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Sustainable Supply Chains with Blockchain, IoT and RFID: A Simulation on Order Management

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Abstract: The digital transformation of supply chains should revolutionize entire management processes and improve various aspects of sustainability. In particular, the plans of Industry 4.0 aim towards a digitization of several procedures by exploiting emerging technologies such as the Internet of Things, RFID and blockchain. The purpose of this study is to highlight how order and disruption events processes can be improved with the adoption of emerging technologies and how this reflects on the improvement of sustainability aspects. The study is based on the comparison of two simulation scenarios between three actors in the cheese supply chain. In particular, a first traditional scenario "as is" is simulated without the use of new technologies and is compared to a second scenario "to be" that adopts IoT, RFID and blockchain. The results show an improvement in time performance for managing both perfect and non-compliant orders. The developed framework highlights the impact of new technologies on sustainability aspects, showing further managerial implications.

Keywords: blockchain; RFID; IoT; order management; digital technologies; disruption events; sustainability; simulation; supply chain

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1. Introduction

In recent years, two important research topics in supply chain management concern the issues of sustainability and the interconnected use of emerging technologies. Sustainability is considered as a key factor for accessing markets and achieving high profits [1,2]. For instance, while in the past the sustainable shipments management was considered as a cost, now, thanks to the new technologies, it is possible to guarantee sustainable logistics [3,4]. Indeed, using these emerging technologies it is possible to save carbon emissions and resources [5]. Furthermore, one of the most important requirements for sustainable supply chains concerns the transparency of information and correct communication between the participants in the chain [6]. In order to achieve these goals, it is essential to have high IT security standards to reduce the risk of systems downtime which will lead to millions of financial losses [7].

As to emerging technologies, the Gartner report included blockchain as a disruptive technology which guarantees greater transparency and traceability in the exchange of data [8]. The exponential increase of data allows companies to operate efficiently and effectively on entire business processes. In fact, the improvement of new different technologies has made consumers more and more aware of the products they bought since the information is easily accessible. However, it is important to collect and store data in an integral, ethical and responsible way in order to increase consumer trust in their purchases.

Certainly, one of the most investigated topics is the use of blockchain for the product tracking and tracing [9,10], which is the last piece of the different technologies already used. In particular, the literature has extensively analyzed detection systems such as RFID, GPS technology and the Internet of Things (IoT) infrastructure [11–15]. These systems have revolutionized the monitoring of products and processes, from the origin to the final consumer, in terms of information such as: price, date, location, quality, certifications. However, they present several issues related to the lack of security, standardization, interoperability and distribution among the players on a large scale [16,17]. Blockchain technology can fill these inefficiencies since it allows to manage goods without intermediaries or trusted parties [18,19]. The efficiency of supply chain transactions can be improved thanks to the distinctive features of blockchain. Indeed, in order to achieve effective visibility, the traceability process must have a unified, reliable and tamper-proof shared ledger that is globally accessible by all the stakeholders [20,21]. Furthermore, the optimization of the entire supply chain can take place through smart contracts in order to verify and allow actions by physical devices that detect information, increasing the security of the IoT infrastructure [22]. Smart contracts would allow the automation of specific actions based on the constant detection of sensors along the supply chain such as, for example, automatic payment after receipt of the product [23] or efficient management of anomalies along the shipment [24].

The study of the blockchain is still in its infancy because the technology has recently appeared in the field of the supply chains. Many contributions are theoretical and conceptual [25–27], whereas others analyze intrinsic aspects of the technology such as consensus mechanism and security [28,29]. The effectiveness and efficiency of the blockchain in supply chain management is not very clear in a quantitative way. This study aims to bridge the research gap by verifying the benefits that emerging technologies provide if compared to traditional solutions because in literature very little has been explored in this direction.

Therefore, the goal of this work is to test and evaluate the real potential of blockchain in terms of time performance in order management between three players. In particular, thanks to the use of a simulation tool, two order management systems are compared: the former traditional without the use of emerging technologies, the latter with the adoption of RFID, IoT infrastructure and blockchain. The work examines the reduction of order management times with a particular focus on disruption events. The reason for this further focus concerns the problems with non-compliant order management procedures that plague modern supply chains [30,31]. In addition, possible improvements in sustainability can be achieved using such technologies. Therefore, further insights for increasing the literature on the improvement of sustainability issues with the use of new technologies are provided in the discussion section.

The rest of this paper is organized as follows. Section 2 presents the theoretical background on the new technologies allowing goods tracking that can be implemented within supply chains, with a particular reference to the order management process. Section 3 presents materials and methods; the two simulation scenarios and implementation aspects are described. Section 4 presents the results with the sensitivity analysis, while Section 5 highlights the discussions with a focus on sustainability issues and managerial implications. Finally, Section 6 presents the conclusions, limitations and insights for future research.

2. Theoretical Background

2.1. RFID for the Supply Chain Management

RFID technologies provide several contributions to the supply chain due to their characteristics such as unique product identification, ease of communication and the availability of information in real time [32,33]. In particular, RFIDs are tools used for acquiring data relating to a specific product. They contain a lot of information that are transferred to the system using special readers. The use of RFID within supply chains is not recent, however many researchers continue to investigate this topic [34]. In fact, there are many areas of exploration, such as warehouse management, order management, inventory management and production scheduling [35].

In particular, greater attention comes from improving the traceability of products along the supply chain, accelerating shipment processes and optimizing the procurement phase [36]. Indeed, the adoption of this technology has several benefits such as cost reduction, process improvements and better quality of the service provided [12].

Many scholars have explored topics related to real time traceability thanks to the use of RFID, which guarantees constant monitoring of supply chains [37,38]. RFIDs are equipped with a magnetic chip that contain a significant amount of information and could uniquely identify each product using the Electronic Product Code (EPC) system for coding the different items. This tool is used to track products and reports counterfeits by checking tags and identifying any inconsistency. Indeed, the adoption of RFIDs has spread in the agri-food [39] and pharmaceutical [40] supply chain sectors because in these sectors it is crucial to collect product information during the entire transformation and transportation cycle. Recent regulations on perishable products require the traceability along supply chains in order to guarantee the safety and the quality of the products [41]. Certainly, using this technology involves costs which should be compared with the level of tracking detail required. Therefore, Aiello, Enea and Muriana [42] evaluated the implementation of a traceability system for perishable products such as fruit and vegetables and evaluated the relative profit. In this way, they compared the economic impact of the presence and absence of the traceability systems in order to establish an optimal configuration. In addition, RFID technologies can address the bullwhip effect by reducing information distortion through data acquisition and real-time communication [43,44]. In fact, there are several simulation studies conducted on this topic [45].

