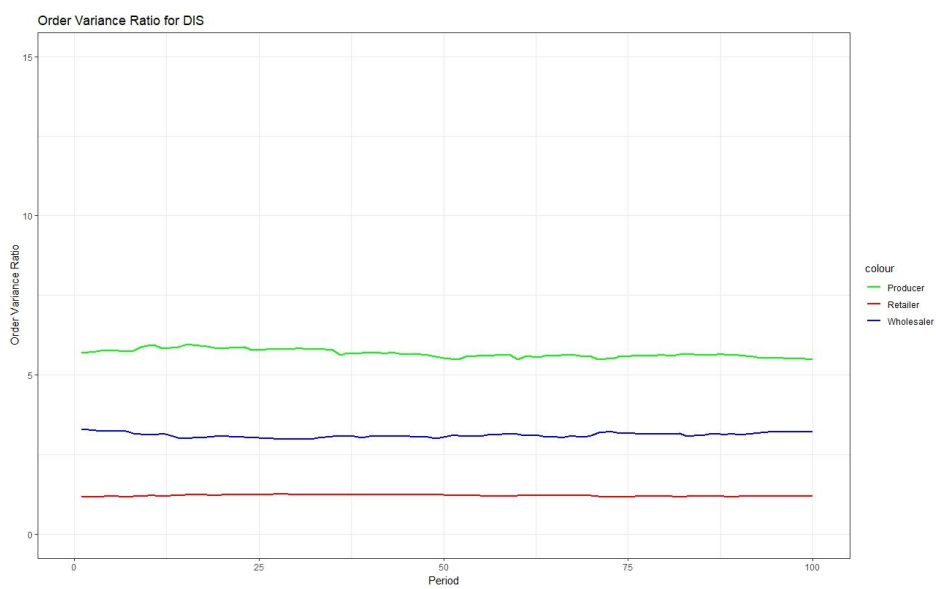
We use the Kruskal-Wallis function from the R stats package to perform ANOVA- Kruskal-Wallis test and analyze the effect of different types of information on the bullwhip effect. Table 3. shows the results of Kruskal-test for the BWE, which appears to be significant with a p-value less than 5%, ($p < 0.05$). This means, that different types of information have a significant effect on the BWE reduction.

Table 3 ANOVA- Kruskal-Wallis test on the BWE

Kruskal-Wallis Test			
The Bullwhip effect	chi-squared	df	p-value
Retailer	249.6	5	< 2.2e-16***
Wholesaler	565.73	5	< 2.2e-16***
Producer	581.06	5	< 2.2e-16***
*	**		***

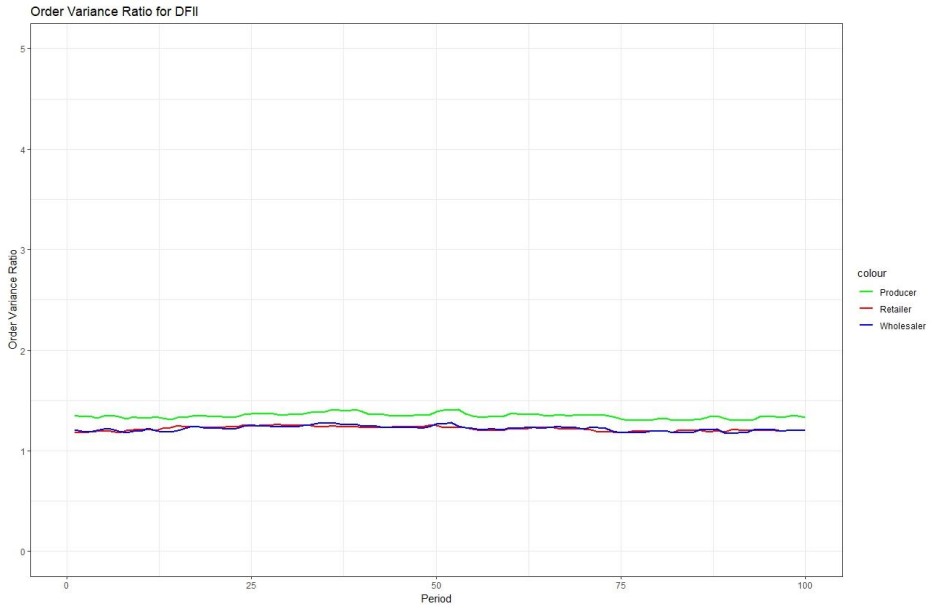


(a)

