Increase Supply Chain Visibility by Incentivizing Stakeholders to Use Blockchain

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Abstract

With increasing customer expectations for fast and cheap deliveries and competition to capture market share, retail organizations are increasingly compelled to make their supply chains as efficient as possible. A major driver of inefficiency in supply chains is the lack of visibility of the goods, information, and financial flows. This lack of visibility leads to decreased customer service levels and increased disputes in the supply chain. To tackle this problem, companies are investing in supply chain visibility tools such as blockchain technology. But there is no clear understanding of the impact of this new technology on supply chains. Our research models the transportation network of our corporate partner, Walmart, through system dynamics methodology and quantifies the impact that blockchain technology would have on the transportation service level and the number of shipment-related disputes. Our results suggest that when stakeholders in a supply chain introduce blockchain-enabled visibility technologies, there is a significant increase in the percentage of deliveries that are on-time and in full (OTIF), and a reduction in dispute management costs. At the same time, there are several disincentives and challenges, such as high setup cost and lack of understanding of the technology, that Walmart needs to consider to increase blockchain adoption among its stakeholders.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

OTIF	On time- In-Full
DC	Distribution center
SVC	Supply chain visibility
KPI	Key performance Indicator
MABD	Must Arrive by date
SD	System dynamics

1. Introduction

1.1 Background and motivation

Modern supply chains are extremely complicated networks that span across multiple geographies and organizations. Inefficiencies in these supply chains result in billions of dollars of losses to organizations every year in terms of lost sales or lost productivity. For instance, a study in UK estimated that supply chain inefficiencies and miscommunication are costing UK businesses over £1.5bn in lost productivity every year (Henderson, 2018). Also, according to a report from Mckinsey & Co (*Defining 'on-Time, in-Full' in the Consumer Sector* | *McKinsey*, 2020), "The US food retail industry loses an estimated $15–20 billion in sales every year because items are out of stock or otherwise unsaleable." Such studies demonstrate the urgent need for companies to invest in technology that can help increase their supply chain efficiencies. Our study is based on the inefficiencies in transportation in Walmart's small package supply chain. In the following section, we describe the current state of this supply chain and further understand these inefficiencies.

1.2 Transportation in Walmart's supply chain

Walmart is one of the world's biggest private companies by revenue and by market capitalization. This giant global retailer runs over 11,700 stores in 28 countries under 59 company names worldwide and manages $32 billion inventory on a daily basis. The company receives and stores goods in its expansive network of more than 160 distribution centers (DCs) with a physical footprint of 120 million square feet (Walmart, 2020). Walmart eCommerce is an initiative by Walmart to connect with this customer through internet and enable them to purchase goods online. It comprises of the following websites: (1) Walmart.com (2) SamsClub.com (3) VUDU. The technology team that manages these three websites are unified under an organization called Walmartlabs.

The transportation network of Walmart's small package supply chain for ecommerce consists of the supplier of goods, a carrier who is in charge of moving the materials through the network, and Walmart. The interactions that happen between these three entities can be classified as (1) goods flow (2) information flow and (3) financial flow. The information flow happens through the IT systems that communicate with each other through various departments within these three entities, i.e. planning systems, purchasing/ procurement, warehouse, transportation department, manufacturing department.

Figure 1 illustrates the flow of information, goods, and money that we created based on our interviews with Walmart and industry knowledge. The flow starts with a buyer (purchasing team) at Walmart who identifies a product that can be sold in one of the Walmart's retail stores. The product is on-boarded into Walmart's IT systems by entering the product information, the GTIN number, tax code and other product master data. Once this process is complete, an order is placed by the replenishment system with the vendor on the basis of the inventory at stores and the inventory replenishment policies that are defined for each specific product.

The order is placed by releasing a Purchase order (PO) to the vendor. Walmart's IT systems sends the PO to the vender's IT system through an Electronic Data interchange (EDI) standard. When the product is ready for shipment, the vendors IT system communicates this back to Walmart's IT system through another EDI standard called Advanced Shipment Notification. The products are packaged and shipped by the vendor with a label that identifies the product and the PO that it belongs to. The next step in the process is the movement of the material from the vendor location to Walmart's warehouse.

Walmart employs a prepaid type of delivery for small package orders. In a freight prepaid delivery the shipper/ supplier is responsible for the paying the shipping charges as well as any other ancillary charges that might come along the way until the goods are handled over to the recipient. (REYES, 2018).

Once the material arrives at a Walmart warehouse, it is in-warded into one of the available docks, unloaded into the bay and finally stored at a specified location. During the in-warding process, the operator at the warehouse uses the PO number that is mentioned on the products and way-bill as a reference to register the delivery in Walmart's system. Against each PO the system registers the received quantity, the received date.

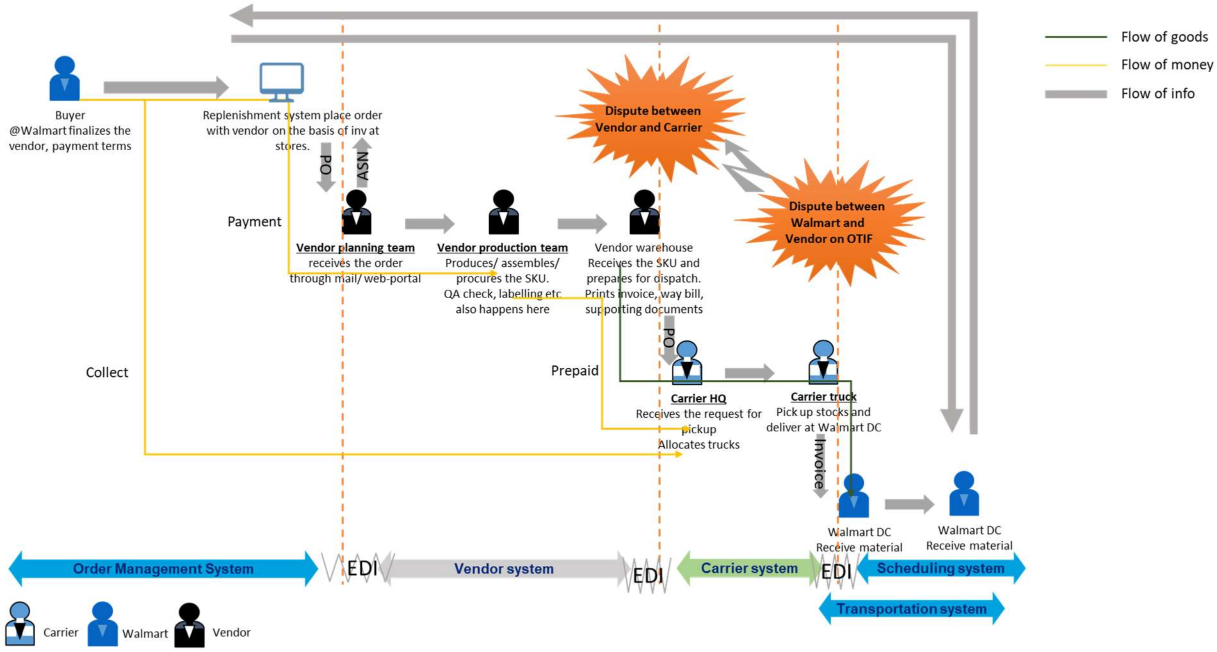

Figure 1 Supply chain mapping of small pack deliveries at Walmart

Though Walmart has one of the best supply chains among the retail organizations (Henderson, 2018b), there still exists pockets of inefficiencies in its supply chain. For example, only 60% of the suppliers have their shipments reach Walmart DCs on time and in full. Remaining shipments either arrives partial, early, late or in some cases lost or damaged. This results in very high number of discrepancies between the expected shipment terms verses what is received. The majority of accountability in OTIF loss is due to shipments not arriving on time (as opposed to not arriving at all). Given that Walmart's annual revenue is 515B+, 40% shipments not meeting OTIF means this is a serious issue for many suppliers and of course retailer. Walmart is in fact, charging penalties to supplier not meeting OTIF targets.

Also, only 75% of the shipments that are received at the warehouses had correct PO data associated with them. This is because the vendors erroneously put wrong PO data in the documents sent with the shipments or because the PO data mentioned in the shipment documents did not match the data in Walmart's IT systems. Moreover, carriers provide dummy PO numbers to Walmart for certain goods. A dummy PO issue happens when a constant number (9xxxxxxx9 or 0xxxxxxx0) is used for filling the PO field in shipment documents instead of entering the correct PO number for the shipment. Due to the dummy POs, multiple vendor-items combination gets mapped to the same PO and results in problems to identify the ownership of the goods. They also face issues with reading labels on the goods due to incorrect labeling or damaged labels resulting from mis-handling of shipments.

1.3 Key performance indicators in Walmart's transportation

Key performance indicators (KPIs) are quantifiable measures that a company or industry uses to gauge or compare its transportation performance in terms of meeting their strategic and operational goals (Wilkinson, 2015). For our study, we focus on two specific KPIs that are linked to the supply chain mapping identified in Figure 1.

a. On Time-In Full

OTIF (on time, in full) measures the extent to which shipments are delivered to their destination according to both the quantity and schedule specified on the order. It is important to note that even early delivery is penalized because an item that arrives early results in increased inventory holding costs as well as results in choking of the warehouse/ distribution center. OTIF is one of the most important metrics for measuring service performance at Walmart. With strong competition from e-commerce players like Amazon, todays shoppers have enough options to look online if a particular product is not available on Walmart's shelves. For Walmart, this represents not just a loss in one sale, but presents the risk of completely losing the customer as he/she gets accustomed to online purchases. But, "OTIF scores for Walmart's top 75 suppliers had been as low as 10 percent. And not one had reached the 95 percent long-term target" (Boyle, 2017). Thus, there is high focus among the leadership team to improve this important measure. The equation that Walmart uses for OTIF calculation is show below,

$$OTIF\ score\ =\ cases\ received\ in\ window\ /\ total\ cases\ ordered$$

The calculation for total cases ordered is shown in the equation below,

$$\begin{aligned} &Total\ cases\ ordered \\ &\qquad =\ cases\ delivered\ early\ +\ cases\ delivered\ short \\ &\qquad +cases\ delivered\ on\ time +\ cases\ delivered\ late \end{aligned}$$

b. Dispute Management costs

Disputes happen when OTIF is missed and stakeholders have different opinions about who should be responsible for it. Due to the significant penalties associated with OTIF misses, suppliers keenly track all OTIF misses. In cases where the supplier's IT system registers that the OTIF is met but Walmart's IT system registers an OTIF miss, a dispute can be filed by the supplier with Walmart. The information mismatch could be because of several reasons including human data entry error, misplacement of goods or because of a malicious actor who has defrauded the system to take custody of the goods.

The current process for resolution of disputes is a highly manual. Dispute resolution teams from Walmart and supplier trace each line item individually to identify the root cause for the data mismatch. With separate IT systems operating independently at Walmart, carrier and supplier, it takes a long time to resolve disputes as there is no single version of truth that everybody can agree on. For instance, in case of an item lost along the way, the supplier may say the number of items dispatched was correct when the goods left its premises, but carriers may insist the number of items had already decreased when they received the load from the supplier. The cost incurred to resolve these disputes is called dispute management cost. It includes expenses on maintaining the dispute resolution teams, cost of litigation and costs incurred in settlement of disputes (Gibson, 2016).

$$\begin{aligned} &Dispute\ management\ cost \\ &\qquad = cost\ of\ maintaining\ dispute\ resolution\ teams + cost\ of\ litigation \\ &\qquad + costs\ incurred\ in\ settlement\ of\ disputes \end{aligned}$$

1.4 Supply chain visibility and blockchain

Supply chain visibility (SCV) can be a solution for decreasing transportation inefficiencies described in section 1.2. SCV is about knowing where the parts, components or finished goods inventory is located at any point in time as they move from the manufacturer to the customer (Quantzig, 2018). The goal of supply chain visibility is to help improve the supply chain by making data easily available to all stakeholders (Quantzig, 2018). The business case for increased SVC stems from rising competition, globalization, and increased complexities in the market that have made the task of tracking goods a challenging task for organizations. (Techtarget, 2009).

It has been suggested that transportation KPIs can be improved through increase in the visibility of goods and financial data between stakeholders (Barratt & Oke, 2007). Through visibility, all stakeholders can track product origin (provenance), reduce chance of counterfeit, increase safety, and data mismatch issues (Banerjee, 2018).

Increased supply chain visibility also has other advantages. It can increase inventory turnover through streamlined goods receipt process and lead to faster cross-docking as well as optimization of material-handling resources(Lavin, 2015). It can also help supply chain entities to: (1) mitigate exceptions quickly (2) measure and control the amount of pipeline inventory and buffer stocks and (3) comply better with regulations (Stanchik, 2016). Besides short-term benefits, supply chain visibility also provides valuable long-term improvements. With full visibility of the supply chain, companies will have sufficient data to carry out network optimization, improve freight-allocation and reduce overhead costs. With data on cargo movements, companies can also improve the accuracy of billing and charges. Good and reliable data can also help supply chain partners evaluate each other by analyzing mutual performance. For example, using metrics, suppliers can negotiate with carriers to get a lower rate when they do not meet service commitments. This can also become incentives for carriers to perform better (Somapa et al., 2018).

Moreover, increased visibility reduces the bullwhip effect in demand as it travels upstream. Bullwhip effect is the phenomena where impact of customer demand swings increases in magnitude as one moves up the supply chain. This can help reduce inventory management costs through enhanced prediction and optimization decisions. (Holgado de Frutos et al., 2020). Ultimately, these benefits result in improved KPIs for organizations.

One of the emerging technologies for enabling transportation visibility and traceability is blockchain technology. Blockchain is a secure ledger for information storage and retrieval that consists of an interconnected and growing list of data records called blocks where supply chain information can be stored (Tian, 2016). The blocks are linked to each other using cryptography like a chain and hence the technology is called block-" chain". This technology provides a whole new way to transact and exchange value between organization because of its immutability and decentralization features (Tian, 2016). Immutability (resistance to unapproved change) helps build trust among all the parties on the blockchain and decentralization (same information is stored in multiple servers at the same time), provide them with data source that can be used as a single source of truth (Underwood, 2016). These features can help bring visibility to transportations (Korpela, 2017).

1.4.1 Current status of blockchain adoption in Walmart

Walmart uses a block chain solution co-developed by Walmart and IBM for tracking information of leafy-green vegetables. This collaboration between Walmart and IBM led to the development of a blockchain based SCV solution called IBM Food Trust. It allows authorized users to access actionable data on their food supply chains from farms to store. All information on the food item including location history, certification data, test and temperature data are fed into the system and is readily available for access within seconds. It is offered as a Software-as-a-service (SAAS) solution to interested clients.

IBM Food-Trust uses GS-1 standards that are already in use in the industry and relies on an open source framework called Hyper ledger fabric as its base blockchain technology. This ensures that there is a high degree of inter-compatibility between existing IT systems and Food-Trust, allowing participants to easily share information on Food-Trust without radical changes to their existing infrastructure. To ensure universal access to a wide range of clients, it is accessible using a browser and communicates with current ERP systems through application-programming-interface (API) calls. Finally, as an offering provided by IBM, it also provides round the clock customer support and a high-availability network, which makes it a good candidate for enterprise blockchain applications. But, this initiative is limited to application in the area of food tracing and has not been extended to the transportation area yet.

1.5 Research Problem

Currently, Walmart is exploring the use of blockchain technology to improve visibility of its transportation for small pack deliveries. Through adoption of blockchain in this supply chain, Walmart intends to improve its On Time and In Full performance and reduce the number of disputes between its supply chain partners. One of the roadblocks that they expect to face while implementing the blockchain is the low adoption rate among its supply chain partners.

The purpose of this project is to analyze how the implementation of blockchain may impact the performance of small package deliveries, measured in terms of On Time and In Full deliveries and dispute management cost, from suppliers to Walmart through system dynamics (SD) modeling and simulation of their transportation supply chain. A system dynamics model is appropriate in this case as there is very limited information available on the complex nature of the transactions that happen among these entities. By analyzing the impact of blockchain in this network, we intend to identify the incentives and disincentives of all involved stakeholders to join the blockchain platform and understand the challenges and opportunities of implementing this technology in Walmart's transportation.

In this chapter we have introduced Walmart's transportation challenges in the small package delivery area and our research problem. Chapter 2 presents the literature review. In Chapter 3 we discuss the methodology that we adopted to tackle our research problem. In Chapter 4 we present our system dynamics model and discuss the results from the simulation. In Chapter 5 we discuss the main insights from the simulation and literature review and our recommendations for Walmart. Finally, in Chapter 6 we present the conclusion of this research project.

2. Literature Review

To understand more about this topic, we start by reviewing existing literature regarding the issues and opportunities in transportation in supply chains, with specific focus on the relationships that exist between different entities in the transportation, and the disputes that happen in the transportation.

Another key focus area for solving our research problem is understanding how visibility can improve transportation processes. To understand more about this topic, we research existing literature on supply chain visibility, and the benefits that companies can realize by increasing visibility of their transportations. Next, as our project is focused on the impact of blockchain on the performance of transportation processes, we research existing literature on the technological underpinnings of blockchain technology, and how this technology can improve visibility on transportations.

2.1 Transportation in supply chains

“Transportation is a part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers’ requirements” (Tseng & Yue, 2005). In the US, transportation related costs accounted for 9.4% of the gross domestic product (GDP) of the country

(CSCMP, 2009). To study how blockchain would impact the visibility over supply chains, we first explore the nature of the relationships among supply chain participants, supply chain metrics and the reason for disputes in the supply chain. Understanding these relationships, metrics and reason for the disputes is required to develop a comprehensive model that captures the KPIs (OTIF and dispute management costs) and the impact when one or more stakeholders in a supply chain adopt blockchain.