Although RFID technology carries out real benefits to supply chain management, the storage and transmission of data is not secure [16]. Indeed, data are often sent through systems such as Bluetooth or NFC which are not secure from an IT point of view and could be tampered with [46]. Moreover, the monitoring between multiple levels of actors is limited and requires the use of a supporting technology that permits authentication and certification between multiple parties. Therefore, the combined use of other technologies such as the IoT and blockchain is crucial and will be discussed in the next sections.

2.2. IoT for the Supply Chain Management

In 1999, Kevin Ashton introduced the term "Internet of Things" to connect the RFID technology with the Internet. Its main purpose was to collect and save data without the need of human interaction [47]. Today's concept of IoT enables the interconnection between various technologies that have the potential to revolutionize several fields, and especially the area of supply chain management [48,49].

Indeed, the supply chain is plagued by many issues such as effectiveness and efficiency of deliveries, continuous monitoring and close relationships between the partners [50]. The IoT establishes a network of physical objects connected to the internet, allowing continuous monitoring and detection by the stakeholders. Therefore, the adoption of this technology allows greater transparency and visibility of data, including the monitoring of temperatures, positions, humidity, pressure, exposure to light, broken seals [51]. Moreover, IoT reduces waste and costs [52,53]. From a technical point of view, the IoT is based on key technologies such as RFID or GPS and other data detection devices which are consequently sent to the Internet. In recent years, IoT applications have been widely used to locate, identify, monitor and track products and services in the supply chain [54]. Additionally, in this case, the technology has been used in many fields, especially in agricultural [55] and health [56] supply chains. The greatest challenges for the implementation of the IoT infrastructure within supply chains concern security issues, lack of standards, interoperability, hardware and software limitations [57]. Although the adoption of RFID technology, which is the main enabler of the IoT, began many years ago, problems persist such as cost, technology adoption, complexity, scale implementation and data management [58,59].

Furthermore, in most use cases two crucial issues are trust and privacy, which for most current scientific publications will determine the adoption of the IoT [60]. Trust affects both the consumer and the players involved within the supply chain. The use of the IoT will generate huge private data raising privacy worries [61]. This issue highlights the need for a security mechanism in order to increase the acceptance of the technology [62]. From a business perspective, trust is the foundation of information sharing. However, a possible solution to strengthen security, and therefore privacy, is the blockchain approach, much discussed in recent literature [63,64]. Decentralized management systems would bring greater security and facilitate data management in emergency situations [65]. Other risks relate to cyber-attacks on centralized databases that can limit the exchange of data between organizations. Finally, it is highlighted how all these issues conflict with the idealistic condition of a transparent global supply chain.

2.3. Blockchain for the Supply Chain Management

Blockchain technology has been hugely successful in the cryptocurrency industry [66]. However, recently the focus has shifted to other sectors, thanks to its decentralization, disintermediation and IT infrastructure security features [20,67,68]. Indeed, the blockchain solves several problems that plague the previously mentioned technologies. The blockchain is a secure, encrypted, immutable and accessible ledger on the network. These features are fundamental for the players who have to make important procurement decisions thanks to the tracking of their products [24,69]. The blockchain has been applied to many sectors of the supply chain such as maritime shipping [70,71], agri-food [72] and pharmaceuticals [73]. In fact, the technology can safely trace the products since the data in the distributed ledger remain immutable thanks to its consensus mechanisms.

In literature, blockchain applications in the supply chain are often linked to the use of IoT devices [74]. The reason comes from the lack of security using only RFIDs and IoT infrastructure [75,76].

Blockchains help identify new devices via IoT and, in this way, the network can extend to billions of devices without any intermediate server becoming a bottleneck in the process [77]. In addition, the optimization of the entire supply chain can take place through smart contracts in order to verify and allow actions by physical devices, increasing the security of the IoT platform [22]. A method to use both tracking tools and blockchain technology in transportation and logistics is associating them with smart contracts that can facilitate payments to suppliers once they perform their tasks such as delivering goods to a warehouse or after reaching a predefined specification in terms of quality and quantity [23]. In particular, the RFID tracking device at a buyer's warehouse is directly connected to the blockchain and once the buyer has received the goods from the supplier, it checks if the agreed quantity has been delivered and if there are no other conditions to be satisfied and the smart contract can automatically release the payment to the supplier [24]. Another implication of the combined use of IoT with blockchain is the improved control of the physical environment (e.g., pressure and temperature) provided for perishable food or biopharmaceutical products [18]. Smart contracts can be used along the chain to ensure that desired conditions are maintained during the whole production and transportation process. In addition, alert signals reporting any anomaly for the goods management along the entire supply chain could be implemented [24].

With the increasing rate of globalization, the development of transparent operations is crucial to ensure environmental sustainability and social responsibility. It has been argued that the use of RFID tags in supply chains promotes transparency. However, the validity and the security of the data cannot be guaranteed without the cryptographic capabilities of blockchains [78]. In this way, blockchains will be the main technology that facilitates traceability and therefore transparency in supply chains by monitoring environmental conditions [79]. Saberi et al. [80] argue that in order to ensure sustainability and ethical business conduct in supply chains, blockchains can help increase inventory traceability and transparency through the combination of RFID and IoT, while maintaining partner accountability on social and environmental aspects. Furthermore, blockchains could accurately track the carbon footprint of supply chains. Hence, blockchain offers a potential solution for managing shipments and relationships between partners in a sustainable and effective way [81].

2.4. Order Management with Digital Technologies

Order management has always been a topic of crucial importance in order to make the logistics of a company efficient and flexible, capable of reacting to unexpected changes in materials flow within the supply chain and keeping time required by business results [82,83]. The term order management refers to the process of receiving, tracking and fulfilling customer orders [84]. Specifically, the order management process begins when an order is placed and ends when the customer receives the goods. Managing orders means keeping track of the orders, managing customer data, having the history of the past orders, detecting customers who pay within the agreed terms, observing the customers who generate the highest volumes, identifying the frequency of the orders, checking the stock levels of the warehouse, monitoring the update of the product catalog [85–88].

However, inaccuracy of specifications, volume variability, frequent change requests, lack of clarity and security are among the most common order management process issues [89,90]. These problems are usually intensified by other problems such as: different information systems, manual errors, various communication channels and several management practices [84]. The combination of these challenges consequently leads to a lack of order traceability, a lack of customer visibility for supply chain actors and consequently a lack of trust and inefficient operations and transactions [83,91–93]. Therefore, an order management system can help to control costs and generate revenues by automating manual processes and reducing errors [94].

