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Impact of IoT on supply chain performance

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Abstract: Aim: To increase the understanding of the Internet of Things (IoT) by demonstrating its impacts and benefits on supply chain performance.
Design/methodology/approach: System dynamics to assess the benefits of using IoT technology to enhance supply chain performance.
Findings: Simulation results show a positive impact on the supply chain activities targeted in three propositions:

1) Better decision-making—Better asset utilization and reduced shipping time. However, transportation costs increase because of the lack of a decision-making system.
2) Reduced lead time—A reduced shipping time for location technology and when all technologies are combined.
3) Better asset utilization—A higher utilization factor, hinting at better asset utilization.

Limitations/implications: The models presented are based on merged data from different sources as well as estimates based on assumptions.
Practical implications: A decision-making processing system that integrates the complete array of appropriated technologies. This system is the underlying concept and the contribution of the IoT.

Keywords: Supply chain performance, Internet of Things, IoT, simulation, case studies

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1. Introduction

Today, individual businesses are part of a supply chain network where multiple businesses must work together to achieve their individual goals (Lambert & Cooper, 2000). Therefore, they operate under a continuous change environment that makes them vulnerable to many factors that present risks (Ben-Daya et al., 2019) because supply chain processes are complex and difficult to control due to rapid changes in technology (Simchi-Levi et al., 2003), highly dynamic economies (Ben-Daya et al., 2019), underperformance of logistic operations, and low visibility due to lack of ability to share information on time and provide accurate data throughout the entire supply chain (Nooraie & Parast, 2015). To subsist, companies must be highly flexible and agile to help mitigate risks, which can be done by increasing the level of visibility through the whole supply chain and achieving the velocity needed to respond quickly to changes with an effective collaboration between suppliers and customers (Ben-Daya et al., 2019). To help overcome supply chain problems by increasing visibility, Internet of Things (IoT) technology applications have been developed to enhance control of supply chains because IoT gives companies the potential to streamline information flow in real time (De Vass, et al., 2018); however, these applications have not been totally integrated in supply chains because of the lack of understanding of their implementation and benefits. The aim of this paper is to increase the understanding of the IoT by demonstrating its impacts and benefits on supply chain performance (SCP). System dynamics simulation modeling is the methodology employed to estimate and assess the benefits of using IoT technology applications to enhance SCP.

Information technology (IT) is crucial for the effective management of a supply chain (Ross et al., 2016). IoT is an IT technology that has increased supply chain communications (van Hoek, 2019), allowing companies to more effectively overcome supply chain management challenges (Ellis et al., 2015). The impacts of IoT on SCP have been addressed in the form of conceptual frameworks by previous studies, such as *Estimating the Benefits of the Internet of Things for Supply Chain Performance—A Conceptual Framework—* (Monsreal et al., 2019), resulting in a set of metrics to evaluate those impacts. These metrics are key performance indicators that match with specific information and communications technologies to estimate the benefits of IoT on SCP. However, measuring the impact of IoT technology on SCP is difficult because the process implies the need to gather data for assessment, and data availability is a challenge. To overcome this data availability problem, the authors of this paper use system dynamics simulation modeling to estimate IoT impacts on SCP combined with the propositions published in Monsreal et al. (2019) to estimate the benefits of the IoT for SCP. Moreover, supply chain operations often present feedback loops that traditional simulation models fail to capture, while a system dynamics simulation model is capable of capturing operational cycles and thus provides higher accuracy and more realistic results. Therefore, the simulation model proposed in this paper is a system dynamics model. The proposed system dynamics simulation model uses the previously selected performance indicators to test four of six propositions from Monsreal et al. (2019) conceptual research. The six propositions from Monsreal et al. (2019) are:

P1: IoT adoption facilitates enhanced information capture.

P2: IoT adoption facilitates better decision-making.

P3: IoT adoption facilitates enhanced supply chain connectivity/collaboration/integration.

P4: IoT adoption facilitates better inventory control.

P5: IoT adoption facilitates reduced lead time.

P6: IoT adoption facilitates better asset utilization.

Monsreal et al. (2019) P2, P5, and P6 are the focus of this work. P1, P3 and P4 are not tested in this model because a different and separate case study was developed to test those two propositions, making them outside the scope of this analysis. The three tested propositions are validated with a 365-day simulation of a beverage company case study with the aim of estimating the benefits of the IoT for SCP. The developed model calculates quantitative measures to assess how IoT technology impacts SCP based on P2, P5, and P6.