2.1.1 Relationships in transportation

The nature of the relationship between a central entity and its extended supply chain plays an important role in its success. These relationships can be strategic, tactical or transactional. In all of the three categories, too much power in any one camp risks undermining the effectiveness of the supply chain. For the success of the supply chain, It is very important that all entities maintain high-trust, mutually beneficial relationships that are enabled by high communication (Andrews, 2020)

Good relationships, communication and visibility is also required inside the four walls of the company (Ackerman & van Bodegraven, 2017). The manufacturing team and the distribution teams need to be constantly aware of the changes in the business needs and establish strong communication lines with sales and marketing functions. Also, the procurement and sourcing teams cannot work in silos and needs to collaborate with other functions in the organization (Pagell, 2004)

In an ideal centralized supply chain, the central supply chain entity connects both suppliers and customers to allow them to easily exchange information (Fischer & Nijkamp, 2011). This would mean linking the IT systems and working together to remove inefficiencies, improve quality, enhance mutual capability and reduce costs. Supply chain visibility initiatives are driven by strong management conviction, talent and a culture of strong relationships (Ackerman & van Bodegraven, 2017). Literature is replete with studies that suggest suggests that such supply chain integration through visibility enhancing technologies, build on relationship of trust between organizations can help improve performance (Pagell, 2004).

2.1.2 Metrics in Supply Chain

Supply Chain metrics are key to implementing, monitoring and measuring the success of these relationships. There are several metrics that measure each minute step in the supply chain processes relating to supplier management, production, transportation, inventory management, material handling, warehousing or customer service. For the purpose of our study, we limit our scope to service and cash metrics. The reason we limit our research to service and cash metrics is because for our model, the incentives that we are focusing on are directly linked to service (OTIF) and cash (Dispute management costs).

Order measurement metrics: A good order measurement metrics calculates the error-free rate of each stage of a purchase order: procurement forecasting, issues in warehouse-pickup, transportation issues and errors in invoicing. On-time-In-Full (OTIF) is an example of an order measurement metric.

Cash Cycle Metrics: Cash to cash cycle metrics calculates the amount of time it takes for the business to convert the cash invested in manufacturing the goods to payments from the customer. A short cash to cash cycle indicates a lean supply chain.

Fill rate: This represents the percentage of the orders from the customer that are fulfilled by the firm. A high fill rate is very important for customer satisfaction as well as maintaining efficiencies in transportation.

Inventory turn-over: This metric tracks the number of inventory cycles per year. It is defined as the average inventory divided by the cost of goods sold by the company in a year. A higher inventory turn-over results in better cash in hand for the company as less money is blocked as dead inventory in the warehouse.

2.1.3 Disputes in transportation

Disputes arise when transportation performance is not as expected by the client but there is no agreement between the parties on the root cause of the performance issue. Thus, a dispute might may happen because the shipments did not arrive on-time or in-full (OTIF) and the supplier, carrier and Walmart fail to agree on who is responsible for this miss. In contrast, if there is an agreement between parties on the root cause of the performance issue, then the matter is resolved as per the clauses defined in the contract between these parties. In case of OTIF, this is in the form of a penalty that is charged by Walmart on the supplier when the average OTIF score for the supplier is below a certain threshold. Such disputes need to be managed within each company and also settled between companies. Dispute management in supply chains require an understanding of the relationships between supply chain entities. When a dispute arises between two entities in the supply chain, clearly defined legal contracts can help in quick amicable resolution. A rewarding and stable relationship between suppliers and buyers involves reducing the scope for disputes throughout the lifecycle of the relationship, starting with the contracting phase (Bowman, 2016). “Supply chain legal disputes don’t start out as legal disputes. They typically start out as badly written contracts, poor communication with supply chain partners, and an inability to resolve conflicts. While legal battles are sometimes inevitable, most of the time, they can be avoided through planning and an informed approach to the supply chain and associated processes.” When disputes occur, the best practice rules to resolve the dispute may be combining observations from the field and information technology(Wolf & Pickler, 2010).

In this section, we described the relationships, metrics and disputes in transportation. All of these three parameters are interlinked and are impacted by supply chain visibility technologies. For example, a dispute arises when there is no consensus between stakeholders on transportation metrics. The outcome of these disputes is linked to the nature of the relationships that exist among stakeholders. Further, transactional and strategic relationships that exists between stakeholders in this field dictate the nature of technology adoption in this sector. By understanding these topics, we can have better knowledge about the variables and the relationships that are needed in our model to simulate impact of blockchain. In the next section we describe blockchain technology and how blockchain can improve these KPIs and reduce disputes by increasing supply chain visibility.

2.2 Blockchain and transportation

2.2.1 What is Blockchain?

As discussed in section 1.3, blockchain is one of the technologies that can be used for improving visibility and consequently the KPIs mentioned in section 2.1. Blockchain is a decentralized transaction and data management technology that enables multiple parties to store and share value without the need for traditional intermediaries. Blockchain technology is based on a distributed ledger that leverages the properties of a peer-to-peer network to verify and approve the transaction. (Agarwal, 2018).

The concept of blockchain was introduced as a part of the white paper on Bitcoin written by Satoshi Nakamoto (possibly a pseudonym for a group of people) (Nakamoto, 2008). Nakamoto proposed a system that combines many of the existing technologies to create a distributed system of ledgers that can be used for exchanging information securely across parties that provides tracking of the transaction history and immutability.

A public blockchain network maintains a copy of the database with a subset of the peers in the network who actively participate in maintaining the network and validating new blocks that are added to the database (Kolb et al., 2020).

Permissioned enterprise blockchains utilizes the same underlying technology of public blockchains, but limits the members who can join the network. For instance, a manufacturer producing a product may use a permissioned blockchain for managing the supply chain inside his organization. The transactions that occur on such a blockchain may also involve logistics partners, financing banks, and other vendors involved in the supply and financing process. These external parties, though part of the whole network, don't have to know the price at which the manufacturer supplies the products to various clients. The use of permissioned blockchains allows such role-limited implementations (Frankenfield, 2019). With restrictions on membership, such services can offer enhanced privacy for private enterprises. Permissioned blockchains have attracted significant interest from the business community. Due to the distributed nature of the network, this technology is perfect for tracking unique digital assets along the supply chains and storing information such as location data, ownership data, product specific features and time stamps as these goods move along the supply chain. (Allen et al., 2019)

To adopt a permission blockchain, an enterprise may have to invest in a significant amount of preliminary work. All initial participants in the chain may have to come together to define the data models, standards of the network, rules for data exchange, governance rules over intellectual property, agree on network financing, software updates control etc. (Lacity et al., 2019)

Ultimately, the safety of the blockchain comes from the underlying property of the network that an attacker would need to compromise 51% of the system to surpass the computing power of the target network (Biswas, Muthukkumarasamy, & Tan, 2017). As a result, it is almost impossible to tamper with transactions stored in a blockchain. (Biswas, Muthukkumarasamy, & Tan, 2017). Because of this immutability and security, blockchain can be one good solution to share information and build trust among parties in the supply chain.

There are many popular providers of enterprise blockchain solutions that are currently operating in the supply chain space. One such application that is championed by IBM is called Hyperledger Fabric (Androulaki et al., 2018). The pilot projects run by IBM involves updating sharing of trade flows, contracts, financing information through Hyperledger. Walmart has used IBM Hyperledger for its proof of concept project on food supply chains.

2.2.2 How blockchain can improve visibility in transportation?

In modern transportation, goods move between multiple entities before reaching the end consumer. Incidents of damage, counterfeiting and data mismatch can happen at these points where goods or documents are passed from one party to another (Banerjee, 2018). Such incidents lead to significant losses for organizations around the world.

Such incidents can be reduced or traced back to its origin by using supply chain visibility technologies. There are several supply chain visibility technologies available in the market, some of which are based on blockchain. A blockchain based technology can be well suited for applications where there is a need for of immutability, security, and transparency. Blockchains provide one single version of truth for data so that all parties can identify incidents of damage, counterfeiting and data mismatch when they happen and can arrive at a consensus easily. (Lacity et al., 2019)

Furthermore, due to the transparent nature of blockchain, the information that is stored on the chain can be accessed by all entities that have been given the permission to access it. Moreover, because of these mutual advantages, blockchain can incentivize different entities to proactively feed information on to the chain further increasing its usefulness (Kim & Laskowski, 2018).

Finally, because it is almost impossible to change the data once it enters blockchain (immutability), all parties involved will have confidence in the shared history. These characteristics of blockchain can solve many current supply chain problems such as tracking/recall, dispute management between retailers and carriers, etc. and make it well suited for application in the supply chain industry (Francisco & Swanson, 2018).

2.2.3 Blockchain vs current systems for supply chain visibility

For the purpose of identifying the incentives and disincentives of blockchain technology it is important for us to understand the unique differentiators of blockchain technology with respect current systems that are being used to ensure supply chain visibility . In this section we compare the differences of blockchain technology with respect current systems on the basis of five parameters: (1) Data storage (2) Cryptographical encryption (3) Cost of dispute management (4) Smart contracts (Yousuf & Svetinovic, 2019). From our research of existing literature, we inferred that these 5 parameters can captured all essential differences between them

The first differentiator for blockchain is in the method of data storage. In existing technologies data is stored in siloed servers. The servers communicate to each other via electronic data interchange protocols. In blockchain, the data is replicated in a large number of identical databases, each hosted and maintained by an interested party. When changes are entered in one copy, all the other copies are simultaneously updated. Hence blockchain can provide a single version of truth for all parties (Filippi, 2016) .

The second major differentiator for blockchain compared to other technologies is its inherent cryptographical encryption. All data is stored in blocks that are encrypted using algorithms and all changes are verified independently by each stakeholder before approving. This can improve trust between all stakeholders in the transportation who access the data. In contrast, encryption is not inherent and needs to be incorporated as an additional feature in other technologies (Kosba et al., 2016)

The third differentiator is in the cost of managing disputes. In organizations that use existing technologies, we see a huge list of, intermediaries like lawyers, brokers, auditors and bankers work as intermediaries for dispute management. As blockchain database has the same version of data for all stakeholders and as the data is trusted by them, disputes that arise with transactions between organizations can be solved internally without the requirement for a costly external intermediary (Catalini & Gans, 2019).

The fourth major differentiator is the additional features such as smart contracts that some blockchain implementations can provide for organizations. Smart contracts are pre-programmed computer codes that execute the terms of a contract or agreement by operating on top of the block chain platform. They track the process status changes that are recorded in the blockchain by supplier, carrier or other stakeholders and can trigger a subsequent process, for example, a payment transaction. The core advantage of using smart contracts on the blockchain platform is that it can reduce the need for human intervention in a trusted and transparent way (Chang & Chen, 2019)

2.2.4 Challenges in blockchain adoption

Despite the advantages of blockchain technology, adoption rate of this technology for industrial applications is still slow. This is due to several challenges that operate as headwinds for blockchain adoption. Firstly, since blockchain is a new technology, there is a lack of awareness and understanding of how a it works, especially in the supply chain context, in many organizations (Ehrlich, 2019).

Secondly, many large organizations are developing their own independent blockchain solutions. This leads to multiple different blockchain standards and issues with interoperability. Even within large organizations, many departments work as siloed verticals. If one vertical of a company adopts a blockchain based SVC technology standard, it may not realize the benefits unless there is an organization wide adoption of the same blockchain standard.

Thirdly, the cultural shift associated with blockchain implementation is also expected to be unsettling for many organizations. It requires a fundamental shift in thinking from the traditional perspective of relying on a central IT system that is fully controlled, to trusting a decentralized network of computers (Mire, 2019).

The efficiency of the blockchain network is another challenge that impedes its adoption. The peer-to-peer transactions are inherently less efficient than relying on a central authority because each node replicates the data in every other node and verifies each of the transactions individually. Therefore, even though blockchains might enhance productivity at the scale of the whole network, it introduces new local inefficiencies in individual nodes. In the context of supply chains, these nodes refer to the IT systems maintained by the supply chain partners of an organization (Deloitte, 2019).

Moreover, most popular blockchain solutions that are under development are championed by a few large organizations, called a *benevolent dictators,* who promotes a particular version of blockchain technology in the eco-system and defines their own governance standards (Batubara et al., 2018). That means that the core computer code that runs the blockchain is controlled by these organizations. Such lack of regulation and governance standards is another challenge that is faced by this technology. Even though there is no clear solution to resolving the problem of lack of regulation and governance standards, there are several methods that have been suggested in literature. One such approach is to choose a governance model that is democratic, with options to consult an advisory board in case of disputes For example, in case TradeLens (a blockchain SVC tool for the shipping industry) the advisory board consists of representatives from three of the biggest competitors in the shipping industry, Maersk, Mediterranean Shipping Company and CMA-CGM) (Jensen, 2019).

In addition, it is difficult to form viable partner consortiums for blockchain technology development when the partners are competitors or have different goals and interests to participate in the network. One approach to solve this problem is to form an initial mutual-trust based blockchain network that is piloted by non-competing partners. Eventually, an industry wide adoption can be realized once the blockchain based eco-system becomes a standard in the industry (Zavolokina et al., 2020).

Lastly, the cost of production-scale blockchain solution is high. According to a report by Ernst & Young, joining a cloud based blockchain solution for small to medium size business can cost around $1 million over a five year horizon, with a total cost of almost $100,000 in the first year due to the initial on-boarding costs and a subsequent on-going maintenance cost of $150,000 per year. Additionally it will cost approximately $600,000 more in platform build costs if the solution is tailor made for the needs of the specific company. (Ernst & Young, 2019).

2.2.5 Blockchain applications in transportation

In this section we cover two use cases for how blockchains adoption is used to increase visibility in the transportation.

Case 1: Maersk

Maersk has been looking for a better way to trace the goods it ships worldwide for many years. Maersk's containers can be held up in port for many days due to missing paperwork, yet this is an issue that involves up to 30 people and over 200 different interactions and communications among them.

To solve this problem, Maersk collaborated with IBM to develop a blockchain enabled software that can be open to everyone involved with every container. When customs authorities sign off on a document, a copy of the document will be immediately uploaded with a digital signature, allowing everyone involved with this document to see that it is complete. If there are disputes later, every person can check the record on blockchain and be confident that the recorded is never altered. This blockchain implementation helps reducing paperwork and adds visibility for each container, as well as reducing the paperwork cost. It also help reduce disputes as every party can go back to the record and be confident that no one had altered it (Kshetri, 2018).

This case is a great example of how blockchain can improve supply chain visibility and reduce disputes. Comparing with the challenges that Walmart is facing in its supply chain, Maersk has more stakeholders involved as they can be from customs, tax officials, or health authorities. Therefore, this case demonstrates that blockchain has the capability to benefit supply chain operations with multiple stakeholders involved.

Case 2: Alibaba

Alibaba has been facing challenges in food safety and counterfeit for years. When it expands its business in New Zealand, Alibaba needs to ensure the food quality and safety standards across this global supply chain. Thus, Alibaba and Fonterra have launched a blockchain pilot for transportation traceability and transparency. The New Zealand based dairy business will use Alibaba's "Food trust framework" to provide trusted information about provenance to consumers. With this pilot project, consumers will be able to trace the products that they purchase online on Alibaba's T-mall global platform. A blockchain-technology based system will be used for storing QR code scans throughout the product's life cycle to authenticate, record and verify the products journey from supplier to end consumer. (Coyne, 2018).

This case is an example of how blockchain can ensure food quality and prevent counterfeit by improving supply chain visibility. The traceability and immutability brought by blockchain can give confidence to consumers and merchants to purchase Alibaba's product. The same applies to Walmart that the supply chain data shared in blockchain can give confidence to supplier stakeholders to improve the supply chain operations and avoid dispute. Yet Alibaba's business in New Zealand is small scale comparing with Walmart's small parcel shipping. We need to see how blockchain works in a large scale.

2.3 Literature review Summary

In this section, we described relationships, metrics and nature of disputes that exist in transportation. This was used for developing the variables and feedback loops in our model. Second, to understand more about the blockchain technology, we also researched about its origins and its application in the enterprise space. Finally, we described the problems that blockchain adoption faces in the industry we learnt about the roadblocks that Walmart may face when it tries to roll out blockchain in its network. By understanding these topics, we have the knowledge to build a model that includes key variables and relationships to model the blockchain's impact on supply chain. The literature review also helps us incorporate the benefits and challenges of blockchain adoption in our managerial recommendations.

3. Research Methodology

Our research methodology consists of the following steps: (1) Problem identification and definition (2) Model conceptualization (3) Model Formulation (4) Model Simulation (5)

Sensitivity analysis (6) Model validation. These steps are pictographically described in Figure 2.

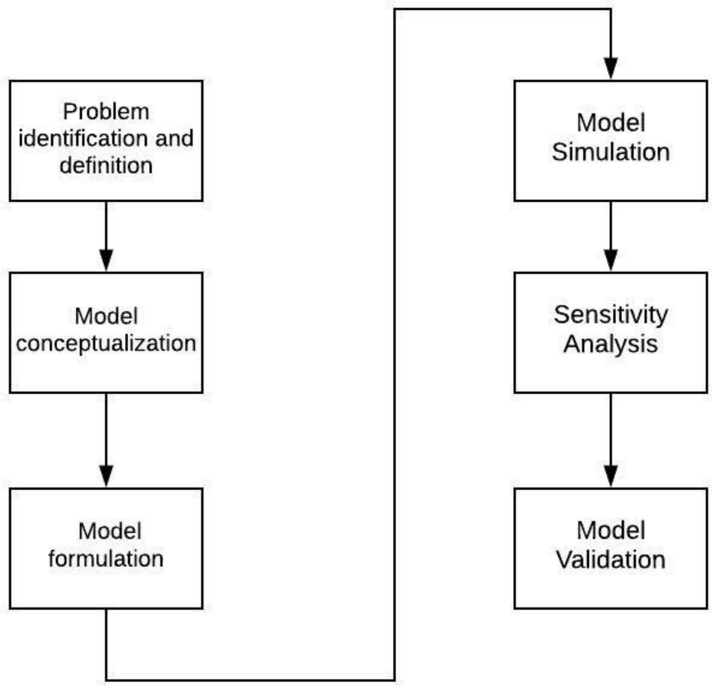

Figure 2 Research Methodology

3.1 Problem Identification and definition

The problem was identified and defined through unstructured in-person stakeholder interviews at Walmart. In un-structured interviews, the interviewer interacts with the interviewee with a set of ideas that he/she wants to explore. The format for this style is like a conversation (Wilson, 2016).