There are several management software that allow to automate the order management process in order to optimize the processing and fulfillment of requests, keep track of information along the supply chain, make demand forecasts based on historical company data [95,96]. However, within the Industry 4.0 paradigm, the introduction of new technologies such as artificial intelligence, big data, machine learning, IoT, drones and sensors will change the business processes [97,98]. By adopting these technologies, companies will be able to obtain significant advantages, as they will be able to guarantee information in real time and continuous monitoring [99]. Within an order management system, these technologies help to make accurate forecasts, prevent any delays due to lack of stock and therefore avoid losing customers [94]. One of the most important technological innovations of our time, which represents a real challenge to existing and consolidated systems, is the advent of blockchain technology which offers many benefits and opportunities to companies [100].

The application of the blockchain in Industry 4.0 has generated several innovative solutions that adapt to a new optimized, flexible and more efficient business model, based on trust and security of the stakeholders. This technology is particularly useful where final consumers are interested in discovering the origin and the provenance of the products purchased, while institutions need stricter controls in the supply chain and production processes [101,102].

The introduction of blockchain within the order management process influences many activities to be carried out in a different way, as it allows to solve a series of issues related to the traceability of the products, the transparency of the transactions, the information sharing and the enhancement of collaboration between the players in the supply chain [103–105].

3. Materials and Methods

Since there are few quantitative works on the real impacts and performance of blockchain within the supply chains, an exploratory research method was chosen, based on simulation. Exploratory research based on simulation study allows for a better understanding of the phenomenon that can lead to the development of new theories through processing [106,107]. The simulation approach used is based on discrete events and the tool adopted is Anylogic 7.0.2 Professional which provides a detailed analysis of all steps, is precise, reliable and easy to program.

Table 1 highlights, for each article, the area of the supply chain in which the study was conducted (e.g., logistics, order management, production and inventory) and the specific research methodology is identified, distinguishing between technical implementation articles such as the use of specific agent-based simulation tools, mathematical approaches that achieve quantitative assessments on the design, and conceptual articles based on logical approaches of the different processes without using numeric variables. As shown in Table 1, the articles highlighting the potential of the blockchain within the supply chains by the means of simulation are relatively few, despite how much this topic has been discussed in the last period [108–110]. The articles regarding the use of blockchain for the supply chains that evaluate the adoptions and limits using multi-criteria methods, literature analysis, case studies, empirical research or theoretical papers have been excluded from this table. Indeed, scientific research on blockchain for supply chains is in its infancy and its use should not only be tested in big international projects but also evaluate its role in small and medium-sized enterprises.

In particular, the studies focus mainly on the performance of the blockchain itself in terms of number of operations, architecture cost, speed of transactions, time consuming and transaction costs, but little is discussed on the impacts in terms of supply chain performance. Furthermore, performances that blockchain guarantees can improve several aspects of sustainability. Therefore, Table 1 shows how only seven articles assess the impacts that blockchain can carry out to supply chains. Below the work aims to explore, quantify and test what the literature has been promoting in this research in recent years. The ability to simulate and carry out a cost-benefit analysis is essential to achieve adoption by more participants and not just by multinational companies where profits are greater and international trade in goods occupy a significant slice of the market.

Table 1. Simulation studies of blockchain for the supply chains.

Reference	Area	Topic	Research Method	Technological Performance of Blockchain						Operations Performance of Blockchain for the Supply Chains				
				Implementation of Smart Contract	N. of Transactions	Architecture Cost	Speed of Transactions	Time Consuming	Transaction Costs	Time Performance	Costs	Stock Performance	Demand Volatility	Carbon Tax
[111]	Inventory management	Inventory strategy	Technical implementation	x										
[112]	Inventory management	Inventory strategy	Technical implementation	x			x		x					
[113]	Inventory management	Information sharing	Conceptual											
[114]	Logistics	Shipping	Technical implementation								x			
[115]	Logistics	Tracking	Conceptual											
[116]	Logistics	International trades	Technical implementation		x								x	
[117]	No specific area	System architecture	Technical implementation			x								
[118]	No specific area	Information sharing	Technical implementation			x	x		x		x			
[24]	Logistics	Shipping	Technical implementation	x										
[119]	Logistics	System architecture	Conceptual											
[74]	No specific area	System architecture	Technical implementation			x								
[120]	Logistics	System architecture	Conceptual											
[121]	No specific area	Tracking and Tracing	Technical implementation	x										
[122]	Order management	System architecture and performance	Technical implementation							x				
[123]	No specific area	Shipping and market demand	Technical implementation					x	x		x		x	x
[124]	No specific area	Risk management	Technical implementation							x		x	x	
[125]	No specific area	System architecture	Conceptual											
[126]	No specific area	Information sharing	Conceptual											
[127]	No specific area	Information sharing	Conceptual											
[128]	No specific area	System architecture and performance	Technical implementation	x										
[129]	Production	System architecture and performance	Technical implementation								x			
Total				5	1	3	2	1	3	2	4	1	3	1

Therefore, two scenarios were developed: a first traditional "as is" scenario without the use of blockchain and other technologies; a second scenario "to be" with the combined use of blockchain technology, smart contracts, IoT and RFID. To improve the state of the art of the existing literature and to validate the research, a simulation study was considered between three actors in the supply chain: the producer, the carrier and the final retailer. The traded goods concern Italian aged cheese which is a product subject to strict certification standards. The phases considered for both scenarios are: order receipt, order processing and order fulfillment for the producer, order shipment for the carrier and order check for the retailer. The same steps and actors are considered for both models to compare the results and provide a good representation of what the impacts of emerging technologies are. Secondary sources were used for data collection such as statistical reports (http://dati.istat.it/ (accessed on 1 June 2021)), consortium reports (https://ar.parmigianoreggiano.it/ar/ar.do (accessed on 1 June 2021)), scientific articles presented in Table 1 and specific modeling used in the literature [130]. Figure 1 shows the method and the steps that allowed the building of the two scenarios.