This paper is organized as follows: Section 2 presents a literature review on IoT technology developed to enhance SCP and logistical operations. Section 3 explains the simulation modeling approach to estimate IoT impacts on SCP based on Monsreal et al. (2019) framework and propositions and presents a real case study from a beverage company in Latin America. Section 4 shows the models developed with the simulation modeling approach and includes an analysis of the results. Section 5 concludes this paper and discusses potential future research.

2. Literature review

Applications of IoT technology in logistical operations can improve its performance in many ways. The list of benefits includes enhanced inventory management, real-time supply chain management (SCM), and transparency in logistics. Moreover, studies have looked at new ways to securely integrate IoT technology applications in supply chains. Those works address different challenges that IoT technology applications must overcome (Abdel-Basset et al., 2018). Some of the improvements that IoT technology applications provide are reduced asset loss, cost savings, inventory accuracy, and product tracking (Aryal et al., 2018; Ben-Daya et al., 2019; Edirisinghe, 2019; Maksinovic et al., 2015). For example, thanks to IoT, international fashion company Zara achieves a highly flexible supply chain with short lead times (Qrunfleh & Tarafdar, 2014). Some other unexpected benefits of IoT implementations on supply chain include demand forecasting, reliable supplier development, and production system flexibility, along with core improvements in operational efficiency, product tracking, inventory management, and asset utilization. However, the absence of a unified protocol is the biggest obstacle to widespread use of IoT technology applications, and there are several challenges for IoT technology applications to overcome in the areas of technology, organization, resources, privacy, and security (Anirudh et al., 2017; Birkel & Hartmann, 2019; Caro & Sadr, 2019; Haddud et al., 2017; Sharma & Khanna, 2020; Urquhart & McAuley, 2018).

Some of the most common and reliable IoT technologies are optical codes, electromagnetic fields, location systems, and demand planning. The most representative optical technology is the barcode, and the most representative electromagnetic field reader is radio-frequency identification (RFID) technology, which is considered a breakthrough in SCM (Kamble et al., 2019; Rejeb et al., 2020). Barcode scanners and RFIDs are the actual tools that connect the codes to the IoT. Since optical codes are printed on paper, the code itself is not connected to the IoT. However, software can be used to connect the code to its stored information, which can be retrieved once scanned. Optical codes still play an important role in SCM and logistics because the technology is cheap and effective. Codes can identify the specific parcel, and that information can be transferred via data transmission technologies. Moving the log of scanned materials through the IoT up the supply chain results in data used for performance measurement within processing software packages (McCathie, 2004). Location systems are mostly based on the global positioning system (GPS). GPS works through signals that satellites send to Earth and that are detected by mobile or stationary receiving devices. The system tracks the GPS's location to pinpoint the location of the receiving device. These data can be stored and monitored and are ideal for the management of truck fleets transferring goods within the supply chain (Prasanna & Hemalatha, 2012; Viani et al., 2012). Demand planning is a forecast-based tool that ensures operations are timely, efficient, and cost effective. Demand planning focuses on product availability to maximize revenues in the marketplace while also considering inventory as a tradeoff as it ties up capital. Demand planning requires a variety of information that is timely, as accurate as possible, usable, qualitative, and quantitative to be effective. IoT shares the information that helps companies understand and collaborate with customers for better demand planning and customer service (De Vass et al., 2018).

Improving the SCP of the fresh food market is still a challenge; thus, this area presents a clear opportunity for new technologies to contribute to food supply chain enhancement. Not only are improvements to customer service important but also improvements to food quality control, meaning that the industry itself can benefit from IoT and supply integration, not just consumers (Pal & Kant, 2018).

A survey of 188 trading companies was performed to determine if interorganizational information integration from IT-enabled collaboration decision-making is a benefit to SCM. Results from the survey and post hoc analysis show a positive relationship between interorganizational information integration and IT-enabled collaboration decision-making. This finding gives support to integrating IT into supply chains to better improve customer service from increased SCP (Aryal et al., 2018; Wong et al. 2015).

Another IoT-related technology that has a direct impact on supply chain logistics is Big Data. Studies show the ability of Big Data to manage many supply chain factors, including optimizing fuel costs, conducting predictive maintenance, and aiding in driver safety. The use of IoT and Big Data allows for achieving these benefits (Hopkins & Hawking, 2018).

It is common to develop simulation models to manage supply chains. For example, Jain et al. (2001) designed a simulation model for a high-level supply chain to evaluate the business processes and inventory control measures of a distribution supply chain. The model inputs are demand, product characteristics, distribution center, and supplier lead times. The study considered how the level of detail affects the model. Too much detail may lead to the model being overly complex to the point where it is not approved for use. Therefore, the level of abstraction used when making a simulation model is important to find a balance between too much and too little detail (Jain et al., 2001).