We interviewed with 3 teams at Walmart to map their supply chain for small pack deliveries from supplier to Walmart, understand the problems caused by lack of visibility and, Walmart's current status of blockchain adoption in its supply chain.

The details of the interviews are summarized in Table 1.

Table 1 Overview of interviews at Walmart

Interview Topic	Members	Date and time	Outcome
WM Blockchain Implementation - Food Safety	1. Mrs. Archana Sristy, Sr. Director Blockchain Platform services 2. Anand Banik, Principal Software Engineer, Block Chain Platform services	10/25/2019, 9AM to 10AM	Learned the status of application of blockchain in Food Trust initiative
E-commerce Supply Chain – Small Pack challenges	1. Stephen M, VP Small pack deliveries 2. Raul, Associate Analyst	10/25/2019, 10.30AM to 2PM	Learned about problems faced in small pack deliveries
Data fields discussion for Small Pack Supply chain	1. Kyle Holmes, Solution Architect WM transportation Systems 2. Ranga Onkaram, Principal Technical Architect – Inbound Supply chain	10/25/2019, 2PM to 4PM	Mapped the supply chain of Walmart's small pack delivery network

3.2 Modeling approach

We decided to use modeling as our primary methodology to answer our research question. The primary reason for adopting the modeling methodology was that it helped us study the impact of blockchain on transportations before actual implementation of the technology at Walmart. Furthermore, through modeling we were able to evaluate different what-if scenarios of blockchain adoption my modifying the model parameters and studying the response.

A model is a representation of a real-world situation in a schematic form, often in a simplified form. Modeling is a way of replicating situations that occur in the real world, often in a simplified form, with the intent of observing the impact of a change or intervention on the future (Verbrugge, 2019). It is applied when prototyping or experimenting with the real system is expensive or impossible.

Table 2 compares the different approaches to modeling that are used in the industry on the basis of data requirements, the advantages (pros) of using the methodology and the disadvantages

Table 2 Comparison of various modeling methodologies

Game Theory	In this approach we create a 3-player mathematical game and allocates the benefits between the stakeholders and study the behavior of each of the players	Low	Can model the conflicting interests of organizations	Multiple uncertainties cannot be considered for modeling Assumes that the economic benefits are objectively measurable and transfer-able	(Leng & Parlar, 2008) (Lozano et al., 2013)
System Dynamics	Build systems with current flow and flow after blockchain. Simulate and compare.	Medium	Mimics the flow of real-world objects	Not considering uncertainties	(Zhai, 2004) (Lertpattarapong, 2002)

Name	Description	Data requirement	Advantages	Disadvantages	Reference
Agent Based Modeling	This is a decentralized modeling approach where the modeler defines behavior at individual level between different agents	High	Works in the absence of the knowledge about the global interdependencies	Not useful for modeling passive and indistinguishable objects	(Borshchev et al., 2004)
Spreadsheet simulation	Can be used to develop equations based on current and after blockchain supply chain flows and simulate the outcome	High	Easy to implement	Hard to scale, does not capture all the details of the flow. Requires numerical data for running the model	(Kleijnen, 2005)

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Out of the different methodologies outlined in literature review Table 2, we decided to use system dynamics methodology for studying the relationships between Walmart, its suppliers, and carriers. We selected this methodology for various reasons. The nature of supply chain relationships is dynamic and complex with numerous factors and multiple feedback loops. Also, there is very limited information on the transactions that happen between these entities. Quantitative models such as spreadsheet modeling and analytical methods cannot represent the internal relationships and interactions different parameters that define these relationships between the entities. They will also not be able to represent the impact of factors like supply chain visibility tools on these relationships. A system dynamics model can depict these time-varying relationships along with the interactions between the variables. This is the reason for deciding to use a system-dynamics based model is used to simulate the flow of the goods in the supply chain, inefficiencies in the supply chain, key performance indictors and the impact of visibility on the network.

In this research, we applied system dynamics to model the behaviors of the three main stakeholders in Walmart's supply chain: Walmart, supplier, and carrier. For simplicity purpose, we are modeling one supplier, one carrier, and one product.

3.2.1 System dynamics Modelling

System dynamics (SD) is a modeling methodology that is used to represent the complex relationships found across many areas of business. Using system dynamics, the effect of such relationships can be understood, and possibilities quantitatively tested and analyzed. In business, most of the KPI are dependent on other independent factors. These dependencies, that can also be captured as in cause and effect diagram, often have a time delay between the cause and the effect. System dynamics aims at investigating the structure of such cause and effect connections and how they evolve over time (Sterman, 2000).

In system dynamics, dependencies, such as technology adoption and network effects, are often represented as loops called feedback loops. An SD model is represented using 4 elements- stocks, flows, variables (parameters) and links (arrows) (Sterman, 2000). The stocks are connected to each other through flows. The flows are influenced by variables/ parameters that can be tweaked by the user of the model to study the behavior of the model. The positive or negative polarity of the arrows represent whether the variables have a proportionate impact or an inverse impact on each other (Sterman, 2000).

3.3 Model Conceptualization

The purpose of our model is to study how OTIF, disputes between Walmart, supplier and carriers, and corresponding dispute management costs change with the implementation of Blockchain. The boundary for this model is limited to include the flow of goods and information of one product among one supplier, one carrier and Walmart.

For the purpose of modeling, we simplified Figure 1 to a form with only the basic mechanisms defined as follows:

Step 1: Walmart sends PO to supplier.

Step 2: Supplier responds by sending material to Walmart through a carrier.

Step 3: Supplier communicates with carrier to schedule pickups

Step 4: Carrier communicates with Walmart to schedule delivery of the goods at Walmart's Warehouse.

These steps are shown in Figure 3. This flow of goods and information from supplier to Walmart through carrier interrupted at various stages because of inefficiencies in the supply chain processes that exist among these three entities.

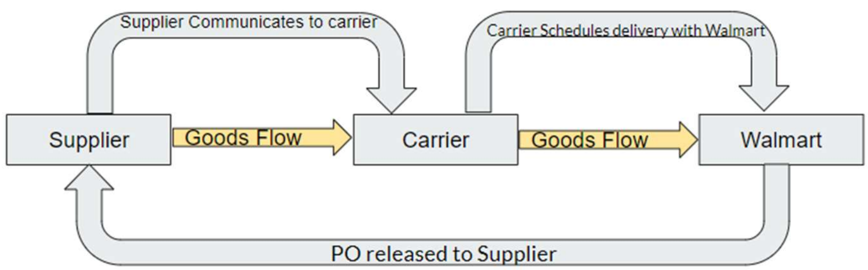

Figure 3 Simplified flow of goods/ information between Walmart, supplier and, carrier

3.4 Model formulation

Model formulation is the process where the modeler assembles the elements and relationships that comprise the model on the basis the problem that has been identified (Willemain, 1995).

The elements used in the model consists of the stocks and flows that represent the goods and information transfer between supplier, carrier and Walmart. The flows can be categorized into 5 sections (1) Main flow of goods (2) Walmart focused flows (3) Carrier focused flows (4) Supplier focused flows (5) Disputes focused flows. The formulas for these flows between the stock variables were determined on the basis of feedback provided by Walmart.

In our study, formulations and relationships used in our model were based on information provided by Walmart combined with industry data we found through literatures. We first initiate the formulas using the data points provided by Walmart. Then for the variables that need more data to complete formulation, we looked for relevant data from literatures and adapt to Walmart's supply chain.

3.5 Model simulation

Simulation is the process of model "execution" that takes the model through (discrete or continuous) state changes over time. In general, for complex problems where time dynamics is important, simulation modeling is a better answer (Borshchev & Filippov, 2004).

We did our simulation of Walmart's supply chain with one supplier, one carrier, and one product, assuming that the number of cases in Walmart's daily PO to supplier follows a normal distribution with mean 10,000 cases and standard deviation of 2,000 cases. We chose a normal distribution because we are not considering factors like seasonality or trend in demand, so normal distribution is good at modeling a fair amount of randomness. We simulated the model for a time period of 30 days, to study the OTIF, disputes, and corresponding costs over one month.

We simulated two scenarios. The first scenario is when there is no blockchain adoption. In this scenario, there is no data shared on blockchain. The second scenario is when supplier, carrier, and Walmart all adopt blockchain and are sharing 100% of their data on blockchain.

3.6 Sensitivity Analysis

Sensitivity analysis is the process of capturing the changes of the conclusions from a model with changes in input parameters and assumptions. There are two major types of sensitivity analysis: (1) numerical (2) behavioral. The numerical sensitivity analysis happens when the change in the assumptions impact the numerical value of the results. A behavioral sensitivity happens when a change in the assumption changes the behavior or output of the model. For example, this happens when, by removing the assumption of a re-enforcing feedback loop the modeler tries to measure the change in system behavior.

We performed two types of numerical sensitivity analysis, one was on change in blockchain adoption rate, the other was on change in supplier/ carrier capacity. We also made one behavioral sensitivity analysis, assuming that either supplier or carrier is not taking the benefit of blockchain, and compared the key variables before and after blockchain implementation.

The reason we conducted the above three sensitivity analysis was because those are common situations that happen in supply chain. Due to reasons like privacy or company policy, supply chain stakeholders often resist to put all their data on blockchain. Also, as the e-commerce market is growing rapidly, suppliers and carriers' performance can be restricted by their capacity to fulfill orders. It is also possible that either supplier or carrier does not join supply chain, but the other stakeholder does. We want to see how the model result variates in those situations.

3.7 Validation of model

Validation of a model is the process of establishing confidence in the outcome and usefulness of the model. It is also defined as the process of determining the closeness of the model to representing real life scenarios (Giannasi et al., 2001).

In our approach to model validation we tested the suitability and consistency of the system dynamics model, using the methods in ‘Validation of Simulation Based Models: A Theoretical Outlook’ (Martis, 2006). Specifically, we checked whether the behaviors of key variables fit real world scenarios, tested with some extreme situations, comparing results with industry data and results of other researches. Through these model validations, we ensured that the model can reasonably simulate the real world system at Walmart.

4. Results

The results of the research include four parts. The first part is system dynamics model built upon Walmart’s supply chain process mapping. The second part is the simulation results generated by the system dynamics model. The third part is sensitivity analysis to study how the impact of blockchain varies in different scenarios. The last part is the validation of the model.

4.1 Developing the System Dynamics Model

In this section, we will discuss how we build the system dynamics model with five steps. In the first step, we start from developing the main flow based on Walmart's supply chain mapping. In our second step, we add OTIF to the main flow. Our third step adds dispute and dispute management cost to the model. In the fourth step, we incorporate the feedback loops in Walmart's supply chain to our model. And our last step models the impact of blockchain on the existing model.

4.1.1 Developing the Main flow

The stock and flow variables of the base model follow the logical flow of goods in the system as shown in Figure 4.

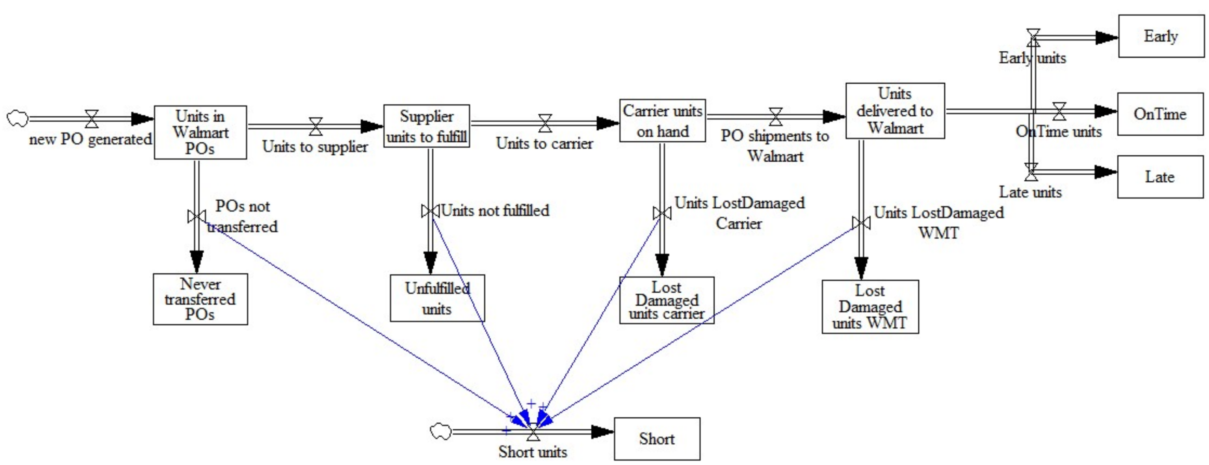

Figure 4 Flow of goods in Walmart supply chain

It starts with New_PO_Generated, that represents the new purchase orders that are released to a supplier by Walmart. The New_PO_Generated flow is the input to

Units_in_Walmart_POs. This represents the total POs that are in the Walmart system at an instance of time.

Some of these PO's never reach the supplier due to data communication errors between the IT systems of Walmart and the supplier. The POs that never reach the supplier are stored in the stock variable Never_Transferred_POs

The POs that reach the supplier feed into the Supplier_Units_to_fulfill. This is the total number of units that the supplier has to dispatch to Walmart to fulfill the PO. Due to various reasons, like stockout problem, quality issues etc., some of these open POs never get fulfilled by the supplier and are represented by the flow Units_not_Fullfilled. The cumulative number of unfulfilled POs are stored in the stock variable Unfulfilled_Units.

Once production is completed, the supplier requests the carrier to pick up the POs and deliver them to Walmart. The flow of POs that get transferred to the carrier with a request to ship are called POs_to_carrier. This feeds to the stock of the total number of POs that needs to be shipped by the carrier, Carrier_Units_to_ship. This flows out as Shipments_to_Walmart. Finally, when these shipments get delivered to Walmart, they feed into the stock Units_delivered_to_Walmart. The units delivered to Walmart can be segmented into three flows (1) Early deliveries (2) Ontime deliveries (3) Late deliveries.

4.1.2 Modeling OTIF

In Walmart's supply chain, the OTIF is calculated as the total number of units that are delivered Ontime divided by the number of units in Walmart's POs. Figure 5 shows what it looks like when we combine the main flow and OTIF calculation.

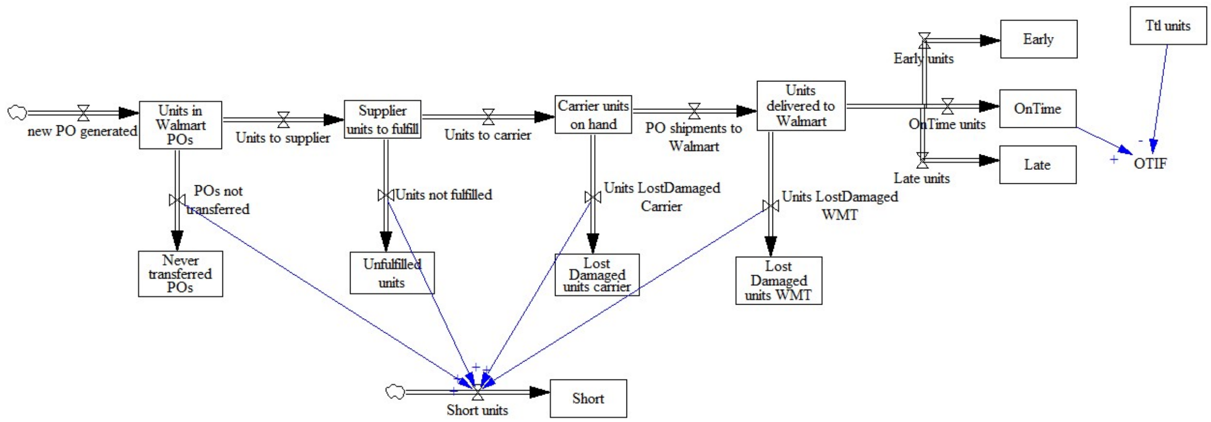

Figure 5 Main flow with OTIF

4.1.3 Modeling disputes and dispute management costs

As shown in Figure 6 below, disputes can happen when supplier is not fulfilling all units, carrier loses or damages goods, Walmart loses or damages goods, and when goods are not shipped on time. Those cases can lead to a penalty to supplier. And when supplier disagrees with Walmart's penalty, a dispute can happen. And some of those disputes can be extended to carrier if supplier thinks it is the carrier's fault.

The dispute management cost of each stakeholder can be different due to different dispute resolution methods within company. So, we are calculating them separately here. Specifically, disputes between Walmart and supplier will add to the cost to manage the disputes to both Walmart and supplier. Likewise, disputes between supplier and carrier will contribute to supplier and carrier’s dispute management cost. We also introduced a variable ‘Effort_to_resolve_per_dispute’ between 0 and 1 that indicates the time and effort it takes to resolve a dispute. Without blockchain, we assume the effort is 1, and 0 means disputes will be resolved automatically.