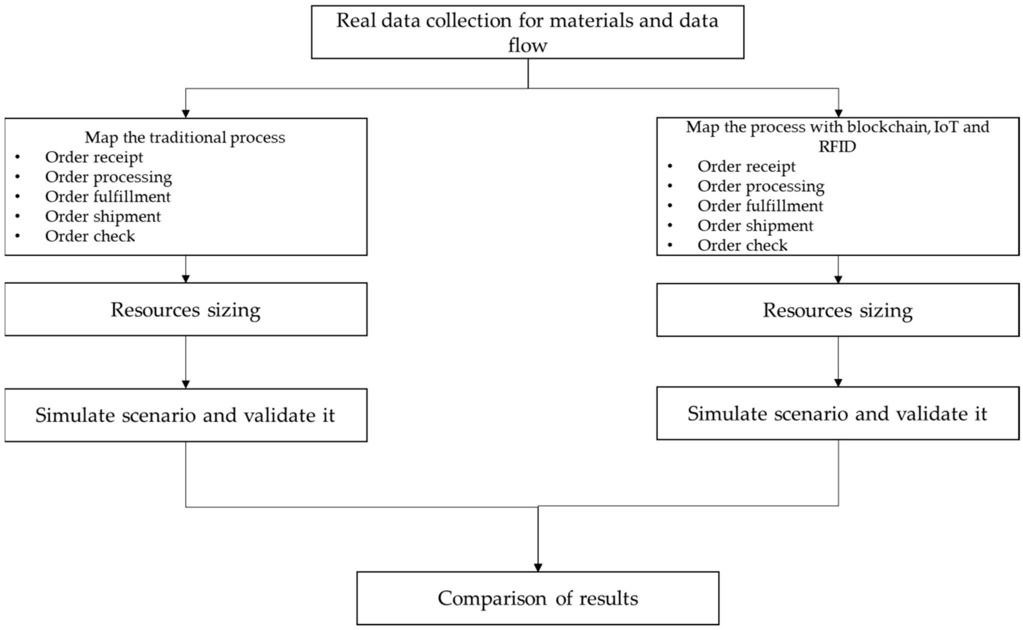

Figure 1. Schematization of the steps for modeling scenarios.

The assumptions implemented for both simulation scenarios consider the producer's warehouse having infinite capacity and therefore there are no out of stock problems. The order from the retailer arrives for the first time at the start of the model, and then every 3 days. In addition, four different products from the retailer are required in an order. The order management offices of both actors work from Monday to Friday for 8 h. Orders are managed following a FIFO (First In First Out) logic, which is widely adopted for food products.

A 5-year simulation was carried out to see what impacts the blockchain could have in the long term. Disruption events were introduced in the scenarios to verify their management both in the traditional scenario and when emerging technologies are considered. In particular, the disruption events are the occurrences for which the product does not comply with the requirements requested by the customer. For instance, a non-compliant product is identified when it has been subjected to a change in its temperature outside the imposed range, the opening of the seal, an incorrect documentation or the carrier does not reach the destination correctly. Finally, a level of service of 96% was considered and the probability of a disruption event occurring was the same for both scenarios. The two scenarios will be described in the following sections.

3.1. Design of the Simulation

In a simulation study, the following aspects must be specified: input parameters to vary, output parameters, duration of the warm-up phase and running time of the model, finally the number of replication [130]. The detailed parameters of our simulation study are shown in Table 2.

Table 2. Parameters of the simulation experiments.

Model Runtime	Varying Input Parameters	Output Parameters	Number of Runs
A total of 5 years. The simulation model starts without a warm-up phase.	Time for the order management of the producer Checking time for the retailer Time to handle disruption events	Average delivery time for perfect orders Average handling time for incorrect orders Average time saving	In total, 3500 replications for each model with relative precision 0.01

3.2. Traditional Scenario Description

In the traditional scenario the order management between the producer and the retailer is carried out through exchanges of e-mail, telephone calls and using Excel. The lack of standardization of the activities requires more time for managing practices. In this scenario, the orders between the two players are manual and therefore associated with human resources. Furthermore, due to the laborious manual activities required for each order, processing and response times are long. The producer receives the order from the retailer and authorizes it. First, the order management department checks the availability of the products in stock and then organizes the shipment. Therefore, the time for order management is carried out by a single employee modelled with a normal distribution. The activities included in this step concern the time required for the order receipt, acceptance, verification of products availability and preparation of the goods. When the order has been organized by the producer, the goods are placed in a waiting area, where the carrier will arrive. Thereafter, the carrier loads the goods on his truck and transport them to the retailer. Shipping time is modelled through normal distribution with a mean of 30 min. Even if this period is quite short and considers only retailers very close to the producer, the parameter is not affected by the use of the analyzed technologies and is equal for the two scenarios, thus allowing generalizability of the results.

Finally, the last step regards the quality control of the goods performed by the retailer. A resource of the retailer carries out a quality control of the orders arrived. In this case there are four disruption events such as non-compliant product due out of temperature, open seal, order not arrived at destination and documentation errors. Following the check, if it emerges that there are non-compliant orders, they are considered rejects and there will be the whole post-sale process of returning the physical and information flow that will allow the rejects to be reported to the system. In this case, the management process of incorrect orders is carried out through exchanges of telephone calls, e-mails and faxes. Figure 2 shows the traditional order management flow.

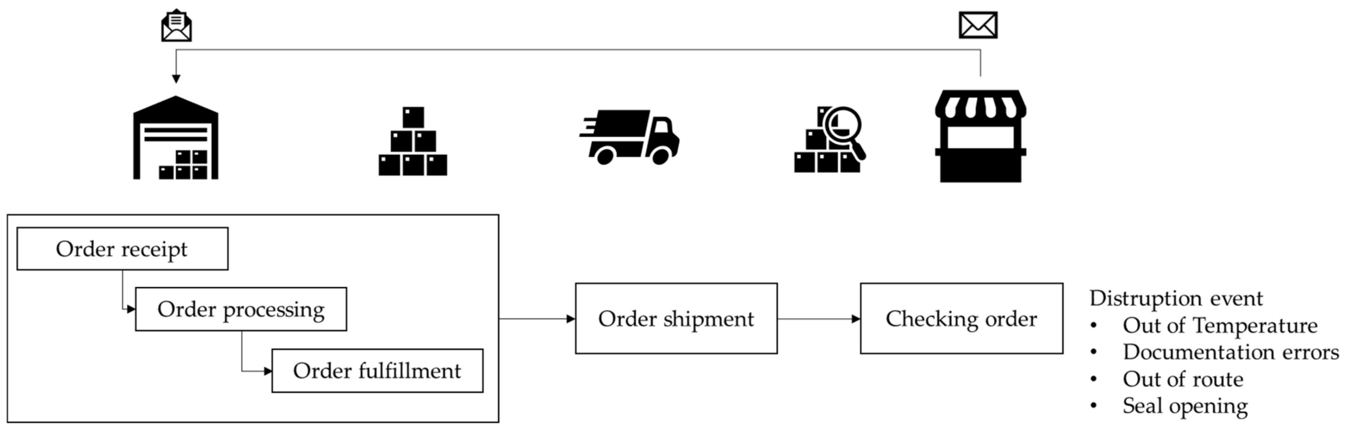

Figure 2. Schematization of the information and material flow in the traditional scenario.