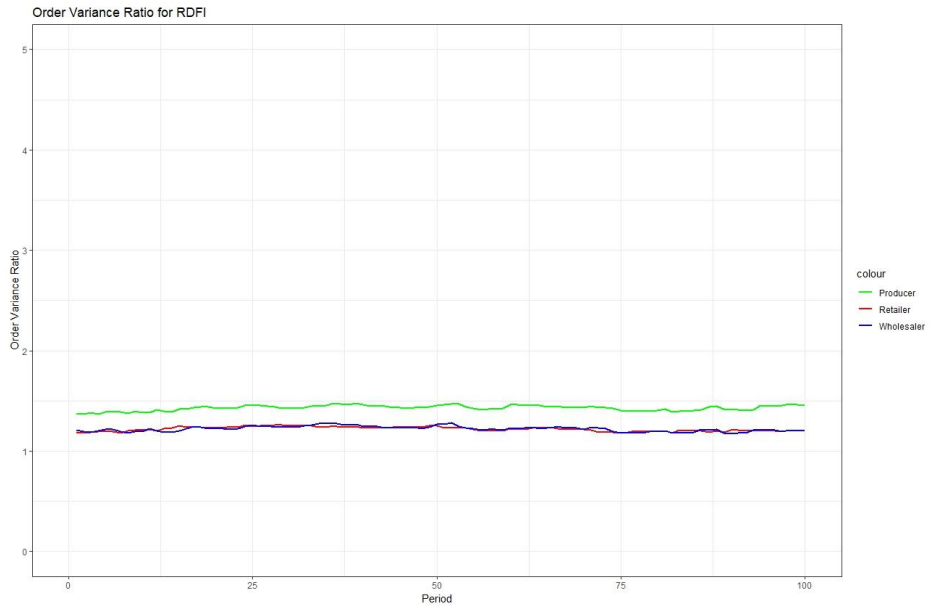


(b)

Fig. 4 The order variance ration under (a) no information sharing and (b) demand information sharing.

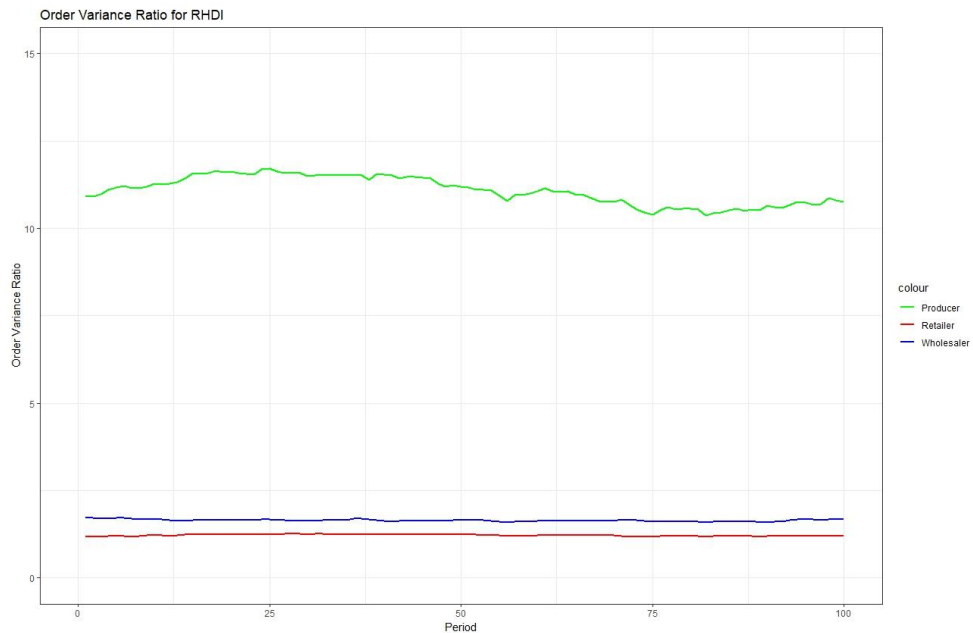


(a)

