An Autonomous Inventory Replenishment System through Real-Time Visibility and Collaboration based on IOT and RFID Technology

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Abstract: - Supply chains consist of interconnected nodes where the movement of materials is dictated by the exchange of information. The more effectively each node gathers and disseminates information to its upstream and downstream partners, the more efficient the material flows become, hence enhancing the efficiency of the supply chains. An essential method for analyzing a supply chain is to concentrate on how inventory meets demand at each point. Insufficient supply leads to lost sales and reduced customer satisfaction, potentially driving customers to seek alternatives, resulting in future lost sales. Therefore, firms are embracing technologies like IoT and RFID to gather data and facilitate more efficient sharing, resulting in improved information and material flow. Data sharing boosts visibility, hence fostering collaboration among supply chain partners. Certain studies in the literature have employed IoT and RFID technology to enhance inventory visibility, while others opt to share the gathered data with their partners to improve inventory replenishment efficiency. Nevertheless, this paper presents an autonomous inventory replenishment system that utilizes IoT technologies to replenish inventory through real-time visibility and collaboration. The system facilitates the sharing of real-time data, such as inventory levels, with supply chain partners. Additionally, it enables automatic collaboration by allowing partners to take action based on the shared data, such as activating orders to replenish inventories at various points in the supply chain. To assess the suggested approach, we conducted an inventory replenishment simulation, comparing it to previous studies in terms of the amount of lost sales incurred when confronted with unpredictable demand. Across the 3 utilized datasets, the proposed approach demonstrated a 22.9% reduction in lost revenue compared to its nearest competition. These findings demonstrate a direct correlation between the utilization of technology in inventory replenishment processes and the speed at which inventory is refilled, as well as the reduction in lost sales.

Key-Words: - Supply chain, IoT, RFID, inventory replenishment, visibility, collaboration.

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1 Introduction

A supply chain consists of many organizations, [1], working together in a collaborative setting to satisfy customers' demands. To enhance collaboration, visibility needs to be improved. To this end, RFID and IOT are two of the main technologies being used, [2]. RFID and IoT technologies make it possible to increase asset visibility, enhance information content, speed up the flow of information, and improve inventory management, [3].

Visibility helps actors achieve an enhanced overview of material flows within complex supply chains, [4], [5], [6]. According to [7], there are three basic "tiers" or levels of supply chain visibility in general:

Tier 1: This level represents the visibility of a company's internal operations and processes.

Tier 2: This level represents the visibility of a company's suppliers and their activities.

Tier 3: This level denotes the visibility of a company's suppliers as well as any other participants in the supply chain.

There exists an additional degree of supply chain visibility, known as the fourth tier, which involves the integration of data from the three previous tiers. This integration allows for a comprehensive understanding of the entire supply chain from start to finish. The objective of the suggested system is to attain the visibility of the fourth tier.

Visibility is currently an enabler for supply chain relationship collaboration, business planning, and decision support, [8]. The concept of collaboration can be categorized into three interrelated dimensions: (1) Information sharing; (2) Decision synchronization; and (3) Incentive alignment, [9].

A supply chain's performance is as good as its ability to satisfy customers' demands. For this reason, in this paper, we focus on inventory replenishment as a measure of how visibility and collaboration enhance supply chain performance. In the literature, higher technology adoption is related to better inventory replenishment. The longer it takes for a store to realize that the stock level of a product has hit the reordering threshold, and the longer it takes to formulate an order and submit it to the supplier, the longer the ordered products will take to arrive at the store and the higher the potential loss of sales will be. The proposed system eliminates all these times by showing real-time inventory levels and triggering automatic orders that are accepted and fulfilled right away throughout the supply chain, guided by a set of rules that the supply chain partners agreed upon. Theoretically, the system eliminates the time to obtain the information (by monitoring inventory in real-time), to make the decision (decide what product to order and how much), and to act based on the decision made (submit the order, accept it, and fulfill it without delays). The system integrates all supply chain nodes (suppliers, transporters, warehouses, and stores) and can share information and trigger orders to replenish inventories throughout the supply chain.