3.3. Scenario with Blockchain, Smart Contract, RFID and IoT

The second scenario is based on the use of emerging technologies and aims to verify and compare the results achieved with the scenario one. In this case each actor has RFID sensors, IoT infrastructure and blockchain. In this way, the products are totally tracked and certified. In particular, RFID sensors are used to capture data relating to the physical conditions of the goods present in the producer's warehouse and in the carrier's truck. The IoT infrastructure is necessary to transfer data from the RFID sensors installed next to the goods to the distributed ledger. Finally, blockchain records the data securely and permanently and guarantees visibility of transactions to the players. In particular, the use of blockchain in this scenario solves the criticality of data management by recording it in a secure and immutable way without being easily tampered with because the transferred data is sent within a distributed ledger and not in a centralized server–client system [64]. Therefore, it is possible to constantly monitor changes in the state due to external factors. The introduction of smart contracts allows for automated order management between the two players. The retailer sends the order request by activating a smart contract. The smart contract provides the sender and the receiver with a passphrase. This passphrase will be associated with the order sent to the producer, while the retailer must provide it to the carrier on delivery in order to receive the goods. The authorization to accept the order or not is required thanks to the authentication on the blockchain platform with public and private key, therefore the accesses are authenticated and certified and there is no possibility to tamper with the system. In this scenario, the use of RFID technology, the IoT infrastructure and the blockchain allows real-time alignment of the real and virtual warehouses. Therefore, the order request and availability check time are reduced and they are modeled with a normal distribution. The shipping time of the goods by the carrier remain unchanged however for the second scenario there is the installation of the RFID and IoT technologies inside the truck to constantly monitor the product. Finally, upon arrival of the goods to the retailer, the carrier needs the passphrase from the retailer to unlock the order. In this scenario, since the goods are always monitored, the occurrence of a disruption event is promptly reported to the players in the supply chain and the goods immediately return to the producer who will send new goods. Furthermore, unlike the traditional scenario, the documentation is written in a digital format. The order management flow with the use of new technologies is shown below in Figure 3. In order to highlight the differences of the two scenarios, Table 3 shows the probability distributions used as input for the two simulation models.

Table 3. Data input parameters of each simulation scenario.

Data Flow Management				
Input Parameter	**Phases**	**Probability Distributions**	**Traditional Scenario**	**Blockchain, IoT and RFID Scenario**
Order management (P)	Order receipt Order processing Order fulfillment	Normal distribution (Mean, SD)	(8 h; 1 h)	(4 h; 30 min)
Order management (C)	Order shipment	Normal distribution (Mean, SD)	(30 min; 5 min)	(30 min; 5 min)
Order management (R)	Order check	Triangular distribution (Min, Max, Mode)	(20 min; 40 min; 30 min)	-
Disruptions event management	Out of temperature	Triangular distribution (Min, Max, Mode)	(10 min; 25 min; 20 min)	-
Disruptions event management	Documentation errors	Triangular distribution (Min, Max, Mode)	(10 min; 30 min; 15 min)	-
Disruptions event management	Out of route	Triangular distribution (Min, Max, Mode)	(1 h; 2 h; 1,5 h)	-
Disruptions event management	Seal opening	Triangular distribution (Min, Max, Mode)	(6 min; 15 min; 12 min)	-
Disruptions event management	Wrong passphrase	Triangular distribution (Min, Max, Mode)	-	(1 min; 5 min; 3 min)
% Level of service			96%	96%
% Out of temperature			1%	1%
% Documentation errors			1%	-
% Out of route			1%	1%
% Seal opening			1%	1%
% Wrong passphrase			-	1%

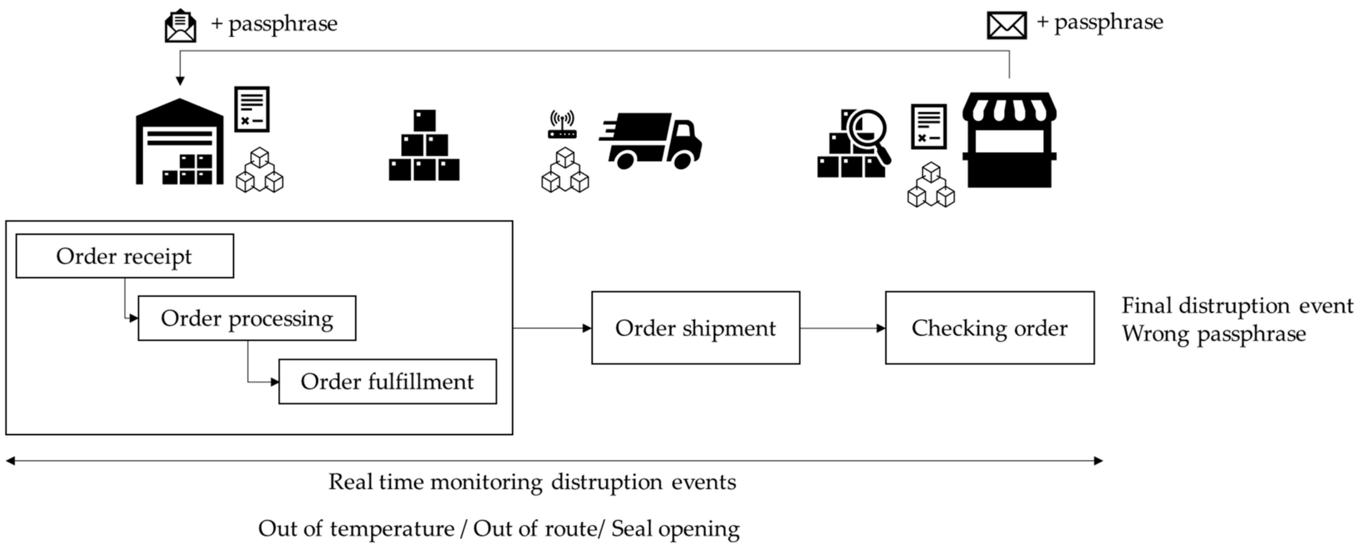

Figure 3. Schematization of the information and material flow in the scenario with blockchain smart contract, IoT and RFID.