System dynamics modeling has been used as a simulation-based approach in SCM—and has become an emerging field of research—because it is a suitable methodology to simulate and study complex and dynamic systems to support long-term, strategic decision-making (Rebs et al., 2019). This modeling approach helps to identify policies and parameters that effectively manage strategic decision problems. The use of simulation helps to answer questions on different scenarios regarding the implementation of strategies on supply chain profit (Georgiadis et al., 2005). Moreover, system dynamics modeling has many advantages, such as the possibility of easily including stochastic variables (Chan & Chan, 2010), allowing stakeholder engagement in the modeling process

(Jahangirian et al., 2010), and taking a broader perspective on systems thinking (Mingers & White, 2010). System dynamics models have been developed in supply chains to manage resources and capabilities (Adamides & Pomonis, 2009), marketing (Adamides & Voutsina, 2006), organizational innovation (Wunderlich & Größler, 2012), strategic management (Cosenz & Noto, 2016), and strategic and operational business functions (Größler et al., 2008).

3. Simulation modeling approach

This section presents an approach to evaluate technology implementation impacts as the development and application of a system dynamics model. Based on *Estimating the Benefits of the Internet of Things for Supply Chain Performance—A Conceptual Framework*—(Monsreal et al., 2019), the researchers selected specific metrics to test how IoT adoption facilitates better decision-making, reduced lead time, and better asset utilization (i.e., P2, P5, and P6). Table 1 shows the specifics of the case study and the metrics selected to test the corresponding propositions.

The case study examines the effects of demand-sharing, GPS, and barcode technologies. This analysis uses four models:

1. Base model with no technology.

2. Model with demand-sharing technology (demand planning).

3. Model with GPS and barcode technology.

4. Model with demand, GPS, and barcode technology.

The simulation is performed using Vensim software and following a system dynamics approach. Researchers chose this technique since system dynamics modeling is more suitable to decision-making because of the causality and impact analysis achieved by defining a problem dynamically and considering loops of information feedback and circular causality.

3.1. Case study

The case study uses real data from a beverage company. Table 2 shows the consolidated data without technology.

Some data could not be directly retrieved from the information provided by the company. The researchers estimated the required set of data values based on the original information from the company. The blue highlighted numbers denote these estimated values.

Next, the researchers estimated technology values based on a literature search for previous studies and experiences. Table 3 shows the consolidated data with technology. In this table, deemed figures show values that did not change with technology. Green highlighted cells represent values estimated with GPS technology, and orange highlighted cells contain values estimated with barcode technology.

Table 1. Case study specifics.

Study Cases	Long-Haul “Optimization”		
Company/Source	Beverage Company		
Supply Chain Scope	Systemic Hinterland		
Product Type	Beverages		
Tested Propositions	P2: Better decision-making	P5: Reduced lead time	P6: Better asset utilization
Metrics	Transportation cost	Shipping time	% of utilization load/utilization factor

Table 2. Case study consolidated data, no technology.

			No Technology			
			PP-CP		CP-CEDIS	
Concept	Period	Units	Average	SD	Average	SD
DC (CEDIS) demand	Day	Cases	10060	1274		
Volume	Day	Trailers	8.60	1.1	10.30	1.3
Fleet size	In the period	Trailers	54.00			
Cargo capacity	In the period	Cases	1371.5	972.5		
Transit time	Day	Days	0.2500	0.025	0.021	0.004
Return time	Day	Days	0.2083	0.021	0.021	0.004
Transportation costs	Day	USD	$1246		$296	
Loading	Day	Minutes	0.0625	0.006	0.063	0.006
Unloading times	Day	Minutes	0.0833	0.008	0.083	0.008
Receiving and dispatching times	Day	Minutes	0.0083	0.001	0.008	0.001
Storage capacity	In the period	Cases	425503		87360	
Desired inventory	In the period	Cases	58311		24805	

Table 3. Case study consolidated data, with technology.

			With Technology			
			PP-CP		CP-CEDIS	
Concept	Period	Units	Average	SD	Average	SD
DC (CEDIS) demand	Day	Cases	10060	1274		
Volume	Day	Trailers	8.6	1.1	10.3	1.3
Fleet size	In the period	Trailers	54.0			
Cargo capacity	In the period	Cases	1372	973		
Transit time	Day	Days	0.065	0.007	0.005	0.001
Return time	Day	Days	0.054	0.005	0.005	0.001
Transportation costs	Day	USD	$1246		$296.2	
Loading	Day	Minutes	0.016	0.002	0.016	0.002
Unloading times	Day	Minutes	0.022	0.002	0.022	0.002
Receiving and dispatching times	Day	Minutes	0.007	0.001	0.007	0.001
Storage Capacity	In the period	Cases	425503		87360	
Desired inventory	In the period	Cases	58311		24805	

4. Models and analysis of the results

The models developed in the case study follow the actual supply chain structure of the company. This structure comprises a producing plant, a consolidating plant, and distribution centers (respectively denoted as PP, CP, and CEDIS in the models). Figure 1 shows this structure graphically.