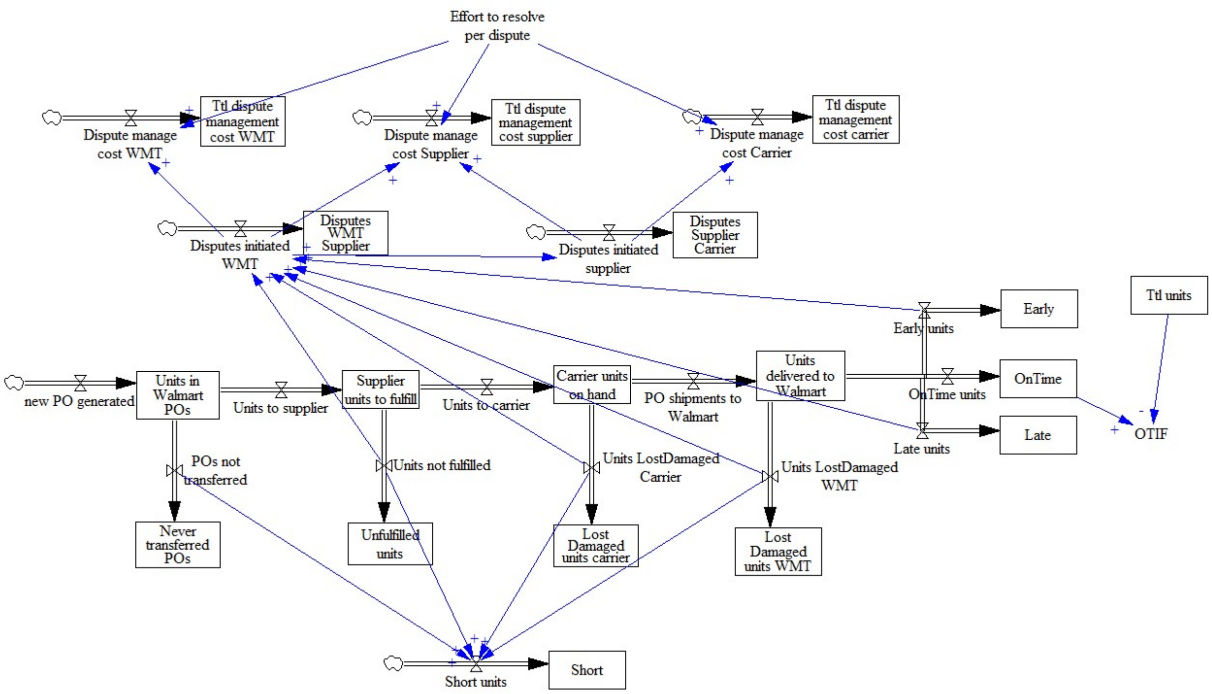

Figure 6 Flow of disputes and dispute management cost

4.1.4 Feedback loops that affect the model output

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In system dynamics, dependencies, such as technology adoption, are often represented as loops called feedback loops. There are 2 basic feedback loops that are modeled using SD, one is the reinforcing feedback loop and the other is the balancing feedback loop. A reinforcing loop feeds on itself and causes the system to grow by itself. Typically, a reinforcing loop is stronger at the start of the cycle and allows the system to grow exponentially. A balancing loop provides a check to the reinforcing loop by feeding negatively on itself. This leads to saturation of the stocks in the long term. (Stempel, 2016)

To analyze how the key factors impact on OTIF and disputes in Walmart's supply chain, we introduce ten feedback loops that depict the relationships of the factors in our model. Based on the main stakeholders involved in each feedback loop, we have three supplier focused feedback loops, four carrier focused feedback loops, and three Walmart focused feedback loops.

There are 2 basic feedback loops that are modeled using SD, one is the reinforcing feedback loop and the other is the balancing feedback loop. A reinforcing loop feeds on itself and causes the system to grow by itself. Typically, a reinforcing loop is stronger at the start of the cycle and allows the system to grow exponentially. A balancing loop provides a check to the reinforcing loop by feeding negatively on itself. This leads to saturation of the stocks in the long term. (Stempel, 2016)

4.1.4.1 Supplier focused feedback loops

Below are three supplier focused feedback loops that represent the feedback relationships brought by supplier's technology investment, dispute management cost, and late shipments and schedules.

Technology investment loop – Reinforcing loop

We learned from Walmart that OTIF is one of the main factors that Walmart use to evaluate suppliers. As the OTIF for the supplier increases, the share of orders that get allocated to supplier increases. Meanwhile, higher OTIF reduces the supplier's penalty. This increases the revenue of the supplier. As the revenue and subsequently the profits increase, the propensity to invest in more visibility enhancing technologies increase, because supply chain visibility has been demonstrated to present a return on investment (Saqib et al., 2019). Also, three-fourths of shippers and third party logistics said they plan to invest in supply chain visibility within the next two years (Infosys et al., 2019). Once companies are equipped with visibility enhancing technologies, they can share not just basic data points such as tracking information of packages, but also other data points such as POS data, SKU data or planning data with their extended supply chains. This leads to better forecast visibility and hence the supplier can plan his production and shipping sequences better (by advanced inventory buildup in case there is a capacity limitation) (Stackpole, 2020). Stockout units will decrease and in turn results in OTIF increase for the supplier. This is shown in Figure 7. Supply chain visibility means the percentage of units that the supplier has visibility. Stockouts indicates the number of units short of supplier to fulfill the POs from Walmart.

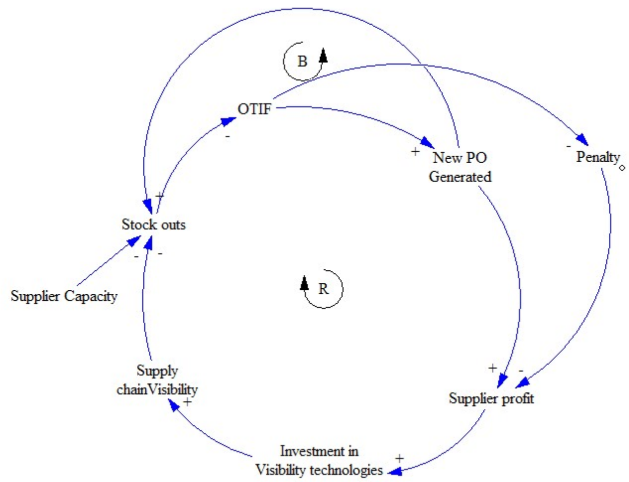

Figure 7 Technology investment loop

Dispute management cost loop – Reinforcing loop

As supply chain visibility increases, it becomes easier for stakeholders to use data to agree on why a shipment is not on-time in full. Thus, the number of disputes in the supply chain decreases. This results in lower dispute management costs for the supplier. The disputes management costs include man-power costs as well as costs of other resources for dispute resolution. Dispute management costs directly impact the profits of a company. Lower dispute management costs thus increase the net profit for the company. With increased profit, the supplier has more capital to invest in visibility enhancing technologies. Number of disputes will be reduced once there is better supply chain visibility.(Agarwal, 2018) This has a reinforcing impact on the supply chain visibility of the network. This loop is shown in Figure 8.

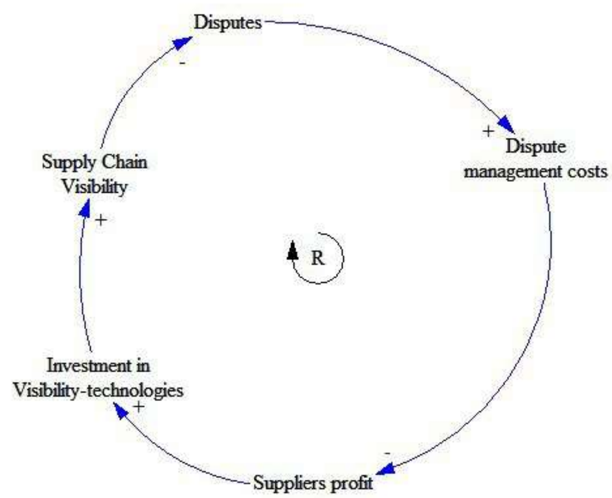

Figure 8 Dispute resolution cost loop

Late shipment and schedules loop – Balancing loop

When supplier ships greater number of orders, it is more likely that they will ship or schedule late. They can cause more units delivered late at Walmart's dock, and hurts the OTIF. We learned from Walmart that OTIF is one of the factors that determines their partnership with supplier. As a result, Walmart will do less business with this supplier because of this lower OTIF. This loop is shown in **Error! Reference source not found.** 9. Supplier shipped late is the number of units the supplier shipped late. Supplier scheduled late is the number of units that supplier scheduled late with Walmart for delivery.

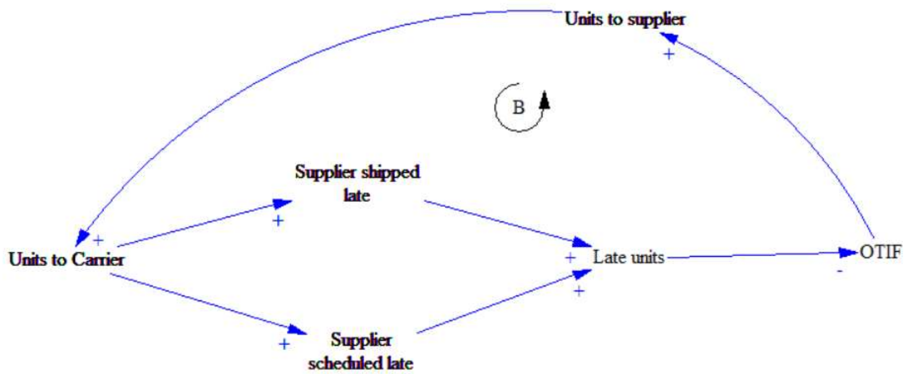

Figure 9 Late shipment and schedules loop

Error! Reference source not found.10 puts the supplier's root causes and feedback loops together with the main flows

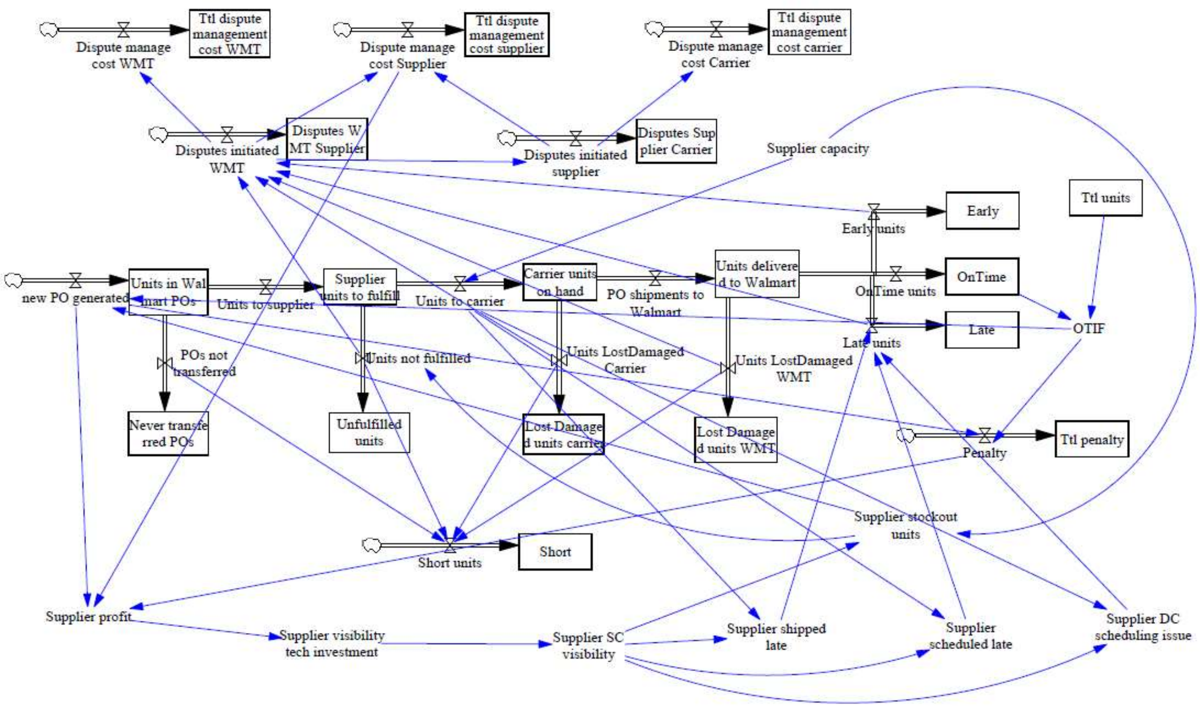

Figure 10 Supplier feedback loops

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The three supplier focused feedback loops include the changes in supply chain visibility with respect to penalty and dispute management cost. The loops also incorporate the effect that supplier may delay in shipping and scheduling when having too many orders to fulfill.

4.1.4.2 Carrier focused feedback Loops

Below there are four carrier focused feedback loops that represent the feedback relationships brought by relationship between carrier and supplier, DC scheduling, avoiding units short, and carrier delay.

Relationship loop – Balancing

When carrier have more orders to fulfill, it is more likely to encounter capacity issues. As the result, it may reject some loads from the supplier. Based on discussion with Walmart, Walmart's suppliers use carrier sequential tendering, which means the supplier will go to the next carrier on its partner list if the carrier rejects the load, supplier will have to pay higher transportation fee. If supplier continues to pay higher fee for those rejections, the relationship between the supplier and this carrier will get worse, and thus the supplier will use this carrier less frequently. This is shown in Figure 11. Carrier capacity issue means the number of units short in carrier's capacity. It positively impacts Supplier additional shipment cost, which means the supplier's additional cost when carrier rejects the shipment request. Carrier supplier relationship is a scale between 0 and 1 that measure the relationship between supplier and carrier: the higher the value, the better the relationship.

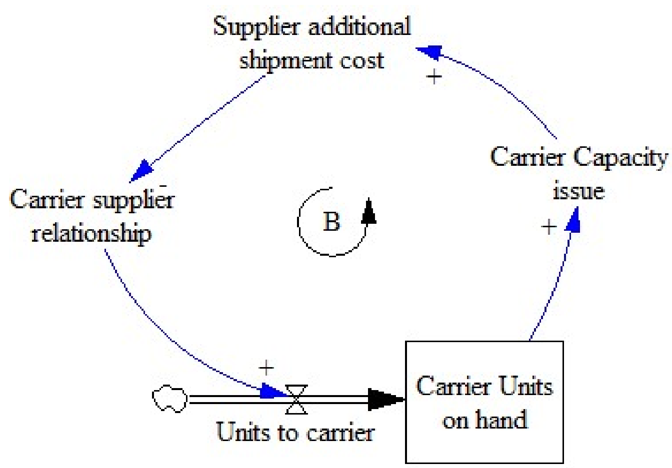

Figure 11 Relationship loop

DC scheduling loop – Balancing

When supplier has more items to ship, there will be more pickup scheduling. So, there will potentially be more DC scheduling issues. As good DC scheduling is important to facilitate the ability for carriers to plan load/unload, those issues can largely affect carrier's efficiency and therefore affect their capacity.(Shearon, 2018) Then, same as the relationship loop, the lower capacity will eventually cause fewer units given to this carrier. This loop is shown in Figure 12. Supplier DC scheduling issue indicates the number of units having issues with appointments with supplier DC.

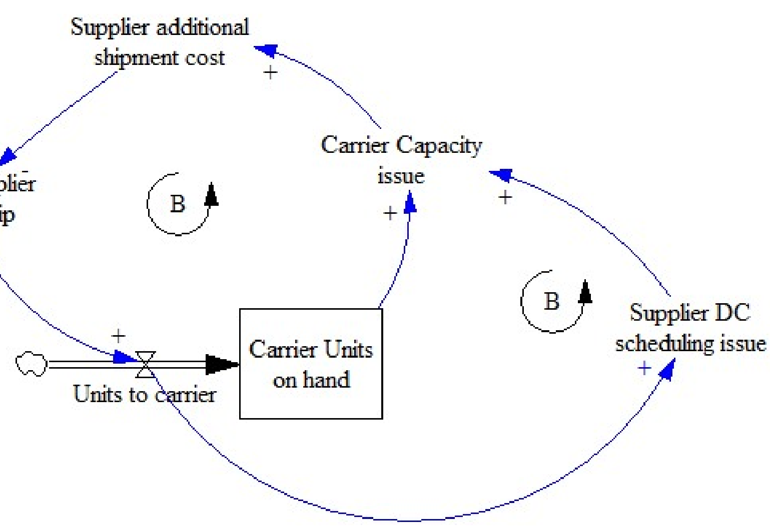

Figure 12 DC scheduling loop

Avoid short units loop – balancing

When there is no package level visibility, it can cause packages not well labeled or not loaded properly. This may increases the chance of the carrier's employee misconduct, and therefore increases the packages lost or damaged by carrier.(Redwood, 2017) As a result, the total number of units short will increase. Consequently, the supplier will do better package labeling to avoid this issue, and carrier will pay more attention to avoid disputes from supplier for damaged packages. This is shown in Figure 13. Package level visibility means the percentage of packages that have visibility. It impacts Carrier employee mistake, which represents carrier employee’s mistakes in loading or transporting goods.