This paper is organized as follows: in the next segment of our introduction, we present the related works. In the third section, we present the system architecture and modules. In the fourth section, we present the simulation and results. Finally, in the last section, we give a conclusion to the conducted work.

2 Literature Review

Prior research in the literature has attempted to improve the inventory replenishment process by augmenting visibility and/or collaboration in various stages of the process. To comprehend the disparities between the prior and the proposed system, it is imperative to first grasp the fundamental stages involved in an inventory replenishment operation. The timing of these steps is contingent upon the technology employed and the extent of visibility and coordination among supply chain participants. The greater the level of automation in a system, the faster the inventory replenishment process will be. The specific durations for each stage are listed in Table 1.

While some of the systems that we will discuss in this section do not have inventory replenishment as their main focus, they improve it indirectly thanks to their architecture and logic. Consequently, we will compare them to the proposed system by their ability to improve the inventory replenishment process.

Table1. Inventory replenishment times sequence

time	description
1	The time duration between hitting the reordering point and being aware of it.
2	The time of formulating a purchase request
3	The time of formulating an order
4	The time to get approval and signatures on documents
5	The time spent on reviewing the order before submission
6	Time spent on order submission and confirmation
7	The time between the supplier receiving the order and starting fulfillment
8	Just-in-time order and transport preparation (no delays)

In [10], an inventory management system using RFID technology to improve inventory searching and counting is presented. However, since it does not allow for real-time monitoring, it does not eliminate time 1 but only reduces it while the proposed system eliminates all the 8 steps. In [11], [12], [13], systems that use IoT and RFID technologies to track and monitor inventories in different industries (food, construction, etc.) were presented. These systems eliminate the need to check the inventory to know at which level it is, thus eliminating the first time in Table 1. In comparison, the proposed system eliminates the time of all 8 steps as it conducts them instantaneously.

In [14], [15], systems using RFID and IoT technologies to make products available in a just-in-time manner are presented. These systems aim to have goods ready for pickup by a transporter to eliminate any delays that can make the inventory replenishment process take longer. This means that these systems eliminate the time of the last step (Table 1) of the inventory replenishment process. In contrast, the proposed system eliminates the time needed for all steps.

In [16], [17], a system allows for a different approach to inventory replenishment called vendor-managed inventory (VMI), in which the supplier (or warehouse) manages the store's inventory. Thanks to RFID and IoT technologies. The supplier or warehouse can track the store's inventory levels and conduct the replenishment process by deploying orders to fill the retailer's inventory, while the retail store only checks the order content and approves (or disapproves) the order. Thus, this system eliminates the time needed to perform all steps (Table 1) except times 5, 6, and 8. While this is a good attempt to optimize the inventory replenishment process, it is still outperformed by the proposed system as it eliminates all 8-time durations.

In [18], the presented system uses IoT technology to track and replenish consumables in customers' home appliances like coffee machines and washing machines. When the stock is low, the supplier automatically sends out a shipment to replenish his customers' inventory. This approach is called smart replenishment. While it is used in a different scenario than the proposed system as it is directed to consumers, it is the most similar to the proposed system in the literature up to date. In comparison to the proposed system, this system eliminates all time durations in Table 1 except the last one, while the proposed system eliminates all of them.

Table 2 shows a direct comparison between the previous systems and the proposed system in terms of inventory replenishment steps optimization.

Table 2. Comparison between the previous systems and the proposed system

		[10]	[11], [12], [13]	[14], [15]	[16], [17]	[18]	The proposed system
1	The time duration between hitting the reordering point and being aware of it.	R	E	N	E	E	E
2	The time of formulating a purchase request	N	N	N	E	E	E
3	The time of formulating an order	N	N	N	E	E	E
4	The time to get approval and signatures on documents	N	N	N	E	E	E
5	The time spent on reviewing the order before submission	N	N	N	N	E	E
6	Time spent on order submission and confirmation	N	N	N	N	E	E
7	The time between the supplier receiving the order and starting fulfillment	N	N	N	E	E	E
8	Just-in-time order and transport preparation (no delays)	N	N	E	N	N	E

Where R denotes "Reduced", E denotes "Eliminated", and N denotes "Normal".