4. Results

Table 4 compares the effects on operations in the two scenarios over 5 years. To fairly compare the results, a level of service of 96% was assumed for both scenarios because the disruption events had the same probability of occurring as these events do not depend on the use of new technologies. Having assumed the same percentage for the disruption events, the average number of non-compliant orders is the same for each case. The number of orders processed in the traditional scenario is lower than in the second one. The reason comes from greater efficiency in automated order management using smart contracts and continuous monitoring throughout the entire process. The average time for perfect orders is defined as the time from the retailer's order launch to the producer until the quality check is completed.

Table 4. Key Performance Indicator for each scenario.

Key Performance Indicator	Traditional Scenario	Scenario with Emerging Technologies	Time Saving (h)	Time Saving (min)	Δ%
Average number of perfect orders	582	584	-	-	-
Average number of out of temperature	6	6	-	-	-
Average number of opening seals	6	6	-	-	-
Average number of out of route	6	6	-	-	-
Average number of documentation errors	6	-	-	-	-
Average number wrong passphrase	-	6	-	-	-
Average time perfect order (h)	41.50	40.97	0.59	36	1.4%
Average time out of temperature (h)	41.59	40.73	0.86	52	2.1%
Average time opening seal (h)	41.78	40.53	1.25	75	3.0%
Average time out of route (h)	42.94	40.77	2.18	131	5.1%
Average time documentation errors (h)	42.00	-	1.11	66	2.6%
Average time wrong passphrase (h)	-	40.89			
Average time disruption events (h)	42.07	40.72	1.34	81	3.2%
Average total time saving (h)	41.96	40.76	1.19	72	2.9%

In the same way, the disruption events are defined as the time that elapses from the launch of the retailer's order to the complete management of the waste which can depend on different factors such as: out of temperature, documentation errors, out of route, opening seal or entering wrong passphrase code. In the traditional scenario, the evaluation of disruption events can only be carried out during the check order phase when the retailer controls the goods arrived. Instead, in the second scenario, the goods parameters and documents are checked in real time and if problems arise, the goods are withdrawn from the market and management is optimized. In both cases, the time between the launch of the order and the arrival of the goods to the retailer is approximately 2 days.

The results show that there is a 3.2% reduction in the average time for handling disruption events. In addition, there is a 1.4% reduction in the average handling time for perfect orders. The average time saved for processing an order is about 72 min. The results show the impact that the second scenario can have on the management of the disruption events.

Sensitivity Analysis

A sensitivity analysis is conducted below to consider the influence of structural parameters on the model outputs. There are different types of sensitivity analysis, depending on the target of the analysis [131]; therefore, factor prioritization was chosen to study the influence of different parameters of the model. Three structural parameters were considered: average delivery time to retailer, time to reorder and number of products requested in an order. In particular, the values of the variations of these parameters are shown in Table 5.

Table 5. Results of the sensitivity analysis: percentage changes in time savings.

Parameter	Value	% Time Saving
Average delivery time to retailer	20 min	1.4%
	25 min	1.6%
	35 min	1.3%
	40 min	4.1%
Time to reorder	1 day	9.7%
	2 days	8.2%
	4 days	7.0%
	5 days	3.7%
Number of products requested in an order	2	5.1%
	3	6.0%
	5	8.4%
	6	9.8%

The results of the sensitivity analysis show that the average delivery time to retailer has a significant influence on time savings when the order shipment phase consumes more time, while variations for short times are irrelevant. This relationship is intuitive since the greater the distances traveled and the greater the real-time detection, the greater impact on the time saved. As for the time to reorder goods, its influence decreases as the time intervals increase. In fact, the shorter the reorder times, the more the order management unit has difficulty in processing orders quickly. However, a solution with blockchain and smart contracts will allow to automate and standardize many operations and reduces the workload on employees. Finally, the number of products required in an order has a strong impact on the time saving percentage as the greater the types of product to be managed, the more the order management office will have to check different types of stocks in the warehouse. However, using technologies such as IoT and RFID there is a constant alignment between the real and the virtual warehouse. Therefore, this solution facilitates the order management unit for the goods management.

5. Discussion

The blockchain significantly reduces the number of manual operations and increases their speed. The order entry process starts when the retailer makes an order request to the producer. Consequently, two scenarios were analyzed: one traditional and one with blockchain, smart contract, IoT and RFID. The analysis of the traditional scenario shows that managing an order requires manual work to check the status of an order. In addition, there are several problems of coordination and management of incoming orders. For example, the non-standard use of order acquisition systems can generate data management problems. Multiple manual inputs and duplication of data explain why an order spends a lot of time in the system. Furthermore, in the traditional scenario, the stocks of the real warehouse are checked periodically and, for this reason, there is a waste of time in the evaluation of stocks. In this scenario, when the goods reach the retailer, there is a quality control by an operator. When a disruption event occurs, the times for their management are extended. These activities can only be carried out upon delivery of the goods and cannot be constantly monitored. Hence, managing these events is time consuming.

The second scenario begins with the request by the retailer using a smart contract via the entry interface of the blockchain platform. In this case, the method of order receipt takes place in a standardized way. Furthermore, the IoT infrastructure and RFID sensors aligns the real and virtual warehouse in real time and shows the current presence of the goods. Since the goods are tracked in all the phases, when a disruption event occurs the goods are immediately withdrawn and the management time for inefficiencies is reduced by 3.2%.

This study shows the impacts that integrated and interconnected technology solutions have on the order management and tracking phases. The use of blockchain and smart contracts allow the automatic order processing through a series of advanced rules, already predefined and set. The more advanced the rules, the more orders are handled automatically. In addition, the network participants know the history and status of an order to have a safe and complete visibility.

The use of blockchain could allow new solutions and create new sets of rules to make the system more intelligent, automated and efficient. Comparing the two scenarios, an overall increase in operational efficiency in the order management process and in the disruption event management is observed when new technologies are integrated. In fact, 81 min were saved for managing disruption events and in addition an average of 72 min were saved overall for managing each order. Furthermore, thanks to the second scenario, inefficiencies have been eliminated, such as the consolidation of a single platform for receiving orders. Visibility to the different participants is improved thanks to the rules defined by the blockchain platform. The number of orders managed is increased and the product status is checked in real time. The disruption events management is no longer a responsibility of the retailer, but rather of the technology that controls the entire system. Regarding the average times for each disruption event, the one that has the greatest impact is when the truck goes out of the route. Indeed, in the second scenario the retailer constantly tracks his shipments.