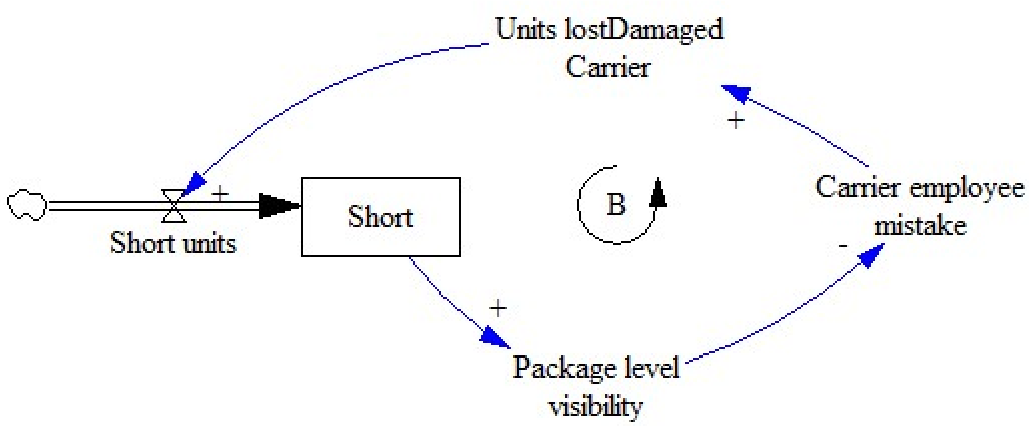

Figure 13 Avoid short-units loop

Carrier delay loop – balancing

Carrier delays hurt OTIF, and therefore Walmart will have less business with the supplier who uses this carrier. Carrier delays can be caused by shipment exceptions including weather delay, wrong address, no recipient, etc.(Buzoianu, 2020) Besides shipment exceptions, carrier’s ability to handle those exceptions also determines the number of delays. Shipment information communication and real time visibility can generate exception alerts, enable enhanced analytics, and planning function, avoiding and handling shipment exceptions.(Stanchik, 2016) This loop is shown in Figure 14. Ship info communication represents the percentage of shipment information being communicated between stakeholders. It negatively affects carrier shipment exceptions, which means the number of units impacted by shipment exceptions like weather delay, address correction, etc. Realtime shipment visibility indicates the percentage of shipments with real time visibility. It has a positive impact on carrier's ability to handle exceptions. Both Carrier's ability to handle exceptions and Carrier shipment exceptions can affect carrier delay, which means the number of units delayed due to carrier's liability.

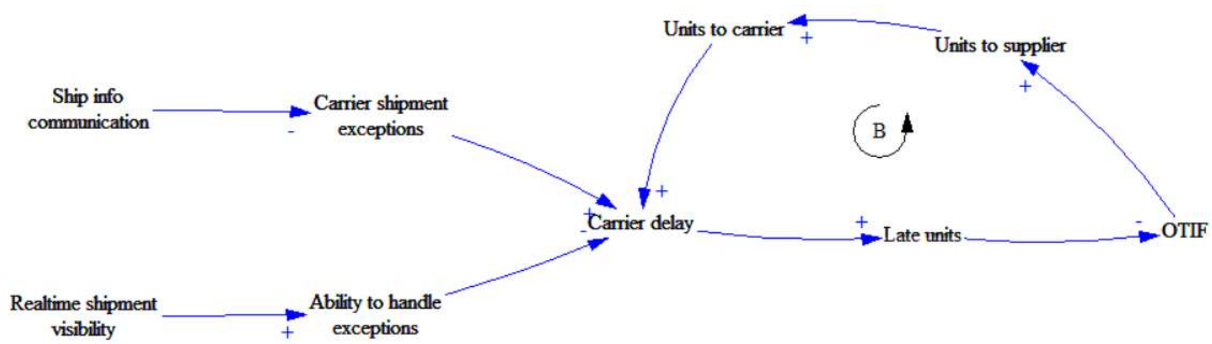

Figure 1414 Carrier delay loop

Figure 15 represents the state of the model after putting the carrier's root causes and feedback loops together with the main flows.

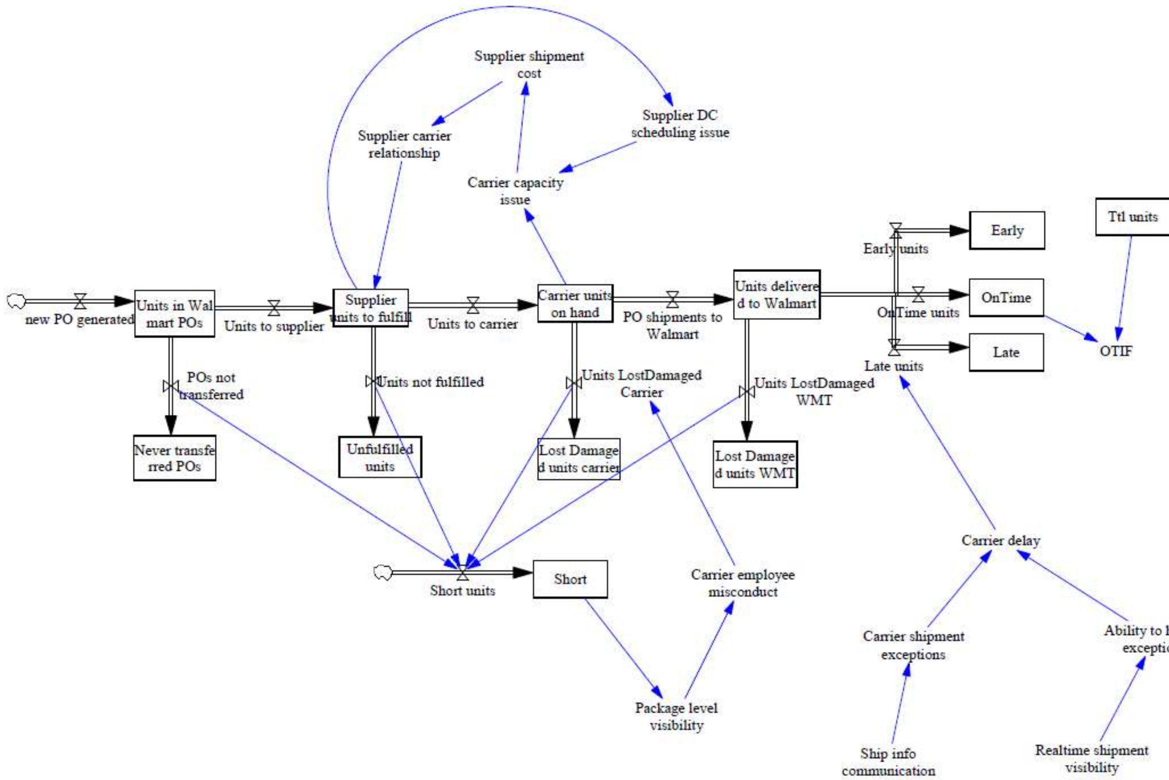

Figure 15 Carrier feedback loops

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The four carrier focused feedback loops demonstrate the balancing effect when carrier have more orders to ship. If the carrier does not have enough capacity, the carrier-supplier relationship and DC scheduling at supplier's DC will slow down the increase in the number of orders to ship. Carrier's OTIF would impact the behaviors of supplier and Walmart, and therefore balancing the number of units short and delayed.

4.1.4.3 Walmart focused feedback Loops

Below are three Walmart focused feedback loops that represent the feedback relationships brought by Walmart's manual POs, handling unexpected deliveries, and stockout effects.

Manual PO loop – reinforcing

If the market demand goes up, Walmart needs to generate more POs including more manual PO. This increases the chance of PO not getting transferred due to human errors.(Rongala et al., 2015) Therefore, OTIF will be negatively impacted, and hurts the supplier's business with Walmart. The loop is shown in Figure 16. Market demand is the consumer's demand of the certain product from Walmart. Manual POs represents the number of manually created purchase orders.

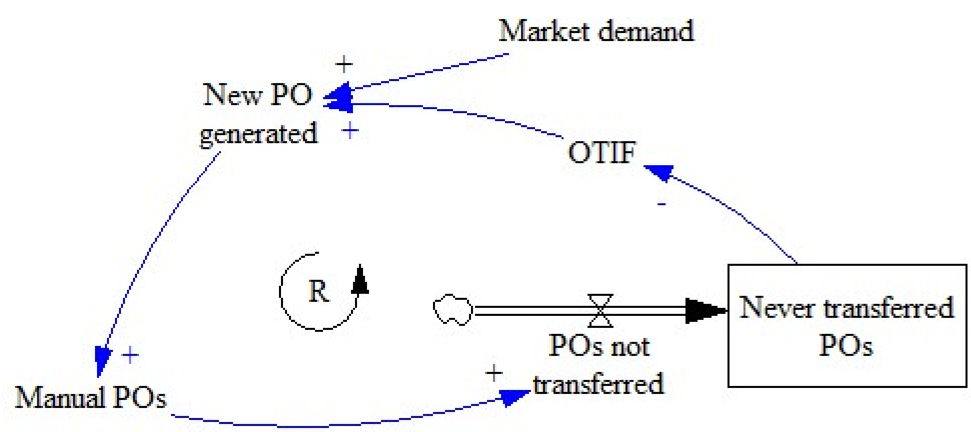

Figure 166 Manual PO loop

Unexpected delivery loop – balancing

Based on discussion with Walmart, early and late deliveries can cause multiple issues at Walmart's dock. One issue is the lack of capacity at the dock because Walmart did not expect the load to arrive. Another issue is that Walmart rejects the load due to company policy. E.g. perishable products cannot come early. One more issue is that because the load is not in the list of the loads to be received on that day, Walmart employee at the dock may forget to scan the items or put in the system. All these issues can increase Walmart's difficulty of receiving goods, and lead to more lost or damaged goods under Walmart's liability. The more units lost or damaged, the fewer units arrive in good condition at Walmart's dock. This loop is shown in Figure 177. Walmart difficulty of receiving means the number of units that Walmart has difficulty to receive.

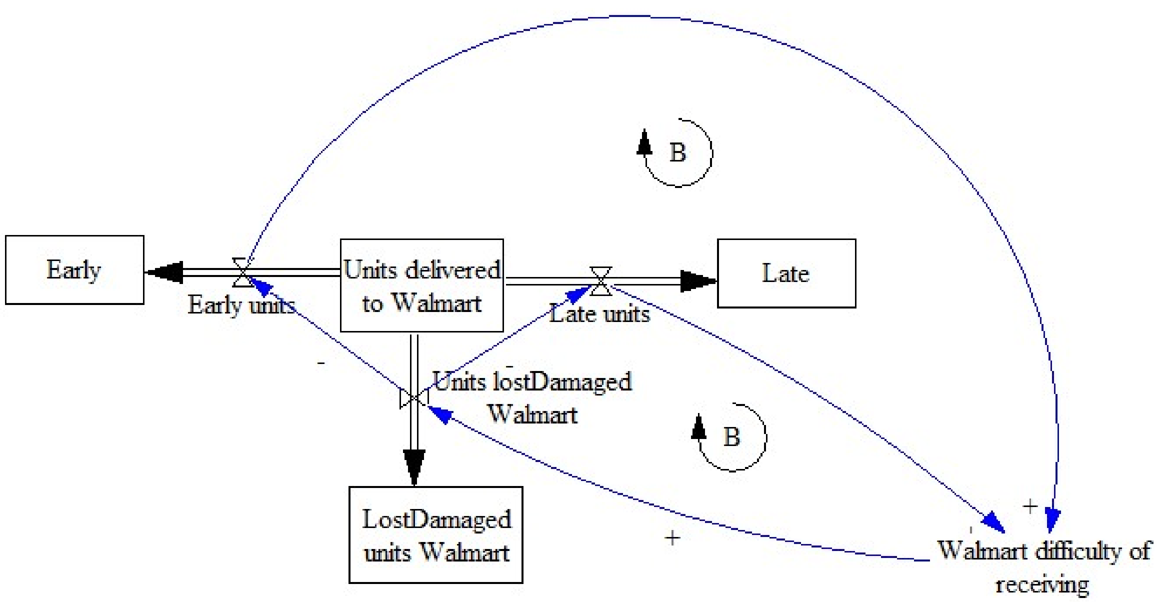

Figure 177 Unexpected delivery loop

Stockout effect loop – balancing

When late deliveries happen, Walmart can be under the risk of stockout. If that happens, consumers may decrease they Walmart loyalty and switch to competitors (Vessella, 2020). As a result, market demand will drop. The number of units in Walmart's supply chain will drop, including the units delivered late. This loop is shown in Figure 188. Walmart stockout indicates the number of stockouts of the product.

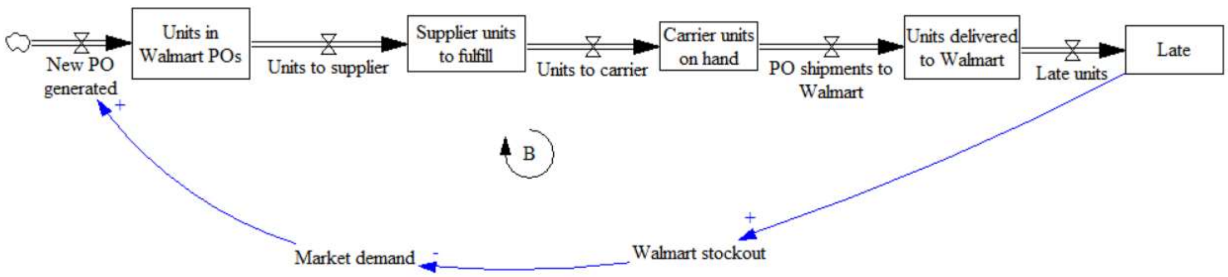

Figure 188 Stockout effect loop

Figure 19 represents what the loop looks like after putting the Walmart's root causes and feedback loops together with the main flows.

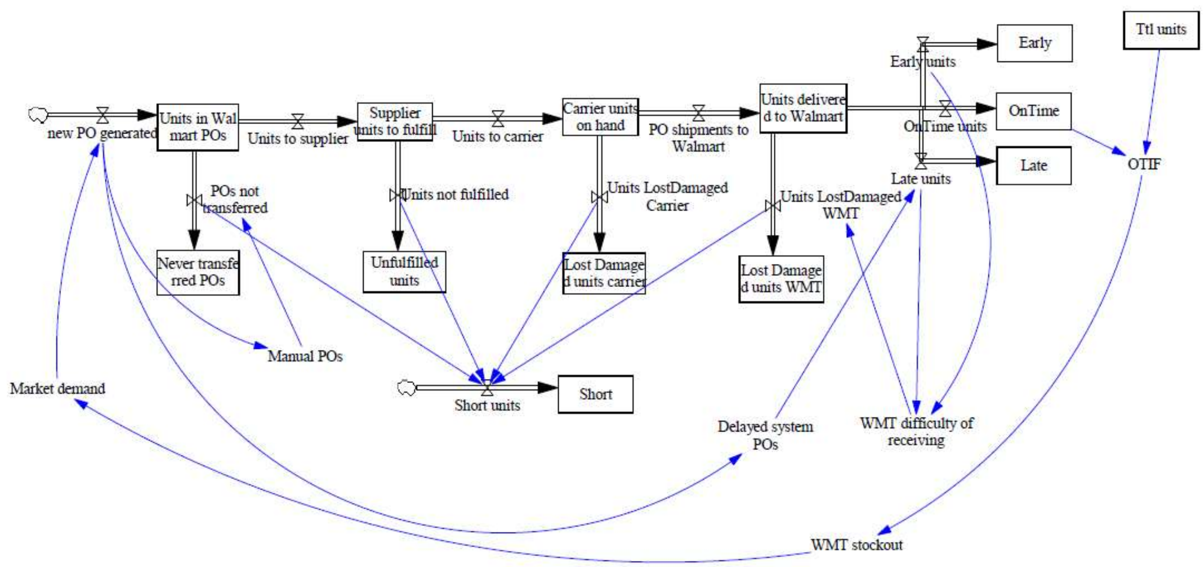

Figure 199 Walmart feedback loops

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The three Walmart focused feedback loops demonstrate the balancing effect when the number of new POs generated get large. Manual POs, and stockouts will happen more often as more units need to be fulfilled. The unexpected deliveries from carrier will increase Walmart's difficulty to receive, and therefore cause more lost or damaged units.

4.1.5 Modeling impact of blockchain

After incorporating all the feedback loops to the model, we can compare the KPIs before and after blockchain. As blockchain provides a single source of truth for all stakeholders, multiple variables will be impacted because of the increased visibility and immutability as follows:

(1) Supplier SC visibility - Supplier now have better visibility over Walmart's supply chain
(2) Walmart difficulty of receiving - BC monitor Walmart's dock and employees to make sure they behave properly
(3) Walmart delayed system POs - BC ensures suppliers can see POs immediately
(4) Shipment info communication - BC becomes a reliable source for info communication
(5) Realtime shipment visibility - BC can provide real time visibility of shipments. So, carrier can use proactive alerts to respond ahead. BC's single source of truth makes sure there is no data error
(6) Package level visibility - BC can enable shippers to put in package level visibility that can be accessed by carrier. So, the packages will be handled better in transportation
(7) Effort to resolve per dispute – BC's immutability ensures the validity of the data stored in blockchain. It becomes easier to solve disputes because people can easily identify who are responsible for shipments that were lost or not on time.

We introduce a variable called Blockchain data sharing level that represents the percentage of data shared on blockchain by stakeholders. Different data sharing level will affect the above variables in different level.

4.1.6 The complete model

After building the main flow, modeling OTIF and disputes, incorporating all the feedback loops, and modeling the impact of blockchain, we combine all these results together to build the final complete model. This model can be found in Appendix I.

To start the simulation, we created formulas to model the feedback relations between variables. We first create formulas using the information provided by Walmart. For example, as descrived in Section 1.3, OTIF score is calculated as

$$OTIF\ score\ =\ cases\ received\ in\ window\ /\ total\ cases\ ordered$$

This was formulated in our model as

$$\mathrm{OTIF}\ =\ \mathrm{OnTime}\ /\ \mathrm{Ttl\_units}$$

where *Ttl_units* is total number of cases ordered in Walmart’s POs.

For formulas that require additional information, the variable values are initiated based on literature review and industry data. For example, market demand is formulated as

$$\mathrm{Market\_demand}\ =\ \max(\mathrm{normal}(2{,}10) * (1 - \min(\mathrm{WMT\_stockout}, 5) * 0.2), 0)$$

where *WMT_stockout* means the number of stockouts happens in Walmart. We created this formula based on a literature indicating that every stockout event increases 20% chance that customer will either not purchase this product or switch to another retailer (Bowman, 2016). Similarly, the other variables in our model was initiated based on the information provided by Walmart, literature review, and industry data. All the formulas we used in our model can be found in Appendix I.