While systems in the literature tried to eliminate the time of one or multiple steps in the quest for better inventory replenishment, the proposed system eliminates the time it takes to do all steps since it makes decisions automatically for all supply chain parties following a set of rules on which they have agreed beforehand. This approach drives the time it takes from information to decision to action to zero while pushing visibility and collaboration between supply chain partners to unprecedented levels.

3 System Architecture

In this paper, we propose an IoT-based real-time supply chain visibility and collaboration system. The system uses RFID and IoT technologies to render objects in the supply chain traceable. An object is defined in this work as any equipment, vehicle, material, or product tagged with an RFID or GPS tag. RFID tags are used for indoor tracking, while GPS tags are used for outdoor tracking. The proposed system collects data from RFID and GPS tags with the help of RFID readers and satellites, respectively. Then, collected data is made available either directly, or after processing, to partners following their functions and their clearances.

The proposed system's objective is to allow real-time collaboration in supply chain management by increasing visibility between supply chain partners. Practically, the system tracks manufacturing, inventory, order processing, and demand to trigger orders automatically at each node of the supply chain.

The system considers a supply chain made of suppliers, transport providers, warehouses, and retail stores. Figure 1 illustrates the considered supply chain model.

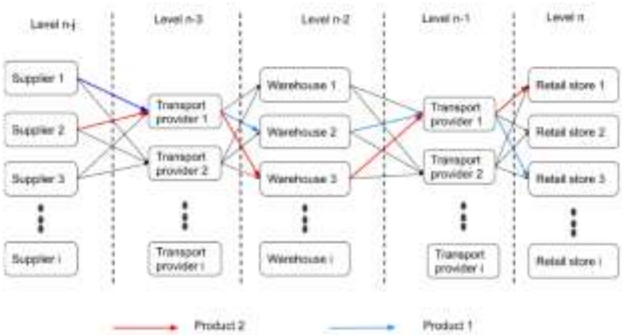

Fig. 1: Considered Supply Chain Model

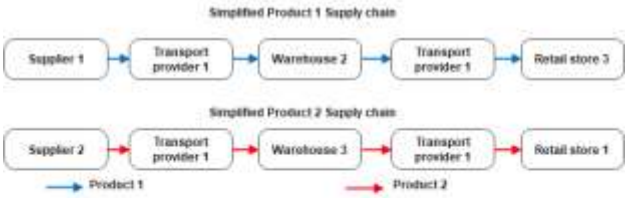

Fig. 2: Simplified product-based supply chains model

Each node of the supply chain can collaborate with more than one other node of the upstream or downstream supply chain, depending on the products pulled by the retail stores.

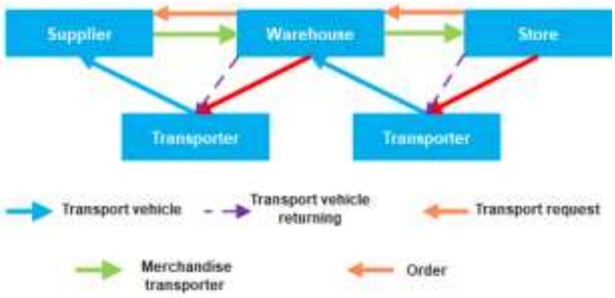

Fig. 3: The considered supply chains model

The system's architecture, as shown in Figure 4, consists of four layers: the data collection layer, the data warehouse layer, the data processing layer, and the user interface layer.

3.1 Data Collection Layer

This layer is responsible for collecting data from each node of the supply chain to store it in the data warehouse layer. Data collection in the proposed system is done in four separate node types (suppliers, transport providers, warehouses, and retail stores).

3.1.1 Supplier Data Collection Layer

We consider that a manufacturer possesses one or multiple manufacturing lines for one or many products. Manufacturing lines consist of a series of inventory and work posts. At each inventory (raw materials, work in progress, and finished goods) and each work post, one or more RFID readers are placed to read the tagged materials flowing in and out of the inventory or work post. This results in better tracking of materials at each step of the manufacturing process.

