LICENTIATE THESIS

Information Sharing and the Bullwhip Effect Reduction

A New Perspective Through the Lens of Blockchain Technology

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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.

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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 has 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.

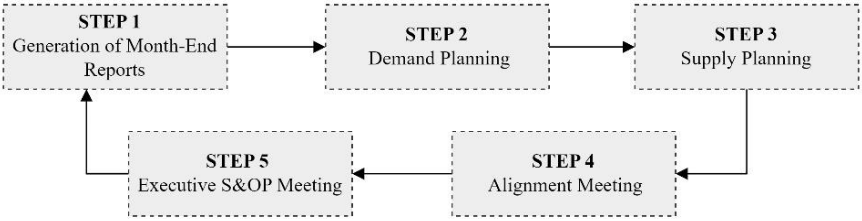


***Figure 1**. The Cycle of S&OP (Sanders, 2014)*

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). Nakatomo (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 (Saberi *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

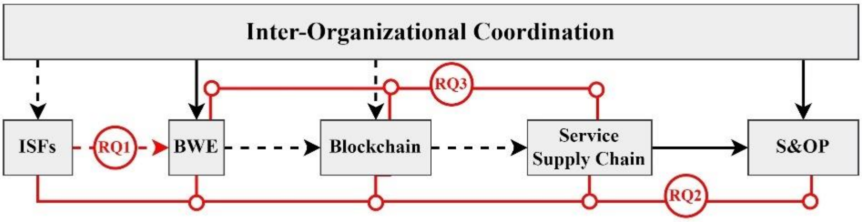


Figure 2. *Relationships between the research questions and the research gaps*

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*

	Research Questions	Conceptual Framework	Literature Review	Simulation
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."

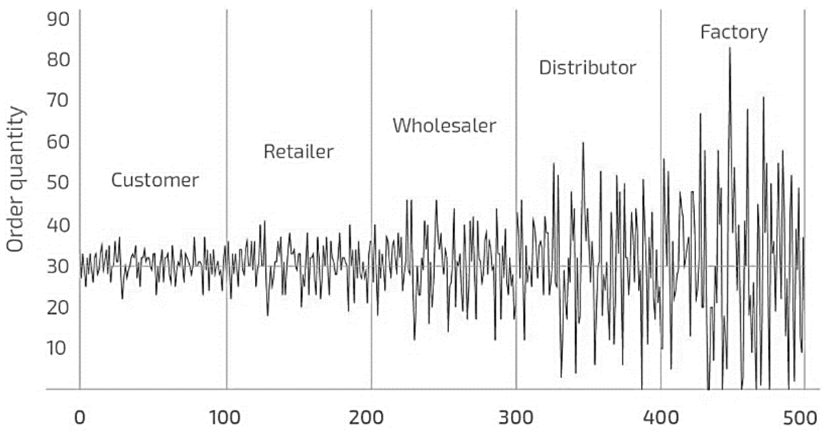


Figure 3. *Orders amplification in the supply chain*

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 (Bhathacharya 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.

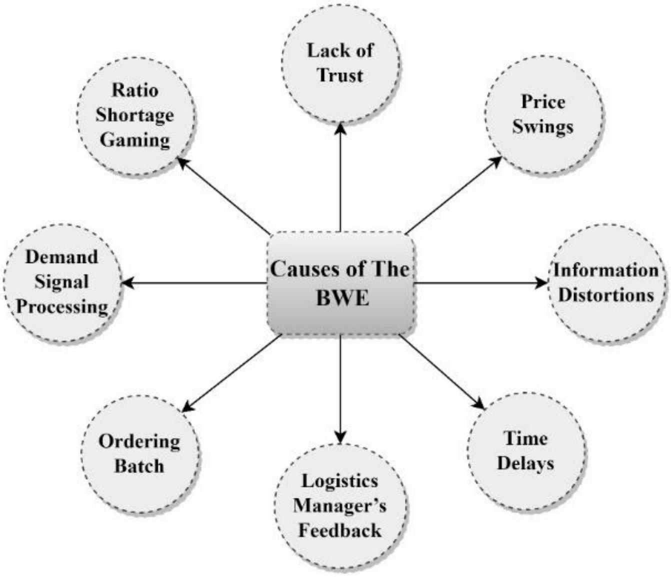


***Figure 4**. The operational and behavioral causes of the BWE*

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:

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

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

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*

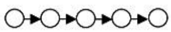
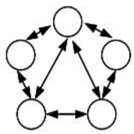
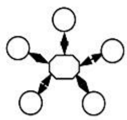
Literature	Shared Information Type
Chen *et al.,* (2000); Chatfield *et al.,* (2004); Asgari *et al.,* (2016); Argilaguet *et al.,* (2017)	Demand
Croson and Donohue (2003); Croson and Donohue (2005); Hassanzadeh et al., (2014)	Sales (POS).
Dominguez *et al.,* (2014); Dai *et al.,* (2016); Wang *et al.,* (2016)	Inventory.
Yu *et al.,* (2001)	Demand and order.
Ouyang (2007); Agrawal *et al.,* (2009)	Order and inventory.
Li *et al.,* (2016)	Order.
Jeong and Hong (2019)	Demand Forecast.
Ding *et al.,* (2011)	Ordered quantity.
Rached *et al.,* (2016)	Demand and lead-time.
Jiang and Ke (2018)	Demand Forecasting and lead-time.
Ojha *et al.,* (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 (Saberi *et al.,* 2018b). Figure 5 shows the working mechanism of BC technology.

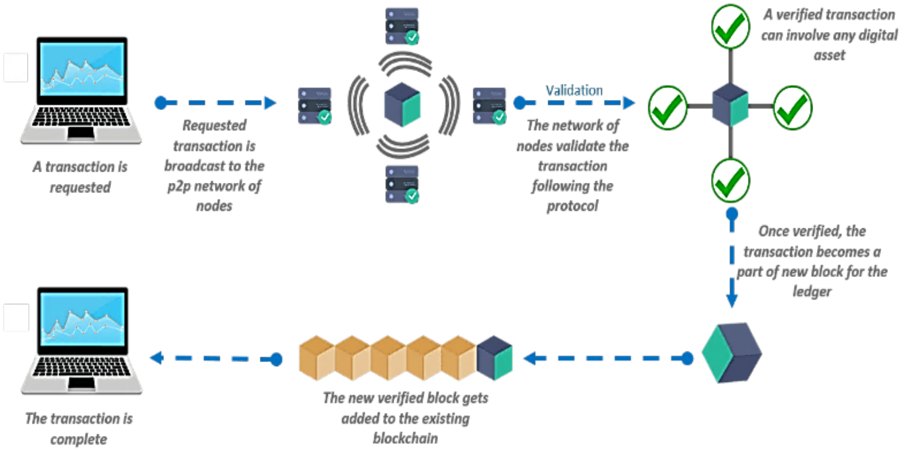


Figure 5. *The working mechanism of BC technology*

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 (Saberi *et al.,* 2019; Saberi *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; Saberi *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 (Saberi *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 (Assaqty *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*

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