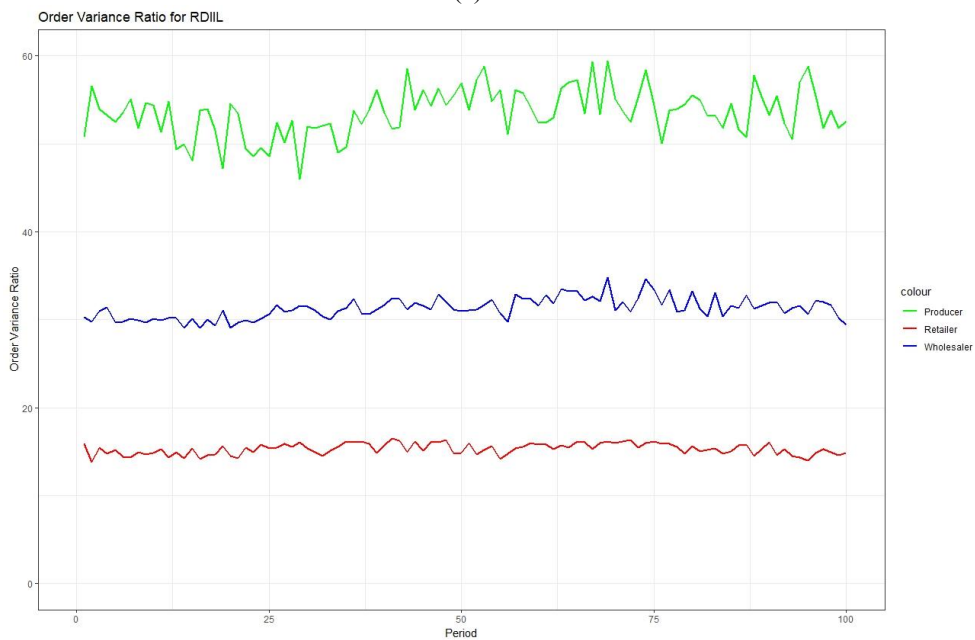


(b)

Fig.5 The order variance ration under (a) immediate echelon demand forecast and (b) sharing the retailer's demand forecast information.



(a)



(b)

Fig. 6 The order variance ration under (a) sharing the retailer's historical demand information and (b) sharing the retailer's customer demand information and inventory levels.

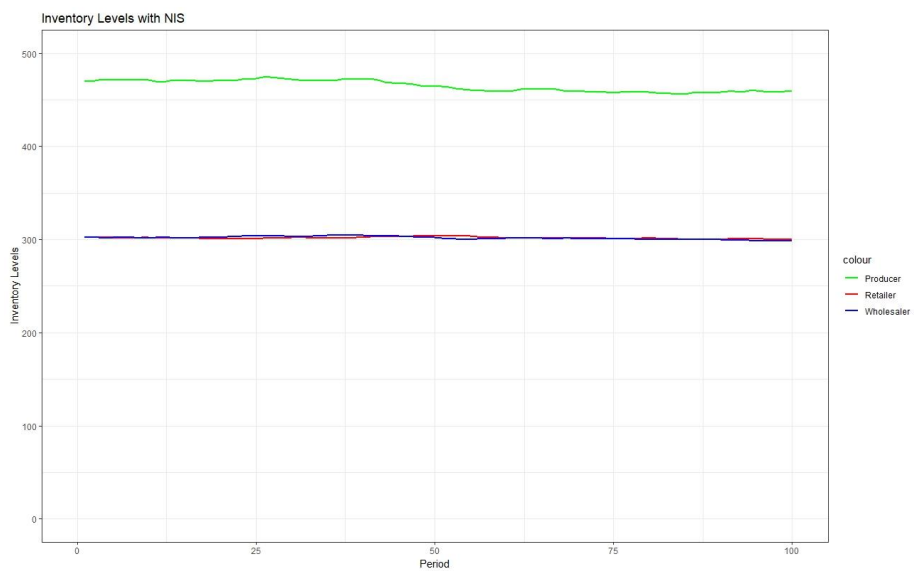
Fig. 4, 5, and 6 show the effect of information sharing on the BWE mitigation for the six scenarios. From these figures we can see that the best scenario corresponding to a dramatic mitigation in the BWE, is the fourth scenario (Fig. 5, b) when the retailer shares his demand forecasting parameters with the wholesaler and the producer. It is followed by the third scenario, (Fig. 5, a) when the downstream echelon shares its demand forecasting information with the immediate upstream echelon. This result is important since it contradicts previous literature results which state that the most important type of information to share in order to mitigate the BWE is the demand information (Jeong and Hong, 2019). However, comparing the no information sharing (traditional supply chain) (Fig 4, a) with the coordinated supply chain (Fig 4, b) we can see the clear mitigation of the bullwhip effect when the retailer share the actual demand information with the wholesaler and the producer and this is in agreement with previous literature results (Dominguez *et al.*, 2021; Jeong and Hong, 2019; Shaban *et al.*, 2020; Cannella *et al.*, 2015). Additionally, the fifth scenario (Fig 6, a) in which the retailer shares his historical demand information, shows a behavior similar to the first scenario where no information is shared. Finally, in the sixth scenario (Fig 6, b) in which the retailer shares both the demand and the inventory levels, it can be seen that there is BWE. Clearly, the mitigation of the BWE cannot be attributed only on the amount of information shared but also on the way this information is used. Thus, the equations used in these scenarios need to be revised and possibly totally new ones to be derived. An additional factor that has to be considered is the costs of information sharing. Since sharing information has a cost which increases with the amount shared, maybe exchanging all the information implied by, for instance scenario six, can be prohibitive.