3.1.2 Transport Provider Data Collection Layer

We consider that a transport provider possesses a fleet of vehicles of varying capacities. Each of these vehicles is traceable via GPS. Thus, the position of the vehicle is known at all times. In addition, because of the integration of the transport provider into the proposed system, the user can know at any time what merchandise the vehicle is carrying and how much.

3.1.3 Warehouse Data Collection Layer

We consider that a warehouse is equipped with readers strategically placed to read every RFID-tagged SKU in the warehouse. Operators are equipped with Personal Digital Assistants (PDA), on which close-range RFID readers are mounted, to verify products' identities before picking. When a product is no longer read by storage placements' readers and is read by operators' readers, it is then concluded that it was picked. When a product is read by the packing zone RFID reader, it is concluded that it is in the packing zone, and when it is no longer read by the packing zone reader (after being read at first), it is then concluded that it left the packing zone and is ready for shipment. If a product is no longer read by storage placements' readers and is not read by any operator's PDA, it is then concluded that it is not tagged correctly (meaning either the damage or absence of the RFID tag).

3.1.4 Store Data Collection Layer

We consider that a retail store is equipped with RFID readers in-store and in stock, strategically positioned to be able to read all tagged products present in its space. When a product's RFID tag is read and separated from it, the system concludes that the product is bought.

3.2 Data Warehouse Layer

This layer is responsible for storing all the data needed for system operation. It stores static data like product identities, tags' identities, readers' identities, vehicle identities, etc. In addition to dynamic data like RFID readings, GPS positions, orders' statuses, etc.