Therefore, the contribution of the work was to quantify the convenience of adopting the two different scenarios. From a timing point of view, scenario two has had some improvements but not drastic. The feasibility of this solution depends on other qualitative features such as information security, transparency, visibility, reduction of workload, efficient management of non-compliant orders, the use of a data exchange platform common to several actors. However, scenario two may be impractical due to the high implementation costs, the costs of the various technologies adopted and costs for qualified personnel.

In summary, it is possible to discuss the benefit that the second scenario carries out to each participant. The producer and the retailer exchange information on a single platform. Therefore, the inaccuracies of the specifications, the requests for frequent changes, the lack of clarity presenting in the first scenario are reduced using blockchain and smart contracts. In fact, the timing for the order management of the two scenarios is different. Thanks to the information sharing within the distributed ledger, there is greater traceability of orders, better visibility for participants and consequently greater trust in operations without the use of other intermediaries. Therefore, thanks to the security, integrity and data traceability features of the blockchain, the collaboration between the producer and the retailer improves. Furthermore, in the second scenario, RFID sensors, IoT infrastructure and blockchain are present within the producer's warehouse. Therefore, this system architecture allows to capture the data of the stock in the warehouse in real time using RFID sensors, transfer the data on the blockchain using IoT infrastructure and finally record it permanently and securely within the blockchain. This configuration saves time for the order management unit and reduces the time required for the control, identification and registration of the product position in the warehouse carried out by an operator. In addition, other data such as temperature, humidity, production date can be recorded within the blockchain. In this way the order management unit knows the status of the product and can ship the goods, guaranteeing quality to the retailer. Therefore, the producer by exploiting these technologies can increase his reputation towards his customers.

In the carrier truck there are the same technologies owned by the producer. Therefore, the carrier is constantly monitored. This allows to easily respond to the occurrence of disruption events. Therefore, if these events occur, the carrier is aware of them and does not deliver the damaged or non-compliant products to the final retailer. However, the producer having visibility of the events on the distributed ledger can automatically schedule a new dispatch for the undelivered goods through a set of rules created specifically by the smart contract. In this way, the retailer has trust in the quality of the goods delivered by the producer. In addition, the carrier does not have to deliver the documentation as it is completely digitized and allows for paper savings while respecting the environment. Delivery takes place safely and reliably thanks to authentication via passphrase that uniquely identifies the receiver of the goods.

Finally, the retailer has the advantage of requesting the goods through the blockchain platform with the activation of a smart contract. In this case, the retailer is guaranteed the quality of the goods thanks to the complete traceability and visibility provided by the blockchain. Furthermore, for disruption events, the carrier is not responsible for carrying out a quality control on the delivered goods because it is constantly monitored and the producer is responsible for shipping and reverse logistics.

Therefore, the time advantage resulting from this solution is only one of several positive factors in order management and disruption events management. In this study it is possible to identify processes that improve economic, social and environmental sustainability. The combined use of these technologies allows to trade avoiding fraud or opportunistic behavior. The second scenario solves the communication issues between the actors, allows reduced delivery times, reduces the potential waste of time due to human error and the presence of unnecessary bureaucratic activities. The information sharing and the transparency allows the producer to increase the reputation towards the end customer and to achieve greater profits in the future.

Furthermore, for social sustainability, transparency allows the products monitoring from origin to the final consumer, in terms of information such as: date, location, quality and certifications. In general, counterfeit foods are a threat to public health. Effective food supply chain management is essential for solving food safety problems. In particular, the use of blockchain is crucial to know the origin of the product and certify its provenance. Finally, as regards the aspects of environmental sustainability, in the second scenario the paper documentation is replaced by the digitization of information which allows a reduction in the waste of paper for bureaucratic procedures.

5.1. Practical and Sustainability Implications

The development of digital technologies for information and communication (ICT) has allowed the creation of new processes and new organizational and operational methods that reduce waste of time, costs and resources, consequently optimizing quality. Therefore, the various waste reductions have a significant impact in terms of sustainability within the supply chains. The ICT has granted, on the one hand, the enhancement of the materials and information flow management; on the other hand, the possibility of optimizing logistic operations in a sustainable way using software, geolocation systems, modern storage systems with digital flow traceability procedures [132,133]. In addition to technological solutions for a sustainable supply chain based on packaging [134], there are other management improvement solutions, such as: elimination of unnecessary travel and the optimization of container loading plans [135]. The practice of scheduled loads reduces environmental impacts, decreasing the wait for transporters during the pick-up and delivery phases and improving the overall efficiency of the service. Furthermore, the delivery rationalization service concentrates the number of deliveries to be made to a group of customers in one shipment, offering the benefits of reducing costs and carbon emissions [136]. In this case it is essential to use order management systems that allow the rationalization of loads. Furthermore, there will be no paperwork as everything is digitalized improving the environmental aspects [137,138].

For a sustainable supply chain, the use of blockchain is essential to securely track transactions, ensuring product transparency. Blockchain technology can have a significant impact on the sustainability of the entire supply chain [81]. In particular, this technology can help keeping product data and various changes on the platform. Each product can have different transactional characteristics recorded in the blockchain platform, which can also store historical data of products. These operations can show the origin of the product, the quality, the quantity, the owners and the time, in order to better manage the recyclability and the carbon footprint [119,123,139]. This information allows customers to be aware of the safe and sustainable production and transportation of the goods. In addition, the blockchain always tracks the position of each product managed by the company. This is essential to improve reverse logistics operations by making them faster and cheaper. Using blockchain technology, product life cycle analysis can be completed using current product data in an accurate and real way [80,140]. In addition, by mapping the journey of the product along the supply chain, the blockchain can accurately identify the carbon emissions of each company, highlight pollution and depletion of energy resources, and thus define incentives for companies that are more careful to the environment. Thanks to the collaboration between the different participants, it is possible to better organize transport activities and reduce greenhouse gas emissions [80,141]. Indeed, by exploiting blockchain and smart contracts, it is possible to combine environmental protection and control initiatives through the careful monitoring of production parameters such as energy resources and processing of raw materials [142].

Finally, the traceability of the information ensures companies to provide their employees with just human rights and that work is carried out safely. Therefore, trust is a fundamental requirement for social sustainability. In addition, especially in the food supply chain, monitoring ensured by the blockchain allows food retailers and producers to respond quickly to complaints and other safety concerns, thus reducing the spread of food-borne diseases [74].