4.2 Impact of information sharing types on Inventory levels

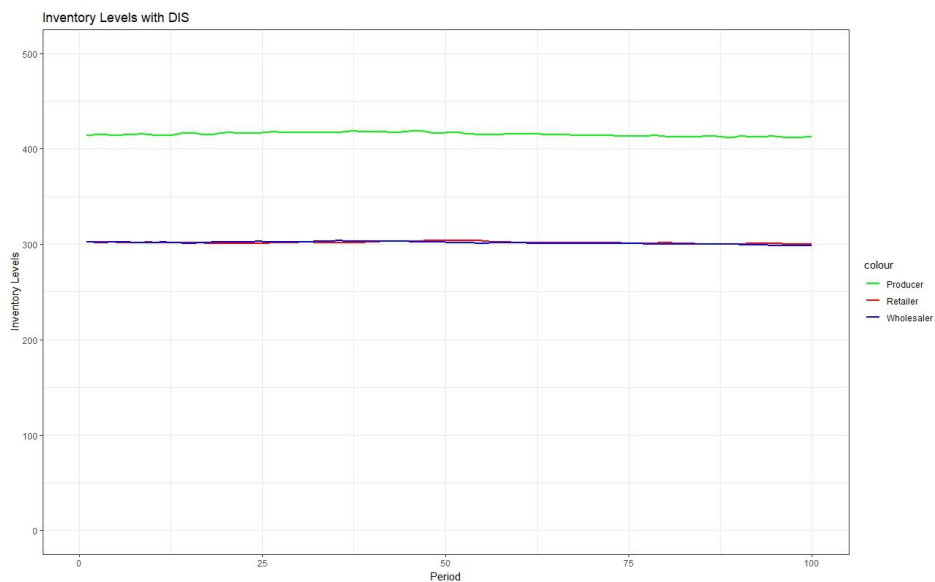
We consider here the impact of the information sharing on the inventory levels of the supply chain partners. The results show that the inventory variance ration is mitigated when the retailers share the actual demand information with the upstream echelons (see Fig. 6, a, and b). Table 4 shows the results of the Kruskal-test for the inventory levels. It shows a p-value less than 5%, ($p<0.05$). This means, that different types of information have a significant effect on the inventory levels reduction.

Table 3 ANOVA- Kruskal-Wallis test on the inventory levels

Kruskal-Wallis Test			
The inventory Levels	chi-squared	df	p-value
Retailer	249.6	5	< 2.2e-16***
Wholesaler	251.46	5	< 2.2e-16***
Producer	554.6	5	< 2.2e-16***
* ** ***			