4.2 Model simulation

Based on the model developed in 4.2, we simulate the model in two scenarios. The first scenario is when there is no blockchain adoption, which is the current scenario. The second scenario is with blockchain adoption and stakeholders sharing 100% data on blockchain. With 100% data sharing, we are trying to model a scenario where all the data in the ERP systems in each of the supply chain partners are fed into the blockchain network. This scenario simulates an end-to-end synchronized supply chain with full visibility of transactional information throughout the chain. We model for a time period of 30 days to study the OTIF, disputes, and corresponding costs over one month. The results of the simulation are described in Table 3. The formulas we used for simulation can be found in Appendix.

Table 3 Simulation results of KPIs before and after blockchain adoption

Scenario	Before Blockchain	After Blockchain - 100% data sharing

OTIF	0.664	0.922
Disputes_WMT_ Supplier(unit)	40.682	13.04
Disputes_Supplier_Carrier (unit)	20.341	0
Ttl_dispute_mngt_cost_ Supplier (1000 USD)	38.017	1.095
Ttl_dispute_mngt_cost_ Carrier (1000 USD)	3.844	0
Ttl_dispute_mngt_cost_ WMT (1000 USD)	51.259	1.643

4.3 Sensitivity analysis

In this section, we conduct two sets of sensitivity analysis to study how blockchain's impact varies with different level of data shared on blockchain, or with different stakeholders adopting the blockchain.

In the first set, we look at the impact on the KPIs with different data sharing level on blockchain. The data sharing level correlates with the percentage of data that stakeholders are feeding into the blockchain network. Besides 100% data sharing, we also simulate the model to see the impact of 33% and 67% data sharing on OTIF, disputes and dispute management costs. In case of 33% data sharing, we are trying to access a scenario where only the minimum needed data fields, such as PO number, are fed into the network. In the second subset, with 67% data sharing, we are modeling a scenario where the partners feed information that are directly related to solving their existing pain points. For instance, a carrier sharing live location information about the goods is an example of this scenario.

In the second set, we look at the impact on the network when Walmart and only one of the supply chain partners adopt the blockchain with 100% data shared. In the first subset, we model a scenario where only Walmart and carrier adopt the blockchain with 100% data sharing. In the second subset, we model a scenario where only Walmart and supplier adopt the blockchain with 100% data sharing.

The overall results of the simulations that examine the KPIs with different percentage of blockchain data adoptions, and when only one stakeholder besides Walmart is utilizing the blockchain's benefits is shown in Table 4.

Table 4 Sensitivity analysis of impact of blockchain adoption on KPIs in different scenarios

Scenario	OTIF	Disputes_WMT_Supplier (unit)	Disputes_Supplier_Carrier (unit)	Ttl_dispute_mngt_cost_Supplier (1000 USD)	Ttl_dispute_mngt_cost_Carrier (1000 USD)	Ttl_dispute_mngt_cost_WMT (1000 USD)
Before Blockchain	0.664	40.682	20.341	38.017	3.844	51.259
After Blockchain – 33% data sharing	0.726	36.32	18.16	22.153	1.712	30.662
After Blockchain –	0.824	26.483	13.241	7.644	0.303	11.012

67% data sharing						
After Blockchain – 100% data sharing	0.922	13.04	0	1.095	0	1.643
AfterBC_WMTSupplierOnly	0.783	31.044	0	2.608	0	3.912
AfterBC_WMTCarrierOnly	0.802	29.015	14.497	2.742	0.304	3.656

4.3.1 Simulation with different blockchain data sharing levels

4.3.1.1 Changes in number of units delivered

To see how the model reacts to the percentage of data shared through blockchain, we ran the simulation with blockchain adoption rate of 0%, 33%, 67%, and 100%. The results of the simulation are shown in Figure 20.

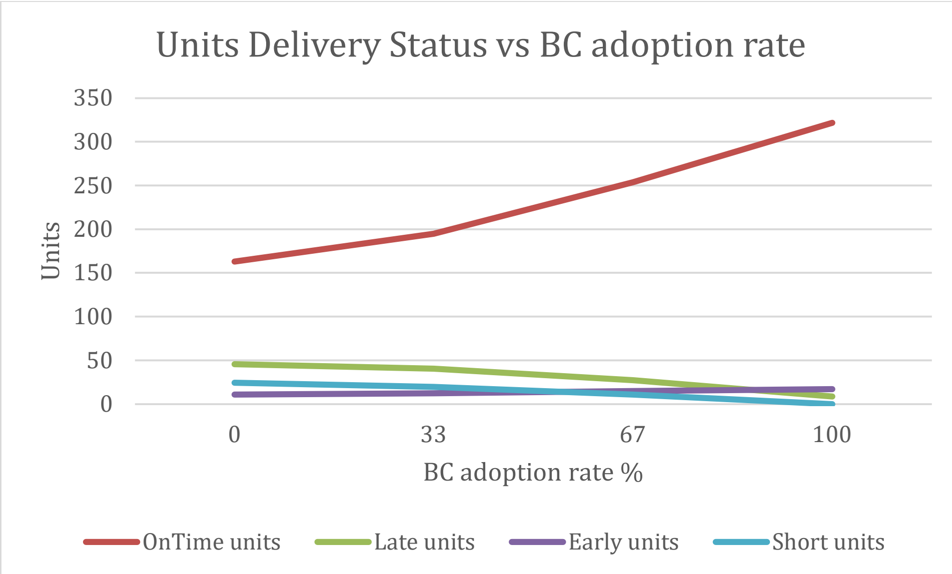


Figure 20 Change in Units delivered with respect to blockchain adoption

We observed that with higher BC adoption, on-time units become significantly higher, and late and short units are reduced. The on-time cases received by Walmart doubles with the help of blockchain. One counter-intuitive observation is that early units increased when BC adoption increased.

4.3.1.2 Changes in OTIF

We observe that OTIF converges from day 1 and stabilizes at around day 7. The baseline OTIF with no blockchain adoption is around 0.66, and it increases with more blockchain adoption. When blockchain adoption rate reaches 100%, OTIF is around 92%. The results of the simulation are shown Figure 21.

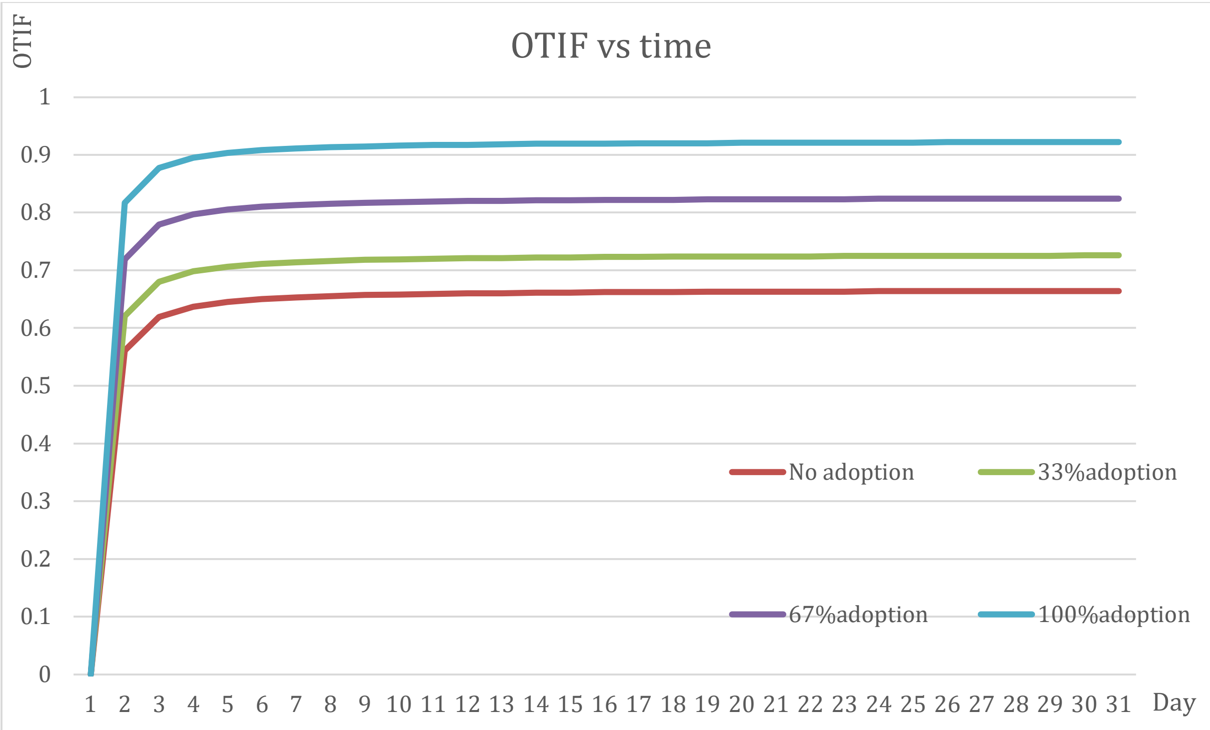


Figure 21 Change in OTIF with time for different blockchain adoption scenarios

4.3.1.3 Changes in penalty

Total penalty dramatically decreases when Blockchain adoption reaches 33%. After that, higher blockchain adoption does not contribute much to reduce penalty. The simulation results are shown in Figure 22.

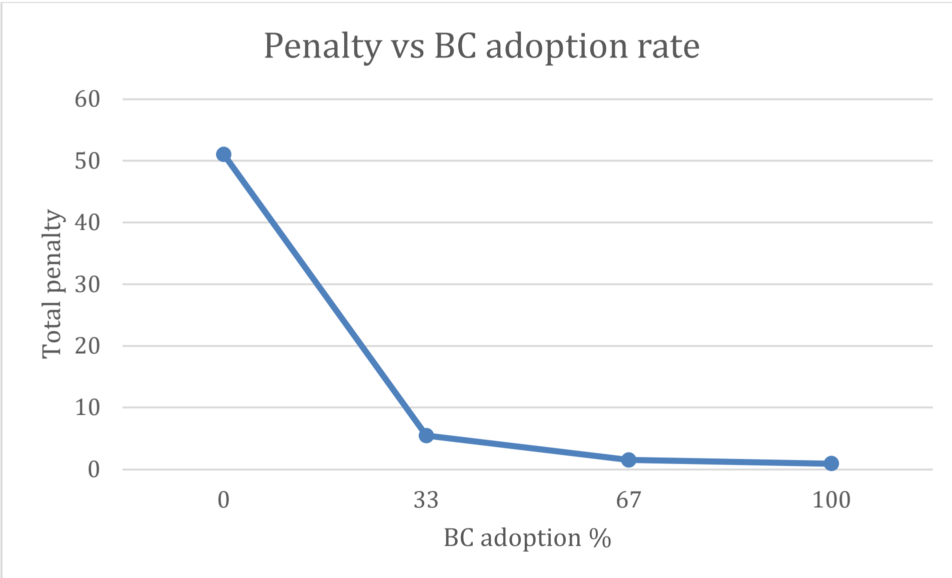


Figure 22 Change in penalty with respect to blockchain adoption

4.3.1.4 Changes in dispute management cost

Walmart benefits the most from blockchain adoption in terms of reducing dispute management cost. And the reduction in dispute management cost slows down after 67% of blockchain adoption. The simulation results are shown in Figure 23.

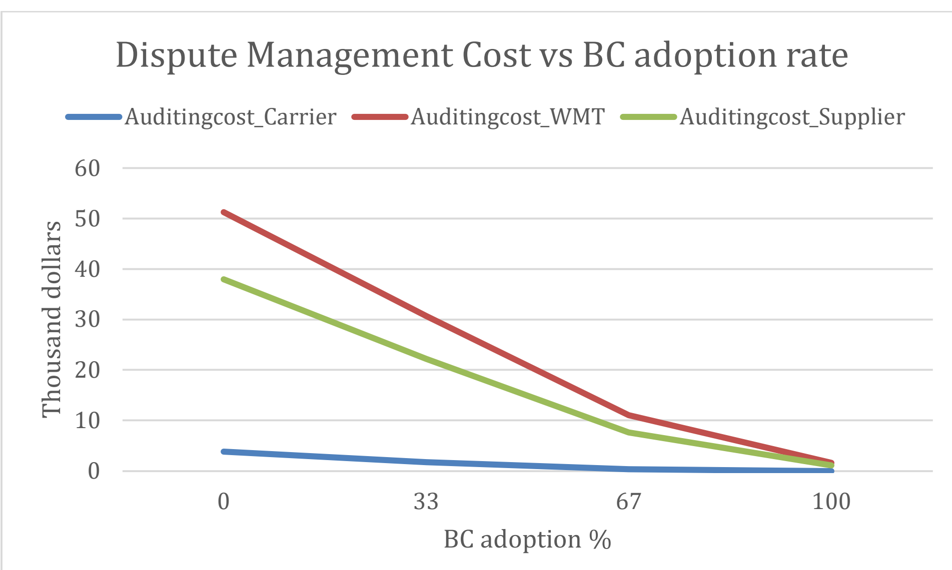


Figure 23 Change in dispute management costs with respect to blockchain adoption

4.3.2 Simulation when one stakeholder not using blockchain

In real world scenario, it is likely that not all stakeholders want to join blockchain. Here we simulated 2 more situations when supplier or carrier is not on blockchain, while the other two stakeholders are sharing 100% data on blockchain. And we compare the OTIF with the result that all three stakeholders are on blockchain. The results of the simulation are shown in Figure 24.

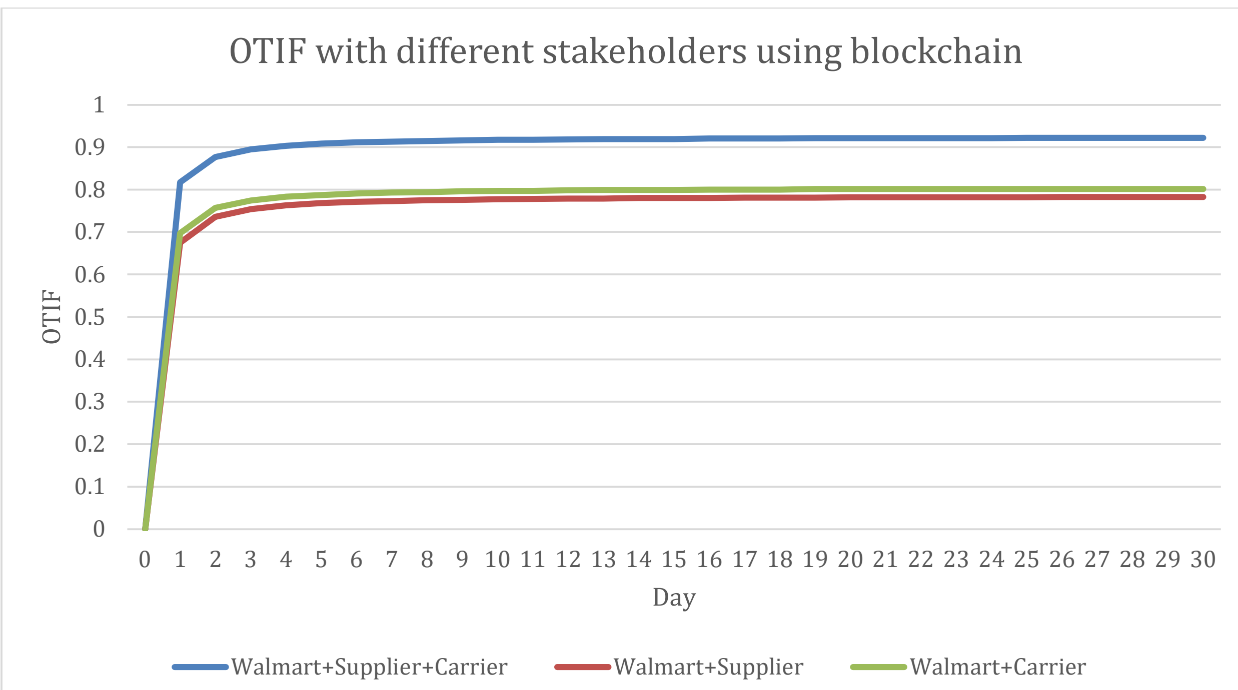


Figure 24 Change in OTIF with different stakeholder adoption scenarios

The result shows that OTIF still converges in the same way, but we observe an over 10% drop in OTIF when carrier or supplier is not using blockchain.

4.3.3 Simulation when supplier and carrier have big capacity issues

In previous simulations, we are simulating with enough capacity for supplier and carrier. What if they are facing huge capacity issues, like during peak time? Here we set market demand per day still being a normal distribution with 10k units, with standard deviation of 2k units. But supplier capacity is only 6k, and carrier capacity is only 4k.

After simulation, we found out that OTIF is 51.2% before blockchain implementation, and OTIF becomes 53.4% after blockchain implementation. The result of the before and after blockchain scenarios are shown in Figure 25. As we can see, if there is a capacity issue, then the impact of blockchain on OTIF is quite minimal.