In Figure 2, input variables are highlighted in red and output variables in green. Input variables are the ones that changed depending on the technology implemented. Additionally, the model structure changes to assess some technologies. For instance, the four models developed for this case study follow a similar structure; however, for demand planning technology, the structure needed to change. This change is represented by the red arrows, which show the demand information sharing by the demand planning system. The model includes ordering processes, forward and returning vehicles transit, product flows, and inventories with stochastic demand and processing times. All distributions are assumed normal, product units are cases, and vehicle flows are truck–trailers.

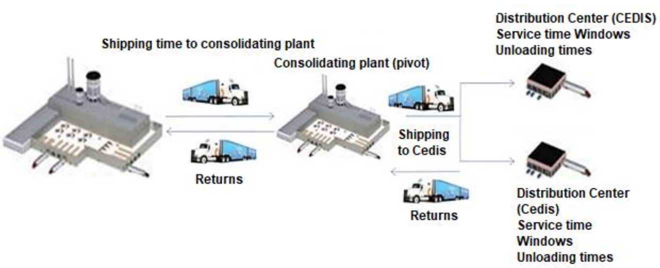

Figure 1. Beverage company supply chain structure.

4.1. Simulation and results

The unit of time of the simulation is "day," and it was run for 365 iterations, or a year.

Table 4 shows the results for the case study on the selected metrics. Additionally, the authors added "unmet demand" as a metric for overall system performance that helps put in perspective the results of the other—more individually focused—metrics.

From Table 4, it is evident that cargo in transit, transportation costs, and use factor all increase with demand technology but not with GPS and barcode technologies. Shipping time decreases with GPS and barcode technologies, but not with demand technology. Unmet demand is at its lowest with all technologies. Demand technology and the combination of all technologies provide the highest return rate of trucks. GPS and barcode technologies, along with no technology, show the lowest inventory levels.

Demand-sharing technology focuses on relaying real-time information to upper nodes/echelons of the supply chain. Thus, the primary focus of this technology is not lowering costs—such as that of transportation—but rather providing on-time information so actual demand can be met. On the other hand, GPS and barcode technologies provide information useful for making operations more efficient; their effect is perceived mostly in time reductions. Unmet demand results show that combining these two technologies provides the largest benefit in terms of effectiveness and efficiency. Results show that technology choice depends on the organization's strategy and purpose (e.g., effectiveness vs. efficiency).

5. Conclusions and recommended future research

In general, results show a positive technology impact on the supply chain activities targeted in the propositions. Specifically, the results indicate:

P2: Better decision-making—The case study shows better asset utilization and reduced shipping time. However, transportation costs increase because of the lack of a decision-making system.

P3: Enhanced..supply chain connectivity/collaboration/integration—The case study shows demand planning technology provides benefits in terms of supply chain integration through demand planning.

P5: Reduced lead time—The case study shows a reduced shipping time for location technology and when all technologies are combined.

P6: Better asset utilization—The case study shows a higher utilization factor, hinting at better asset utilization even without a decision-making system.

The implementation of data collection or data transmission technologies alone is not sufficient to obtain full benefits. A decision-making processing system that integrates the complete array of appropriated technologies should also be implemented. This system is the underlying concept and the contribution of the IoT.

The models presented here are based on merged data from different sources: primary and secondary sources and estimates based on assumptions. The mere nature of the base data limits the precision of results. To increase precision, a higher resolution in processes and data of a specific case are needed. Future research should focus on the technology integration aspect of the IoT.