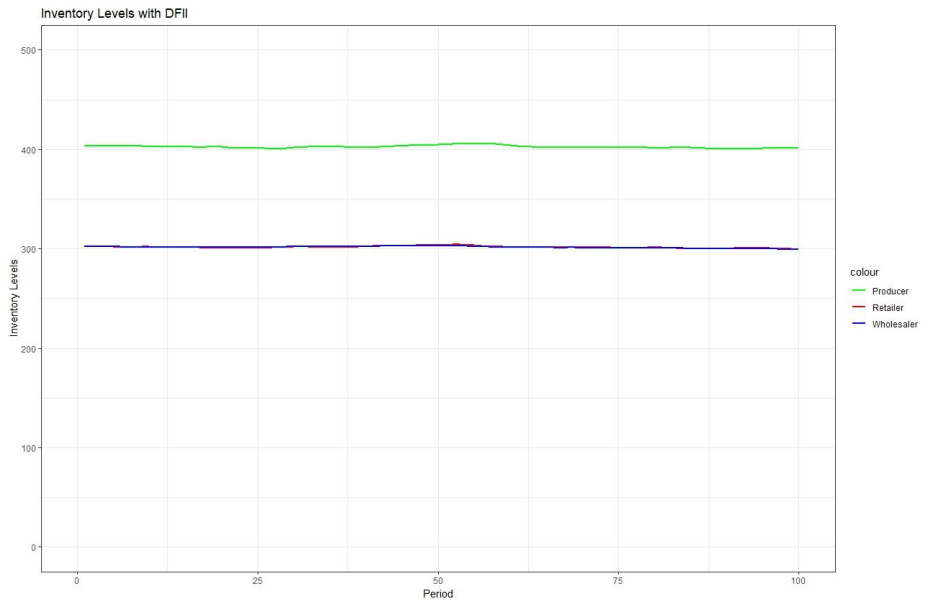


(a)

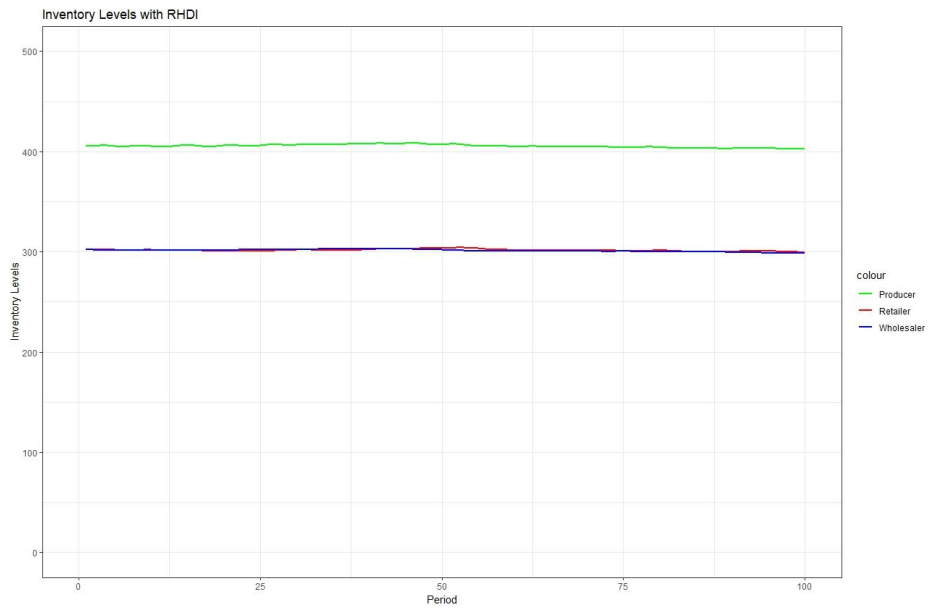


(b)

Fig. 7 The inventory variance ratio under (a) no information sharing and (b) demand information sharing.

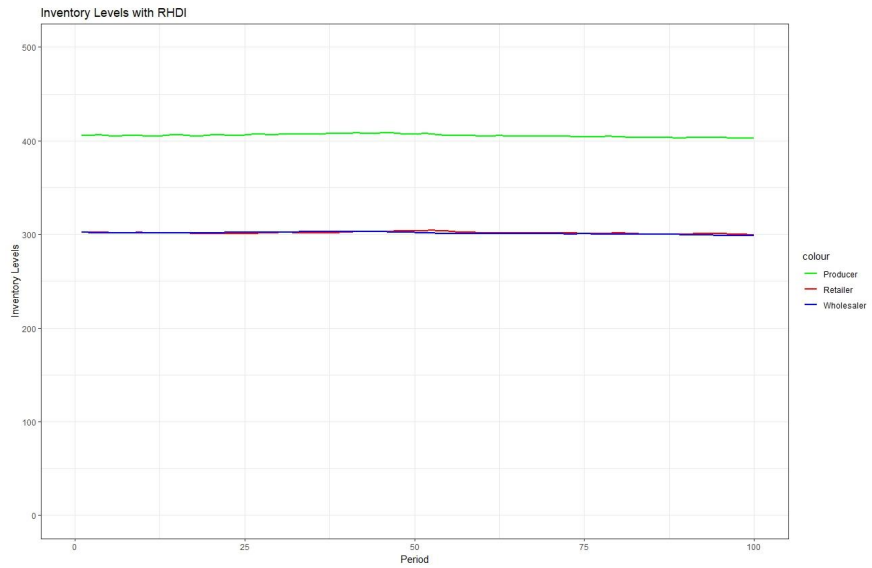


(a)