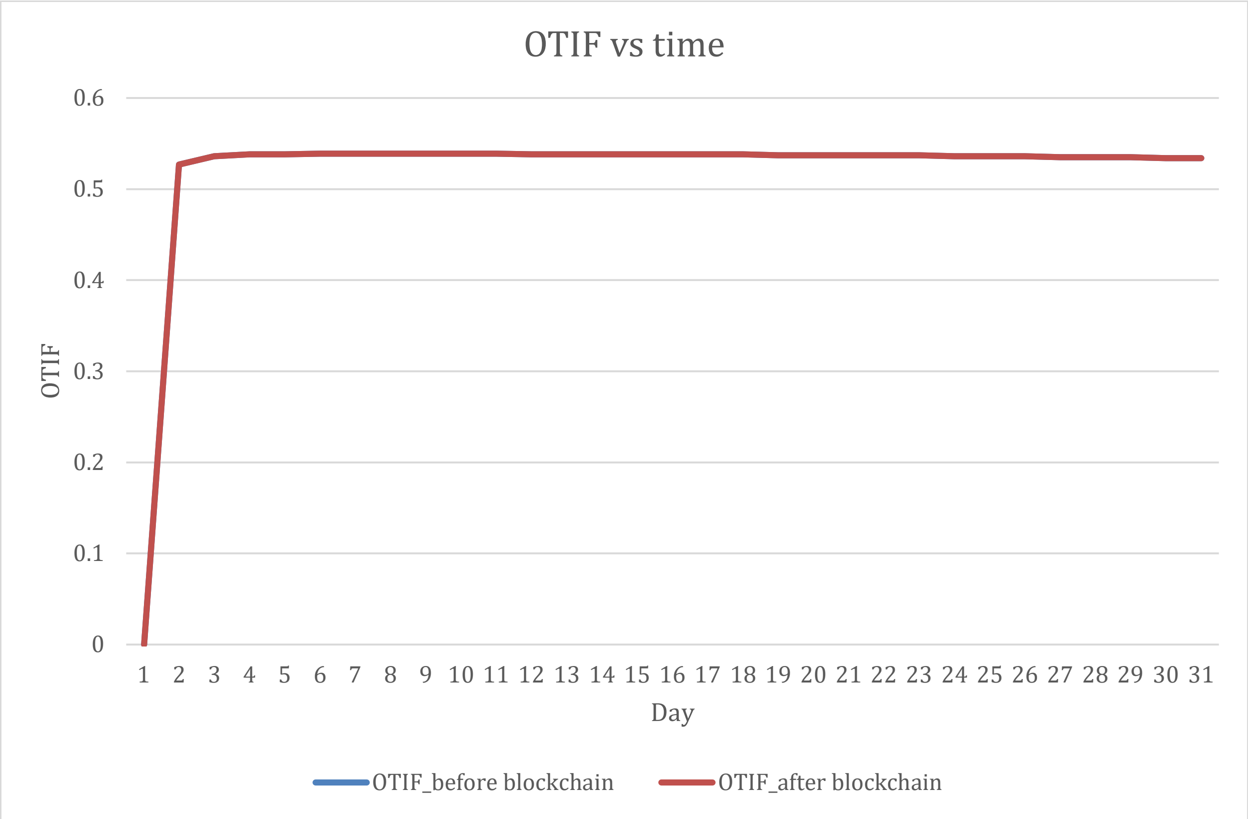


Figure 25 OTIF before and after blockchain if supplier or carrier has capacity issues

4.3.4 Simulation result summary

Based on the above simulation results, we have the following observations,

When supplier, carrier, and Walmart all adopt blockchain and share all their data, OTIF increased from 66.4% to 92.2%; disputes between Walmart and supplier dropped 67.9%; disputes between supplier and carrier dropped to 0. The corresponding dispute management costs of Walmart dropped 96.79%; the dispute management cost of supplier dropped 97.12%; the dispute management cost of carrier dropped 100%. This means that blockchain can lead to a huge reduction in dispute and the cost to manage those disputes. We also observed that Carrier's dispute management cost is always significantly lower comparing with the other two stakeholders.

Even though penalty and dispute management cost decrease as the adoption of blockchain increase, the decrease in penalty dramatically slows down after 33% of blockchain adoption, and the decrease in dispute management cost largely slows down after 67% of blockchain adoption.

When carrier or supplier is not on blockchain, OTIF will still be around 80% even when the other two stakeholders share 100% of their data. Specifically, OTIF is 78.3% when carrier is not on blockchain, and 80.2% when supplier is not on blockchain. Those numbers are better than the 66.4% when none of the parties use blockchain, but worse than the 92.2% when all three stakeholders share all the data on blockchain.

We also observe that blockchain cannot solve carrier or supplier's capacity problem, as we see the increase in OTIF is negligible when carrier and supplier's capacity is much lower than the demand. OTIF only increased 2.2% after all stakeholders share all their data on blockchain.

4.4 Model validation

To validate the model, we tested the model's suitability and consistency. Test of suitability and consistency checks if all the parameters in the model have right dimensions and have real system equivalents. It also involves checking if the model structure behaves as expected even in extreme conditions.(Martis, 2006)

4.4.1 OTIF validation

We first checked if the OTIF fits real world scenarios. We compared simulated OTIF with Walmart supplier's OTIF. As we can see in table 2, the OTIF is 0.66 when there is no blockchain implemented. This number is close to Walmart's average supplier OTIF of 0.6. With the increase of blockchain_adoption_rate, OTIF also increases to 0.922. It matches our hypothesis that blockchain adoption should help improve OTIF.

We also compared our simulated OTIF with those of other projects. In one project, the author developed a simulation-based framework for a Chemical Company GCCB using the Llamasoft Supply Chain Guru Software, and achieved a baseline OTIF of 0.65. (MEUNIER, 2013) Byrne and Heavey observed different OTIFs varying from 0.376 percent to 0.980 for different products with different stocking policies in their simulation of SME supply chains. (Byrne & Heavey, 2004) Our simulated OTIF is in line with their results.

4.4.2 Dispute management cost validation

We also checked the validity of model by comparing dispute management cost with industry data. In our model, we have assumed market demand to be a normal distribution with mean 10k and standard deviation 2k. We also assumed supplier selling this item to Walmart with $20 price. So, the supplier's expected monthly revenue is 10k*20*30 = $6 million. With an industry data of 0.63% of revenue being spent in dispute management in transportation industry (Mazareanu, 2019), the dispute management cost is $6 million * 0.63% = $37.8k, which is very close to our simulated supplier's dispute management cost of $38.017k before blockchain implementation.

4.4.3 Tests of extreme situations

Finally, we tested how the model behaves in extreme situations.

1. When Market_demand is 0, we see OTIF, dispute management cost, and all other stocks stay at 0. The model is behaving properly in this case because there should be no units flowing in the model when there is no demand. Thus, OTIF and dispute management cost should be 0.
2. When setting Carrier_capacity to 0, we see OTIF is 0, and units accumulate in Carrier_units_onhand. It means that the units in POs flow from Walmart to supplier without problem, but supplier's shipment request cannot be fulfilled because carrier has no capacity. The behavior of the model matches the real-world scenario in this case.

3. When Supplier_capacity is 0, or both Supplier_capacity and Carrier_capacity is 0, we see OTIF is 0, and units accumulate in Supplier_units_to_fulfill. It means that supplier is not able to ship any products because they have no capacity. The model's behavior matches the real-world scenario in this case.

In sum, our simulation results of OTIF and dispute management cost match the numbers in real-world scenarios. The simulation results are also in line with industry data and results of similar researches. The model behaves as expected in some extreme conditions.

5. Discussion and Recommendations

In section 4, we presented the results of the system dynamics model built based on Walmart's supply chain mapping, the simulation results before and after implementing blockchain, and the model validation and limitations. In this chapter, we will summarize the main insights from this research project, recommend strategies for Walmart to roll out the blockchain technology, and finally discuss the limitations of our research.

5.1 Main insights

Based on simulation results summary in section 4.3, blockchain technology can improve OTIF, reduce disputes, and lower the dispute management cost in Walmart's supply chain. For suppliers, the disputes with Walmart drops 67.9%, and the total dispute management cost drops 97.12%. The drop in number of dispute and dispute management cost can save the supplier a large amount of labor and cost. For carriers, the OTIF increases from 66.4% to 92.2%, and the dispute management cost drops to 100%. The increase in OTIF can bring the carrier benefits like a better reputation and can potentially lead to more business for carrier. This can be the good incentive for stakeholders to adopt blockchain.

Besides, there are other incentives as well for suppliers and carriers to join blockchain initiatives that were described in the literature review. Firstly, as it is almost impossible to change the data once it enters blockchain, stakeholders involved will trust the data and its shared history. This characteristic can help supplier and carriers to track or recall goods at low cost as we see in Maersk's case of tracking containers in section 2.2.5. Besides this, the visibility brought by blockchain can help suppliers and carriers with operations by reducing the time products spend in the transit and shipping process, improving inventory management, and ultimately reducing waste and cost (Agarwal, 2018).

Though there are big incentives in blockchain adoption, Walmart also should take a few disincentives into consideration. The simulation results show that penalty and disputes decrease with more blockchain adoption, yet the decrease slows down after a certain level. The underlying reason may be that Walmart does not penalize suppliers when OTIF is higher than 70%. OTIF stabilizes after supplier hits this 70% bar, leading to smaller decrease in penalty and dispute management cost. This can be a disincentive for the supplier to share more data because they can achieve the OTIF target while sharing only a limited part of their data.

Another disincentive is that the improvements in OTIF is low when only one of supplier or carrier is using blockchain. In these scenarios, the stakeholders who use blockchain may not be satisfied with this result because their investment in blockchain are the same, but the return of the investment is smaller than expected. This scenario is even more likely to happen for Walmart because the carrier’s dispute management costs are smaller than those of suppliers. Thus, carriers may have weaker incentive to adopt blockchain.

Besides the above two disincentives, there are other challenges with blockchain adoption. The first one is the cost. As we learned in literature review, Ernst & Young reported that it cost $ 997,758 in the first year for a small business to setup blockchain. Even though blockchain can bring long term benefit, this initial setup cost can be a burden for small companies. Besides, the unsettling cultural shift associated with blockchain implementation, and the inefficiency of blockchain due to proof of work systems are also challenges to be dealt with. Also, the inefficiency in blockchain transactions, lack of awareness and understanding of blockchain technology, the difference in blockchain standards with different blockchain solutions are other challenges that can slow down blockchain adoptions.

Lastly, though blockchain helps to improve OTIF and reduce costs, there are still problems in supply chain that blockchain cannot solve. One example is capacity issues, as we see the increase in OTIF is only 2.2% when carrier and supplier’s capacity is lower than the demand. Thus, if low OTIF is due to capacity issues, the suppliers and carriers can benefit more by improving their capacity rather than investing in blockchain.

Overall, our research shows that there are strong incentives for blockchain adoption, yet the disincentives and challenges need to be addressed before a large-scale adoption of this technology.

5.2 Recommendations for Walmart

Based on the above observations, we have the following recommendations for Walmart.

To incentivize suppliers to join a blockchain initiative, Walmart should use the reduction in penalty and dispute management cost as the biggest incentives for them to use blockchain. To encourage suppliers to share more data, Walmart may consider having a stricter OTIF standard, increasing the OTIF expectation from 70% to 80% or even higher. We see in the Results chapter that the drop in penalty slows down after 33% of data sharing on blockchain. This is because supplier’s penalty from Walmart largely decreases when supplier' OTIF is higher than 70%, and suppliers can achieve this 70% OTIF just with 33% data sharing. Suppliers may be hesitant to share more data due to privacy issues. Setting a higher OTIF expectation will further incentivize suppliers to share more data to meet this expectation and to avoid penalty.

To incentivize carriers to join a blockchain initiative, the reduction in dispute management cost brought by blockchain is not as large as that for suppliers, so Walmart should focus on improvements in OTIF while promoting this technology among carriers. A good OTIF can increase carrier's efficiency as it indicates a decrease in delivery mistakes that need to be corrected. A good OTIF can also improve a carrier's reputation in the industry and can potentially lead to more business for the carrier.

For internal stakeholders, Walmart can focus on the decrease in dispute management cost. As per our model, with the implementation of blockchain Walmart had the biggest savings in dispute management costs. Walmart can also benefit from the increased OTIF. In our model, we saw a doubling of on-time and in-full cases with the blockchain implementation.

To alleviate the large burden of initial setup cost of blockchain, Walmart should consider using subsidies for smaller suppliers and carriers in the first year to help them adopt the technology. Meanwhile, Walmart should ensure that the blockchain solution is efficient enough to handle Walmart's large volume without high latency.

Given all the benefits brought by blockchain, Walmart also needs to be aware that blockchain has limitations, it cannot solve transportation problems caused by capacity issues. Also, as we discussed previously that a report by Ernst & Young shows it takes almost $200,000 in the first year to join a cloud based blockchain platform for small business, not to mentioned that it takes another $660,000 if the company builds its own blockchain(Ernst & Young, 2019). Walmart may consider other more cost-effective technologies to improve its supply chain visibility. Even though those technologies may not be as effective in terms of resolving disputes, they can be effective to improve supply chain operations as blockchain does. Also, it is important to have all stakeholders on-board, otherwise the impact of blockchain will be limited for all stakeholders in Walmart's supply chain.

5.3 Limitations

Our model can be used by organizations to decide the viability of implementing blockchain in their organizations. By modifying the parameters used for simulation to match their current state of the supply chain, organizations can use our model to study the impact that blockchain will have on their OTIF and disputes. Furthermore, it can help organizations convince its supply chain partners on the benefits that investment in blockchain can bring to their supply chain operations.

Yet, our model is theoretical. Due to the complexity of Walmart's supply chain, there can be underlying feedback loops not included in the model. Besides, the model needs to be refined with more real data. Meanwhile, the assumptions in the model need to be further validated. As a result, the simulation results may not be exactly the same as the numbers in Walmart's supply chain. However, as shown in model validation in section

4.4, we believe the model overall behaves the same way as real system and provide useful insights.

6. Conclusion

Supply chains in modern organizations are extremely complicated networks that span across multiple geographies and organizations. Inefficiencies in these supply chains result in billions of dollars of losses to organizations every year. The root cause of many of these inefficiencies can be traced back to the lack of visibility in the supply chain networks and can be reduced by introducing technologies that improve visibility for all stakeholders in the supply chain. Blockchain is one of the tools that can be used for increasing visibility in a transparent and trustworthy manner among all stakeholders.

The purpose of this project was to analyze how the implementation of blockchain could impact the performance of small-package deliveries from suppliers to Walmart. This performance was measured in terms of On Time and In Full deliveries and dispute management costs. through system dynamics (SD) modeling and simulation of their transportation supply chain. Through this model, we analyzed the impact of blockchain in Walmart’s supply chain and identified the various incentives and disincentives for Walmart and its external stakeholders to adopt blockchain. We also looked at the various challenges and opportunities for implementing this technology in Walmart’s transportation network.

Our simulation results show that blockchain can help suppliers, carriers, and Walmart to improve OTIF and reduce dispute management costs. It can also bring the stakeholders other benefits related to visibility and the immutability of data. However, blockchain adoption also faces several challenges. Our simulation shows that suppliers may be hesitant to share all their data due to a lack of strong incentives. Also, stakeholders may be concerned about whether other stakeholders will join the blockchain, as the blockchain's impact will be weakened if some stakeholders do not adopt it. Other challenges like high setup costs and lack of understanding of blockchain technology can also potentially slow down blockchain adoption.

Applications of blockchain-based visibility technologies are a rapidly evolving area of supply chain management. Many leading organizations around the world are running proof-of-concept models for testing the impact of this technology on their supply chains. This topic remains an active area of research where new business models and frameworks are being developed. In this context, we hope that our study can help supply chain practitioners to evaluate the impact of blockchain in their organizations and understand the various incentives and disincentives that would drive blockchain adoption in their extended supply chains.

Our research focused only on one supplier, one carrier, and one product. As a next step, the model could be enhanced by introducing multiple suppliers and carriers that compete for a limited amount of orders. The interactions between these players could be modeled to understand the impact of one stakeholder implementing the blockchain on other stakeholders. It would be helpful to analyze how the benefits change as the number of participants and products involved increase. Also, the model used in our study was created from the retailer's perspective. It is missing the perspectives of supplier and carrier, who are important stakeholders in the supply chain. An avenue for further research would be to discuss the model with suppliers and carriers to incorporate their viewpoints.

References

Ackerman, K., & Bodegraven, A. V. (2017). *Relationships for supply chain success – Strategy – CSCMP's Supply Chain Quarterly*. https://www.supplychainquarterly.com/topics/Strategy/scq200704book/

Agarwal, S. (2018). *Blockchain technology in supply chain and logistics* [Thesis, Massachusetts Institute of Technology]. https://dspace.mit.edu/handle/1721.1/118559

Andrews, J. (2020). *The Importance of Supply Chain Collaboration*. http://www.supplytechnologies.com/blog/the-importance-of-supply-chain-collaboration

Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., Ferris, C., Laventman, G., Manevich, Y., Muralidharan, S., Murthy, C., Nguyen, B., Sethi, M., Singh, G., Smith, K., Sorniotti, A., Stathakopoulou, C., Vukolić, M., … Yellick, J. (2018). Hyperledger fabric: A distributed operating system for permissioned blockchains. *Proceedings of the Thirteenth EuroSys Conference*, 1–15. https://doi.org/10.1145/3190508.3190538

Banerjee, A. (2018). Chapter Three - Blockchain Technology: Supply Chain Insights from ERP. In P. Raj & G. C. Deka (Eds.), *Advances in Computers* (Vol. 111, pp. 69–98). Elsevier. https://doi.org/10.1016/bs.adcom.2018.03.007

Barratt, M., & Oke, A. (2007). Antecedents of supply chain visibility in retail supply chains: A resource-based theory perspective. *Journal of Operations Management*, *25*(6), 1217–1233. https://doi.org/10.1016/j.jom.2007.01.003

Batubara, F. R., Ubacht, J., & Janssen, M. (2018). Challenges of blockchain technology adoption for e-government: A systematic literature review. *Proceedings of the 19th Annual International Conference on Digital Government Research Governance in the Data Age - Dgo '18*, 1–9. https://doi.org/10.1145/3209281.3209317

Bowman, R. J. (2016, March 24). *How to Avoid—And Defend—Supply-Chain Disputes*. https://www.supplychainbrain.com/articles/23491-how-to-avoid-and-defend-supply-chain-disputes

Boyle, M. (2017, December 7). *Wal-Mart Will Punish Its Suppliers for Delivering Early—Bloomberg*. https://www.bloomberg.com/news/articles/2017-07-12/fined-for-arriving-early-wal-mart-puts-its-suppliers-on-notice

Buzoianu, G. (2020, January 31). What Causes a Delayed Delivery? *Eurosender.Com - Blog*. https://www.eurosender.com/blog/en/delayed-delivery/

Byrne, P., & Heavey, C. (2004). *Simulation, a Framework for Analysing SME Supply Chains. 2*, 1167–1175. https://doi.org/10.1109/WSC.2004.1371444

Catalini, C., & Gans, J. S. (2019). *Some Simple Economics of the Blockchain*. 40.