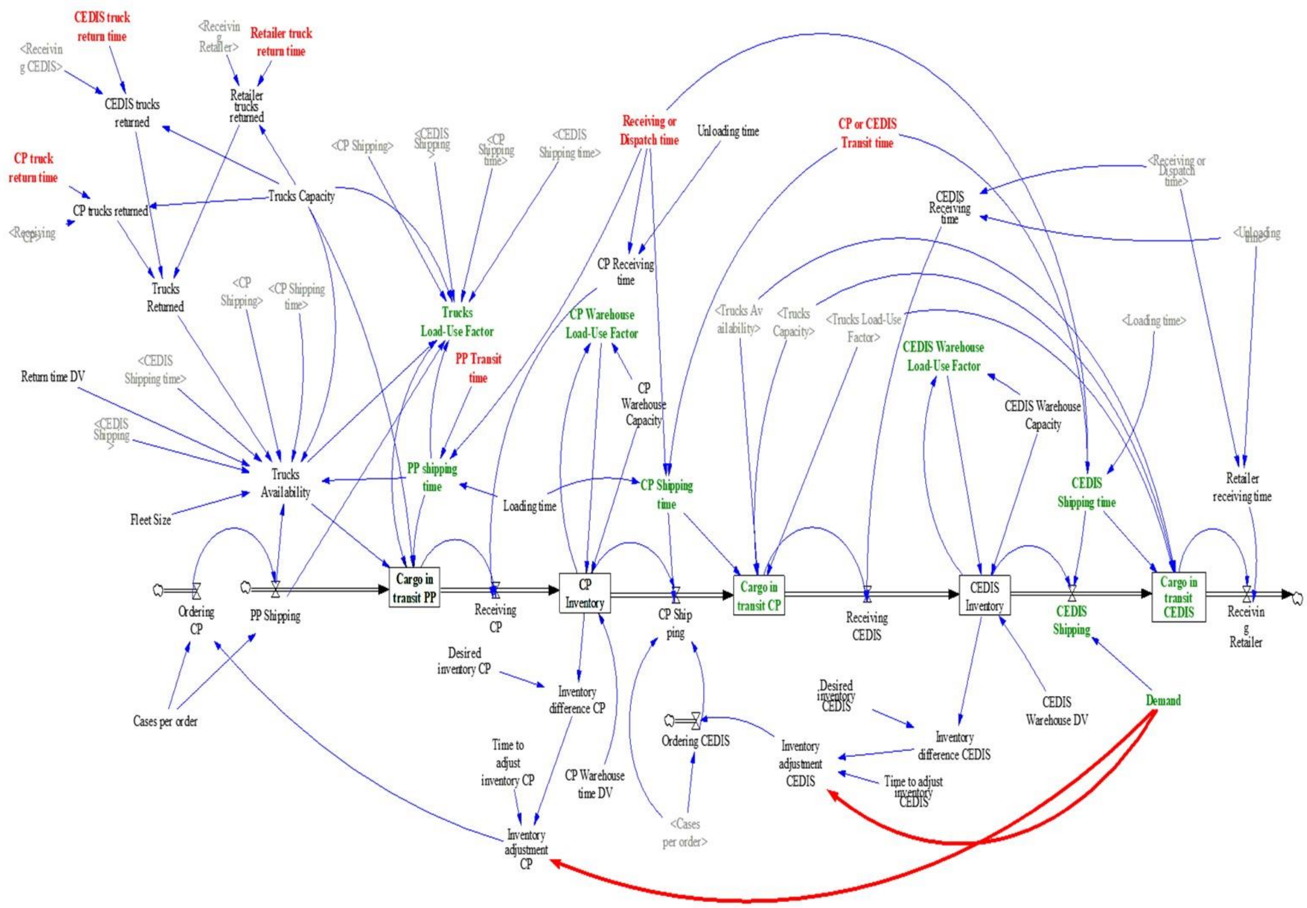

Figure 2. Vensim model (namely "molecule") representing this operation.

Table 4. Case study (beverage company) results.

	Base Model	Demand	GPS+Barcode	All Technologies
Total Transportation Cost (USD)	616,285,172.00	910,873,829	605,719,593	927,757,226
Cargo in transit CEDIS	52,487,983.00	54,440,173	52,282,120	54,579,093
Cargo in transit CP	82,109,506.00	88,945,920	81,279,697	88,924,685
Cargo in transit PP	481,687,683.00	767,487,737	472,157,776	784,253,448.00
Average Use Factor (%)	23.20%	126.30%	20.90%	137.30%
CEDIS Warehouse	11.80%	95.90%	11.90%	108.70%
CP Warehouse	47.00%	269.50%	45.70%	296.60%
Trucks	10.80%	13.50%	5.20%	6.50%
Average Shipping Time (days)	0.167	0.167	0.094	0.094
CEDIS	0.091	0.091	0.074	0.074
CP	0.091	0.091	0.074	0.074
PP	0.319	0.319	0.134	0.134
Unmet Demand (cases)	620,107	522,636	629,655	513,476

Conflict of interest

The authors do not have any type of conflict of interest to declare.

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