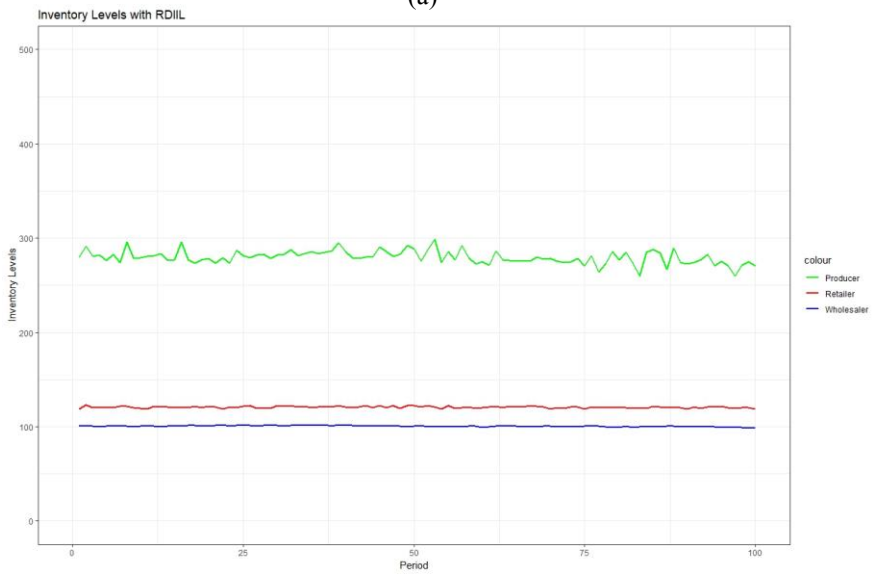


(b)

Fig. 8 The inventory variance ration under (a) sharing the downstream forecasting model and (b) the retailer's demand forecasting information.



(a)



(b)

Fig. 9 The inventory variance ratio under sharing the retailer's historical demand information and sharing the retailer's customer demand information and inventory levels.

In Fig 7, a and b, we can observe that the inventory variance ratio is mitigated when the retailer shares the actual demand information with the wholesaler and the producer. We also observe that the producer benefits from IS more than the wholesaler. In addition, a slight mitigation in inventory levels can be observed when comparing the graphs (a) with (b) in Fig 8 i.e., when sharing actual demand and demand forecasting parameters with the immediate neighbor. However, the graph (b) in Fig 7, the graphs (a) and (b) in Fig 8, and the graph (a) in Fig 9 appeared to have the same mitigation level on the wholesaler and producer inventories. In contrast, graph (b) in Fig 9 also shows a slight reduction in producers inventory level when the retailer shares the actual demand information and his inventory levels. Moreover, the wholesaler's inventory levels become almost equal to the retailer's inventory levels. We conclude that the better scenario is when the retailer shares both demand and inventory information with the wholesaler.

Conclusions

It is well known that IS can mitigate the bullwhip effect. However, there are different aspects of IS that must be taken into consideration such as how to share, and what to share. Therefore, in this study we investigated the impact of different types of information sharing on the mitigation of the BWE and inventory levels in a serial supply chain. We model a blockchain technology architecture using agent-based simulation under stochastic lead times, safety stock levels and exponential smoothing factor. One of the main results revealed is that the demand forecasting information seems to be more beneficial in terms of BWE and inventory levels mitigation than just sharing the customer demand information. Upstream echelons, which are often more severely affected by the BWE, are the ones most benefited from IS. In addition, blockchain technology with its inherited features is shown to be able to mitigate the BWE in terms of decentralized decision making and in a stochastic environment.

Several limitations “which are mainly related to the assumptions made” can be observed and pave the way for new future research. We have considered the exchange of only three sources of information (actual demand, inventory levels, and demand forecasts). Future work could analyze other types of information IS where different types of information are exchanged among the participant members. In addition, supply chain structure is important assumption. In our model we assume that the supply chain structure is serially connected with four echelons, Thus, analyzing the performance of the blockchain-IS structures in divergent and convergent supply chain could be another research avenue. Another consideration is the demand assumption to be i.i.d. Therefore, assuming correlation may lead to different findings in terms of investigating partial IS in SC. Another future research could be enriching the model by assuming limited capacity for both the supplier and the producer. Finally, the way information is handled mathematically must be further investigated and possibly new equations be derived. This is important for the forecasting process.