Chang, S. E., Chen, Y.-C., & Lu, M.-F. (2019). Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process.

Technological Forecasting and Social Change, *144*, 1–11. https://doi.org/10.1016/j.techfore.2019.03.015
Defining 'on-time, in-full' in the consumer sector | McKinsey. (2020, January 1). https://www.mckinsey.com/business-functions/operations/our-insights/defining-on-time-in-full-in-the-consumer-sector
Deloitte. (2019, January 1). *Blockchain POV | Blockchain Innovation Report | Deloitte UK*. Deloitte United Kingdom. https://www2.deloitte.com/uk/en/pages/innovation/articles/blockchain.html
Ehrlich, T. (2019, January 1). *The Challenges Facing Blockchain Adoption in Logistics*. https://blog.kencogroup.com/the-challenges-facing-blockchain-adoption-in-logistics
Ernst & Young. (2019). *Total cost of ownership for blockchain solutions*. 16.
Filippi, P. D. (2016). *The interplay between decentralization and privacy: The case of blockchain technologies*. 19.
Fischer, M., & Nijkamp, P. (2011). *Supply Chains and Transportation Networks.pdf*.
Frankenfield, J. (2019, August 17). *Permissioned Blockchains*. Investopedia. https://www.investopedia.com/terms/p/permissioned-blockchains.asp
Giannasi, F., Lovett, P., & Godwin, A. N. (2001). Enhancing confidence in discrete event simulations. *Computers in Industry*, *44*(2), 141–157. https://doi.org/10.1016/S0166-3615(00)00084-1
Gibson, G. E. (2016). *DECISION MAKING, TRANSACTIONAL COSTS AND DISPUTE RESOLUTION: IS THERE A BETTER WAY?* 18.
Henderson, J. (2018, January 1). *Supply chain inefficiencies costing UK businesses more than £1.5bn*. https://www.supplychaindigital.com/scm/supply-chain-inefficiencies-costing-uk-businesses-more-ps15bn
Infosys, Penske, Korn Ferry, & PennState. (2019). *2019-3PL-Study.pdf*. https://www.kornferry.com/content/dam/kornferry/docs/article-migration//2019-3PL-Study.pdf
Jensen, T., Hedman, J., & Henningsson, S. (2019). How TradeLens Delivers Business Value With Blockchain Technology. *MIS Quarterly Executive*, *18*(4), 221–243. https://doi.org/10.17705/2msqe.00018
Kim, H. M., & Laskowski, M. (2018). Toward an ontology-driven blockchain design for supply-chain provenance. *Intelligent Systems in Accounting, Finance & Management*, *25*(1), 18–27. https://doi.org/10.1002/isaf.1424
Korpela, K. (2017). *Digital Supply Chain Transformation toward Blockchain Integration*. 10.
Kosba, A., Miller, A., Shi, E., Wen, Z., & Papamanthou, C. (2016). Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts. *2016 IEEE Symposium on Security and Privacy (SP)*, 839–858. https://doi.org/10.1109/SP.2016.55
Lacity, M., Sabherwal, R., & Sørensen, C. (2019). Special Issue Editorial: Delivering Business Value through Enterprise Blockchain Applications. *MIS Quarterly Executive*, *18*(4), ix–xix.
Lavin, P. (2015). Supply chain visibility: Operational benefits and business challenges. *Operations Management (1755-1501)*, *41*(3), 40–42.

Leng, M., & Parlar, M. (2008). Allocation of Cost Savings in a Three-Level Supply Chain with Demand Information Sharing: A Cooperative-Game Approach. *Operations Research*, *57*(1), 200–213. https://doi.org/10.1287/opre.1080.0528

Martis, M. S. (2006). *Validation of Simulation Based Models: A Theoretical Outlook*. *4*(1), 8.

Mazareanu, E. (2019). *Legal services: Spending on disputes as a proportion of revenue by industry 2017*. Statista. https://www.statista.com/statistics/956116/legal-services-spending-on-disputes-revenue-share-industry/

MEUNIER, J. (2013). *What are the root causes of low customer satisfaction indices for a complex supply chain and how can the situation be remedied?*

Mire, S. (2019, June 30). What Are The Challenges To Blockchain Adoption In Supply Chain Management? 17 Experts Share Their Insights. *Disruptor Daily*. https://www.disruptordaily.com/blockchain-adoption-challenges-supply-chain-management/

Pagell, M. (2004). Understanding the factors that enable and inhibit the integration of operations, purchasing and logistics. *Journal of Operations Management*, *22*(5), 459–487. https://doi.org/10.1016/j.jom.2004.05.008

Quantzig. (2018, May 8). *Top Four Reasons Why Supply Chain Visibility Is More Important Than Ever Before | Quantzig*. https://www.businesswire.com/news/home/20180508006009/en/Top-Reasons-Supply-Chain-Visibility-Important-Quantzig

Redwood. (2017, June 22). *7 Ways to Avoid Freight Damage*. Redwood Logistics. https://www.redwoodlogistics.com/avoid-freight-damage/

REYES, G. (2018, July 31). Freight Collect and Freight Prepaid—What's the Difference? *Amware*. http://www.amware.com/freight-collect-freight-prepaid-whats-difference/

Rongala, A., Manager, Development, B., Marketing, & Technologies, I. (2015, April 27). Top 6 Manual Data Entry Challenges Companies Face. *Invensis Technologies*. https://www.invensis.net/blog/data-processing/top-6-manual-data-entry-challenges-companies-face/

Saqib, Z. A., Saqib, K. A., & Ou, J. (2019). Role of Visibility in Supply Chain Management. *Modern Perspectives in Business Applications*. https://doi.org/10.5772/intechopen.87202

Shearon, M. (2018, March 9). *How dock scheduling can ease carrier capacity problems*. https://www.transporeon.com/us/expertise/blog/article/how-dock-scheduling-can-ease-carrier-capacity-problems/

Stackpole, B. (2020, February 14). *5 supply chain technologies that deliver competitive advantage*. MIT Sloan. https://mitsloan.mit.edu/ideas-made-to-matter/5-supply-chain-technologies-deliver-competitive-advantage

Stanchik, A. (2016). *The effect of supply chain visibility systems on business processes: A multi-case study analysis* [Thesis, Massachusetts Institute of Technology]. https://dspace.mit.edu/handle/1721.1/107508

Stempel, N. D. (2016). *Driving the New York State hop industry to meet demand* [Thesis, Massachusetts Institute of Technology]. https://dspace.mit.edu/handle/1721.1/107507

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world* (Dewey Library - Reserve Stacks HD30.2.S7835 2000 CDROM). Boston : Irwin/McGraw-Hill, c2000.

Techtarget. (2009, October 1). *What is supply chain visibility (SCV)? - Definition from WhatIs.com*. SearchERP. https://searcherp.techtarget.com/definition/supply-chain-visibility-SCV

Tian, F. (2016, January 1). *An agri-food supply chain traceability system for China based on RFID & blockchain technology—IEEE Conference Publication*. https://ieeexplore-ieee-org.libproxy.mit.edu/abstract/document/7538424

Tseng, Y., & Yue, W. L. (2005). THE ROLE OF TRANSPORTATION IN LOGISTICS CHAIN. *Proceedings of the Eastern Asia Society for Transportation Studies*, *5*, 16.

Underwood, S. (2016). Blockchain beyond bitcoin. *Communications of the ACM*, *59*(11), 15–17. https://doi.org/10.1145/2994581

Vessella, V. (2020). *How Stockouts Can Hurt Your Business (And How to Prevent Them)*. https://www.repsly.com/blog/consumer-goods/how-stockouts-can-hurt-your-business

Walmart. (2020). *About Us*. Corporate - US. https://corporate.walmart.com/our-story

Willemain, T. R. (1995). Model Formulation: What Experts Think About and When. *Operations Research*, *43*(6), 916–932. https://doi.org/10.1287/opre.43.6.916

Wilson, V. (2016). Research Methods: Interviews. *Evidence Based Library and Information Practice*, *11*(1(S)), 47–49. https://doi.org/10.18438/B8404H

Wolf, F., & Pickler, L. (2010). Supply Chain Dispute Resolution: A Delphi Study. *International Journal of Information Systems and Supply Chain Management*, *3*(3), 50–65. http://dx.doi.org/10.4018/jisscm.2010070104

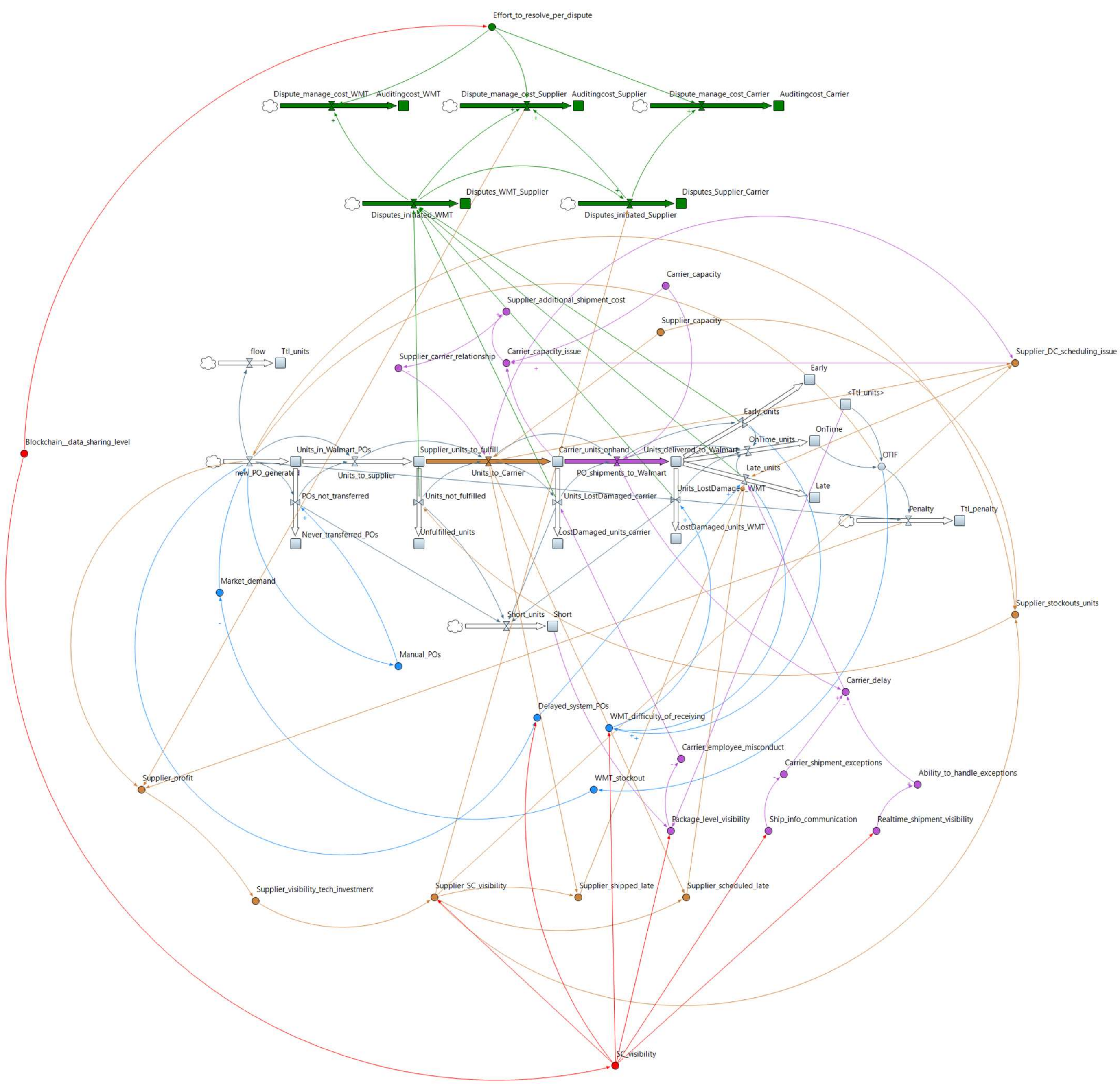
Yousuf, S., & Svetinovic, D. (2019). Blockchain Trust and Decentralization in Supply Chain Management. *2019 27th Telecommunications Forum (TELFOR)*, 1–4. https://doi.org/10.1109/TELFOR48224.2019.8971219

Zavolokina, L., Ziolkowski, R., Bauer, I., & Schwabe, G. (2020). Management, Governance, and Value Creation in a Blockchain Consortium. *MIS Quarterly Executive*, *19*(1), 1–17. https://doi.org/10.17705/2msqe.00022

Appendix I

Complete system dynamics model

The gold color represents the supplier, blue color represents Walmart, purple color represents carrier, green color represents disputes and red color represents impact of blockchain.



Formula Explanations

1. Formulas used in Main flow:

i. New_PO_generated = Market_demand*OTIF

ii. POs_not_transferred = 0.0001*new_PO_generated+0.01*Manual_POs

iii. Units_to_supplier = new_PO_generated-POs_not_transferred

iv. Units_not_fulfilled = max(0,Supplier_stockouts_units)

v. Units_to_Carrier = min((Units_to_supplier-Units_not_fulfilled)*Supplier_carrier_relationship,Supplier_capacity)

vi. Units_LostDamaged_carrier = Units_to_Carrier*Carrier_employee_misconduct

vii. PO_shipments_to_Walmart = min(Carrier_capacity,Units_to_Carrier-Units_LostDamaged_carrier)

viii. Units_LostDamaged_WMT = 0.5*WMT_difficulty_of_receiving

ix. Early_units = PO_shipments_to_Walmart*0.05

x. Late_units = Delayed_system_POs*10+Carrier_delay+Supplier_shipped_late+Supplier_scheduled_late+Supplier_DC_scheduling_issue

xi. OnTime_units = PO_shipments_to_Walmart-Units_LostDamaged_WMT-Late_units-Early_units

xii. OTIF = OnTime/Ttl_units

2. Formulas used in Walmart focused flows

i. Market_demand = max(normal(2,10)*(1-min(WMT_stockout,5)*0.2), 0)

ii. Manual_POs = max(new_PO_generated*0.01,0)

iii. Delayed_system_POs = new_PO_generated*0.001*(1-SC_visibility)

iv. WMT_difficulty_of_receiving = max(0,(Early_units+Late_units)*0.1*(1-SC_visibility))

v. WMT_stockout = (1-OTIF)*2

3. Formulas used in Carrier focused flows

i. Carrier_employee_misconduct = 0.1*(1-Package_level_visibility)

ii. Carrier_shipment_exceptions = 0.08*(1-Ship_info_communication)+0.05

iii. Ability_to_handle_exceptions = Realtime_shipment_visibility*0.5

iv. Carrier_delay = (Carrier_shipment_exceptions*(1-Ability_to_handle_exceptions))*PO_shipments_to_Walmart

v. Package_level_visibility = max(SC_visibility, min(1,Short/Ttl_units))

vi. Ship_info_communication = max(0.5,SC_visibility)

vii. Realtime_shipment_visibility = max(SC_visibility,0.1)

viii. Carrier_capacity_issue = max(Carrier_units_onhand-Carrier_capacity+Supplier_DC_scheduling_issue,0)

ix. Supplier_additional_shipment_cost = Carrier_capacity_issue

x. Supplier_carrier_relationship: max(1-Supplier_additional_shipment_cost*0.01,0)

4. Formulas used in Supplier focused flows

i. Supplier_DC_scheduling_issue =0.05*Units_to_Carrier*(1-Supplier_SC_visibility)

ii. Supplier_stockouts_units =max(0,(new_PO_generated-Supplier_capacity)*(1-Supplier_SC_visibility))

iii. Supplier_shipped_late = 0.05*Units_to_Carrier*(1-Supplier_SC_visibility)

iv. Supplier_scheduled_late = 0.02*Units_to_Carrier*(1-Supplier_SC_visibility)

v. Supplier_SC_visibility = max(0,min((Supplier_profit/1000),1))

vi. Supplier_profit =5*new_PO_generated-Penalty-Dispute_manage_cost_Supplier

vii. Supplier_visibility_tech_investment = max(0,Supplier_profit/100)

viii. Penalty = (OTIF<0.7) ? 20*new_PO_generated*(1-OTIF)*0.03 : 0

5. Formulas used in Disputes flows

i. Disputes_initiated_WMT = 0.5*(Units_not_fulfilled+Units_LostDamaged_carrier+Units_LostDamaged_WMT+Late_units+Early_units)

ii. Disputes_initiated_Supplier = 0.5*Disputes_initiated_WMT*(1-Supplier_SC_visibility)

iii. Dispute_manage_cost_WMT = 1.26 * Disputes_initiated_WMT*Effort_to_resolve_per_dispute

iv. Dispute_manage_cost_Supplier = (0.84*Disputes_initiated_WMT+0.21*Disputes_initiated_Supplier)*Effort_to_resolve_per_dispute

v. Dispute_manage_cost_Carrier = 0.21 * Disputes_initiated_Supplier * Effort_to_resolve_per_dispute

vi. Effort_to_resolve_per_dispute = max(1-Blockchain_adoption_rate,0.1)