In particular, the study highlighted how the combined exploitation of these technologies achieves time advantages. From the economic sustainability point of view, blockchain allows reduced delivery times, faster monitoring of goods and can reduce potential losses due to human error and the use of unnecessary bureaucratic activities. In particular, technology can improve productivity, reduce the time spent controlling processes and increase competitiveness in B2B companies. However, on the side of social sustainability, the digital transformation changes the economy and therefore jobs. The blockchain automates many processes and workflows causing the disappearance of intermediate jobs, which add to traditional unemployment. Obviously, the resolution of this problem is faced with a radical change of obsolete skills and professions. Companies that implement these systems may structure secure relationships with partners by reducing audit costs due to manager oversight.

5.2. Managerial Implications

This document provides clear guidelines for managers to implement emerging technologies in their fields. Although the process tested in this case was the order management process and disruption events management, the approach can be extended to other supply chain processes such as warehousing, shipping, product development, relationship management. Furthermore, these processes could be combined with optimization strategies such as Just in Time, Vendor Managed Inventory and Collaborative Planning, Forecasting and Replenishment.

As seen in the simulation scenario, blockchain greatly simplifies entire business processes and makes the entire supply chain more responsive and efficient. Through this technology, companies can increase their levels of efficiency, verification and automation [143]. Consequently, blockchain technology has a time-saving advantage and can simplify many business activities and eliminate inefficiencies that result from outdated processes. In addition, it can improve efficiency and optimize resource allocation. Thanks to the absence of intermediaries, the problems related to transaction costs are solved, therefore time and waste are reduced. Human error is reduced thanks to the automation of operations and rapid data sharing. In addition, costs related to product quality verification, business process distortion and ownership transfer between partners are minimized [142].

Furthermore, with blockchain the supply chain risks between partners are reduced. The completeness, transparency of information and transactions on the blockchain are the key factors required to establish a relationship of trust between the players. Hence, the increased efficiency and accountability leads to significant improvements to the company reputation [9,144].

It is essential to proceed with the digital transformation to achieve the sustainability and performance objectives that the new guidelines of the Industry 4.0 and sustainability plans required [125,145]. Companies must take advantage of innovation and transformation of business processes to gain a competitive advantage [146]. The use of blockchain and its real-time visibility of data would allow managers to set customized rules in the order management routines and provide faster responses to customers.

Considering the sustainability aspects that arise from the adoption of digital technologies, managers must take the initiative and apply these emerging technologies for better controlling the supply chain. Certainly, revolutionizing business strategies can generate problems during the first times. However, migrating to new tools can carry out benefits in partner relationships and business reputation. Indeed, a company that adopts these technologies can achieve greater profits in the long term. Trust and data sharing is a fundamental step in moving towards the fourth industrial revolution and improving global sustainability.

Why is the adoption of this technology slow? First of all, technical skills and knowledge are still limited for managers and therefore they are afraid to use these new technologies [80]. Furthermore, the introduction of blockchain requires high investments in hardware, software and resources capable of using them [25]. Indeed, a cost–benefit analysis for small and medium-sized enterprises is still unclear [114]. Moreover, the blockchain requires agreement between the parties and some organizations are reluctant to share critical information [80]. Another challenge is the change of regulations present in the trade of goods: indeed, states should clarify the regulatory and legal frameworks to protect the actions of the partners in the chain [18]. In the current market there are several blockchain platforms, therefore a common standard should be reached for the complete integration of the different partners [80]. In addition, blockchain should integrate with other IT systems to improve business performance. Finally, the technological performance of the technology is the main bottleneck of the implementation. To date, there are still few real cases and many of the projects are under development.

6. Conclusions and Limitations

This document has examined the effects that the combined use of technologies such as RFID, IoT and blockchain have on order management and disruption events management. The literature on blockchain and supply chains is growing exponentially [24]. However, little is discussed about the real quantitative benefits from an operations management perspective [112,124]. This research shows the time savings that the combined use of emerging technologies carries out to today's supply chains. The study highlights how the traceability of the entire supply chain and continuous monitoring can bring benefits in economic and environmental terms. The main benefits of the distributed ledger relate to visibility, transaction security and traceability [144]. Therefore, this work contributes to the literature as it aims at verifying whether the qualitative characteristics of blockchain declared in the literature achieve real benefits and advantages.

Furthermore, the simulation of the cheese supply chain takes on symbolic significance. Many traceability works are focused on agri-food products as more and more consumers need detailed information about the product they buy. The use of blockchain guarantees the certification and authentication of the final product without the use of external intermediaries. Blockchain fundamentally changes the way people operate from manual functionality to the use of a predefined set of rules.

This research is based on a single in-depth simulation study that compares two different scenarios. However, the results can be easily generalized to other processes in the supply chain, since some activities are common to multiple processes such as receipt, modification and order processing. Furthermore, the study does not evaluate the costs related to inefficiencies and does not compare the costs of the architecture and the human and digital resources between the traditional scenario and the scenario with emerging technologies. In particular, implementation costs, technology management costs, personnel costs are not quantified. Further future research will investigate and add these aspects to clarify the feasibility of the two scenarios.

In addition, the time to complete an order is short. Indeed, the impacts would be more significant if the simulation assessment were conducted on international shipments. In this way the difference between the "as is" and "to be" scenario would be clearer. Future research must focus on studying new ways of managing supply chain operations with emerging technologies. Researchers should integrate emerging technologies with optimization strategies and theories that are currently difficult to implement such as trust between partners and collaborative relationships [147]. Moreover, an additional level of investigation could consist in comparing other scenarios with modern IT and blockchain systems. In this case, the risks of non-standardization are reduced and it would be interesting to evaluate the actual benefits or disadvantages of the two solutions. The simulation concerns the orders management between three actors; therefore, it would be interesting to evaluate the orders management with many players in the network. A further improvement of this simulation study is to evaluate the impact on the environment of the combined use of technologies. For example, thanks to blockchain technology it is possible to track the carbon emissions of trucks permanently and safely. Therefore, by capturing this information it is possible to control the trucks that consume the highest carbon emissions. Furthermore, future research could investigate simulation models that simulate the behavior of transporters when they have deliveries that are expiring and evaluate the different impacts of emissions using tracking technologies. Finally, a possible development could concern exploring the timing in international deliveries, where there are multiple external actors and factors, and evaluating the additional benefits deriving from the adoption of these technologies.

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