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Appendix A

The three random sets used in the simulation experiments.

	Ld-R	Ld-W	Ld-P	Ld-S	SS-R	SS-W	SS-P	alpha-R	alpha-W	alpha-P	See	Random #	OVR-R	OVR-W	OVR-P	Inv-R	Inv-W	Inv-P
1	1	3	1	3	2	2	3	0.11	0.38	0.68	1	50	1.246	3.159	35.492	303.79	302.24	464.552
2	1	3	1	3	2	2	3	0.11	0.38	0.68	1	150	1.289	3.353	41.899	296.86	297.65	458.432
3	1	3	1	3	2	2	3	0.11	0.38	0.68	1	250	1.467	3.448	46.060	300.79	301.94	456.832
4	1	3	1	3	2	2	3	0.11	0.38	0.68	1	350	1.489	3.403	47.899	301.58	302.61	454.432
5	1	3	1	3	2	2	3	0.11	0.38	0.68	1	450	1.478	3.187	45.307	303.25	302.69	453.916
6	1	3	1	3	2	2	3	0.11	0.38	0.68	1	550	1.501	3.289	42.590	300.48	298.93	457.688
7	1	3	1	3	2	2	3	0.11	0.38	0.68	1	650	1.296	3.244	37.334	298.63	297.22	459.056
8	1	3	1	3	2	2	3	0.11	0.38	0.68	1	750	1.261	3.219	37.202	297.26	298.02	456.144
9	1	3	1	3	2	2	3	0.11	0.38	0.68	1	850	1.408	3.577	36.854	296.66	294.18	464.696
10	1	3	1	3	2	2	3	0.11	0.38	0.68	1	950	1.393	3.072	34.910	293.2	296.18	460.284
11	1	3	1	3	2	2	3	0.11	0.38	0.68	2	50	1.246	3.817	21.093	303.79	302.14	417.04
12	1	3	1	3	2	2	3	0.11	0.38	0.68	2	150	1.289	3.908	21.701	296.86	297.07	410.244
13	1	3	1	3	2	2	3	0.11	0.38	0.68	2	250	1.467	3.520	18.825	300.79	301.43	414.404
14	1	3	1	3	2	2	3	0.11	0.38	0.68	2	350	1.489	3.432	17.936	301.58	302.16	412.604
15	1	3	1	3	2	2	3	0.11	0.38	0.68	2	450	1.478	3.108	19.723	303.25	302.45	411.156
16	1	3	1	3	2	2	3	0.11	0.38	0.68	2	550	1.501	3.392	20.655	300.48	298.78	409.052
17	1	3	1	3	2	2	3	0.11	0.38	0.68	2	650	1.296	3.567	20.895	298.63	297.44	408.036
18	1	3	1	3	2	2	3	0.11	0.38	0.68	2	750	1.261	3.416	20.792	297.26	297.97	408.68
19	1	3	1	3	2	2	3	0.11	0.38	0.68	2	850	1.408	3.697	21.088	296.66	294.4	407.588
20	1	3	1	3	2	2	3	0.11	0.38	0.68	2	950	1.393	3.434	20.708	293.2	295.32	409.368
21	1	3	1	3	2	2	3	0.11	0.38	0.68	3	50	1.246	1.265	1.388	303.79	302.96	404.832
22	1	3	1	3	2	2	3	0.11	0.38	0.68	3	150	1.289	1.292	1.428	296.86	296.68	395.204
23	1	3	1	3	2	2	3	0.11	0.38	0.68	3	250	1.467	1.512	1.719	300.79	300.93	400.672
24	1	3	1	3	2	2	3	0.11	0.38	0.68	3	350	1.489	1.590	1.826	301.58	301.78	403.244
25	1	3	1	3	2	2	3	0.11	0.38	0.68	3	450	1.478	1.537	1.749	303.25	302.82	402.932
26	1	3	1	3	2	2	3	0.11	0.38	0.68	3	550	1.501	1.607	1.876	300.48	299.78	399.592
27	1	3	1	3	2	2	3	0.11	0.38	0.68	3	650	1.296	1.329	1.478	298.63	298.72	397.856
28	1	3	1	3	2	2	3	0.11	0.38	0.68	3	750	1.261	1.245	1.387	297.26	298.26	398.236

29	1	3	1	3	2	2	3	0.11	0.38	0.68	3	850	1.408	1.428	1.653	296.66	295.96	395.436
30	1	3	1	3	2	2	3	0.11	0.38	0.68	3	950	1.393	1.448	1.726	293.2	293.85	390.824
31	1	3	1	3	2	2	3	0.11	0.38	0.68	4	50	1.246	1.265	1.454	303.79	302.96	404.524
32	1	3	1	3	2	2	3	0.11	0.38	0.68	4	150	1.289	1.292	1.582	296.86	296.68	395.708
33	1	3	1	3	2	2	3	0.11	0.38	0.68	4	250	1.467	1.512	1.766	300.79	300.93	401.092
34	1	3	1	3	2	2	3	0.11	0.38	0.68	4	350	1.489	1.590	1.695	301.58	301.78	403.076
35	1	3	1	3	2	2	3	0.11	0.38	0.68	4	450	1.478	1.537	1.573	303.25	302.82	402.876
36	1	3	1	3	2	2	3	0.11	0.38	0.68	4	550	1.501	1.607	1.803	300.48	299.78	399.032
37	1	3	1	3	2	2	3	0.11	0.38	0.68	4	650	1.296	1.329	1.516	298.63	298.72	396.848
38	1	3	1	3	2	2	3	0.11	0.38	0.68	4	750	1.261	1.245	1.468	297.26	298.26	397.48
39	1	3	1	3	2	2	3	0.11	0.38	0.68	4	850	1.408	1.428	1.724	296.66	295.96	394.932
40	1	3	1	3	2	2	3	0.11	0.38	0.68	4	950	1.393	1.448	1.767	293.2	293.85	391.16
41	1	3	1	3	2	2	3	0.11	0.38	0.68	5	50	1.246	1.661	11.058	303.79	302.28	407.468
42	1	3	1	3	2	2	3	0.11	0.38	0.68	5	150	1.289	1.772	11.697	296.86	297.41	401.1
43	1	3	1	3	2	2	3	0.11	0.38	0.68	5	250	1.467	1.888	11.265	300.79	301.68	405.224
44	1	3	1	3	2	2	3	0.11	0.38	0.68	5	350	1.489	1.920	10.604	301.58	302.21	404.864
45	1	3	1	3	2	2	3	0.11	0.38	0.68	5	450	1.478	1.723	10.616	303.25	302.45	404.688
46	1	3	1	3	2	2	3	0.11	0.38	0.68	5	550	1.501	1.790	11.829	300.48	298.76	401.676
47	1	3	1	3	2	2	3	0.11	0.38	0.68	5	650	1.296	1.728	10.931	298.63	297.41	399.492
48	1	3	1	3	2	2	3	0.11	0.38	0.68	5	750	1.261	1.664	10.516	297.26	297.95	400.06
49	1	3	1	3	2	2	3	0.11	0.38	0.68	5	850	1.408	1.921	11.399	296.66	294.6	398.428
50	1	3	1	3	2	2	3	0.11	0.38	0.68	5	950	1.393	1.659	10.946	293.2	295.24	398.12
51	1	3	1	3	2	2	3	0.11	0.38	0.68	6	50	14.785	30.976	56.899	122.2	100.91	288.932
52	1	3	1	3	2	2	3	0.11	0.38	0.68	6	150	15.200	32.476	57.119	119.47	99.088	293.212
53	1	3	1	3	2	2	3	0.11	0.38	0.68	6	250	18.216	34.101	52.758	121.1	100.52	287.112
54	1	3	1	3	2	2	3	0.11	0.38	0.68	6	350	19.785	37.040	62.337	121.37	101.09	291.84
55	1	3	1	3	2	2	3	0.11	0.38	0.68	6	450	19.793	37.944	62.645	119.98	100.8	288.888
56	1	3	1	3	2	2	3	0.11	0.38	0.68	6	550	17.444	35.282	52.722	119.74	100.43	276.544
57	1	3	1	3	2	2	3	0.11	0.38	0.68	6	650	15.057	32.606	53.325	120.72	99.62	283.6
58	1	3	1	3	2	2	3	0.11	0.38	0.68	6	750	15.288	30.712	61.161	119.61	99.04	275.108
59	1	3	1	3	2	2	3	0.11	0.38	0.68	6	850	15.468	32.876	51.608	120.87	97.704	287.296
60	1	3	1	3	2	2	3	0.11	0.38	0.68	6	950	14.509	28.588	50.776	120.14	98.232	282.38

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