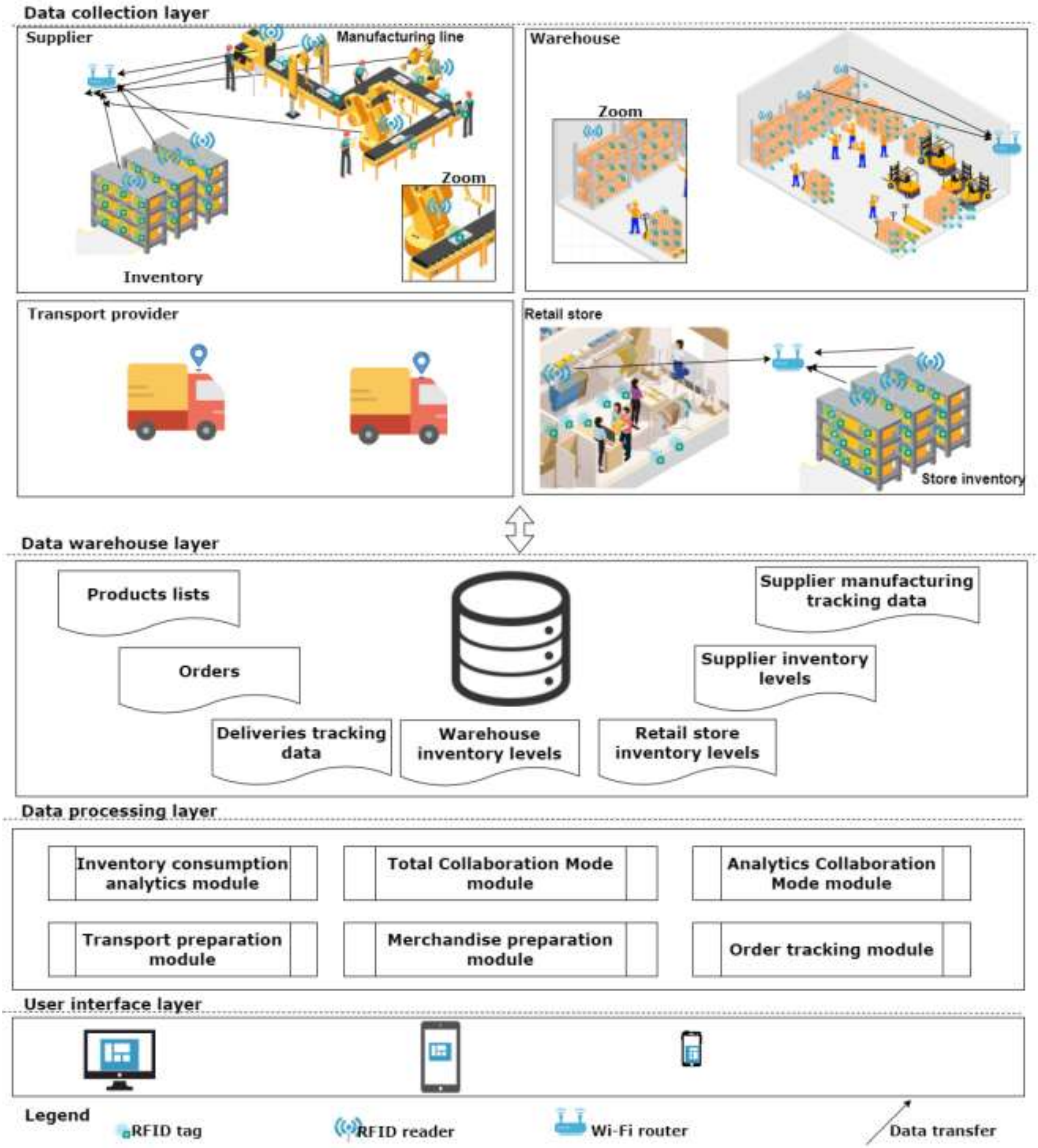

Fig. 4: System architecture

3.3 Data Processing Layer

3.3.1 Inventory Consumption Analytics Module

This module, which is used at each inventory within the supply chain, is responsible for tracking inventory consumption, as shown in Figure 5. It works using a KPI called inventory consumption per time unit (i.e., hour), which indicates the speed at which the products' stock is being drained. This information, when visible to other upstream partners, can be used to adjust manufacturing planning and transport schedules. The following formula can be used to determine how much inventory was consumed over a certain period, [19], [20]:

$$IC = SI - P - EI$$

IC: Inventory Consumption
SI: Starting Inventory

P: Purchases
EI: Ending Inventory

The original value of the inventory that a corporation possesses at the start of the period under examination is referred to as "beginning inventory." The term "purchases" denotes the total cost of merchandise that the business purchased during the specified period, including both direct.

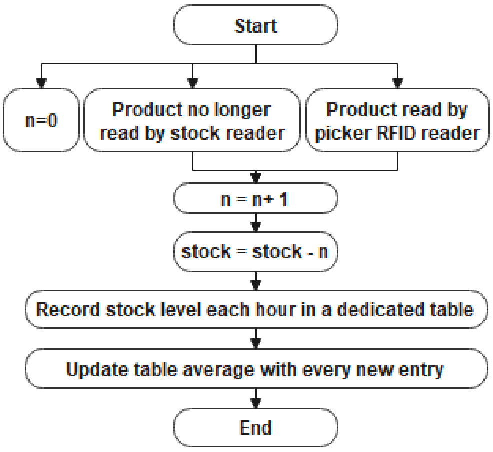

Fig. 5: The inventory consumption algorithm

3.3.2 Collaboration Modes Module

These modes define the level of the collaboration of partners on the same supply chain:

-Total collaboration mode: in which all partners collaborate not just by sharing data but also by permitting the system to act based on that data to place automatic orders, prepare merchandise, and transport. To operate, this mode needs to calculate the inventory threshold on which an order for a product is placed. To do this, the system calculates how much time the remaining inventory will take to drain based on the current inventory draining speed. To explain how this module works, we consider the Figure 2 supply chain model. When, for example, the retail store's product's inventory level reaches a certain threshold, which can be defined by the user or defined automatically by the system, this module first checks if there are no incoming shipments of that same product with the desired quantity and then places an order at the warehouse level. If the warehouse inventory of that same product cannot satisfy the placed order, this module checks if there are any incoming shipments of that product from the supplier to the warehouse with the desired quantity; if not, it then places an order at the supplier level. If the product, at the supplier level, is ready to be shipped, this module reserves a transport volume for the order to be shipped and prepares the orders to be shipped in the meantime. When the order is shipped, the warehouse is notified of the approximate arrival time to prepare reception, and the transporter (between the warehouse and the retail store) is also notified to prepare shipping to the retail store.

The retail store is also notified to prepare reception.

Having all partners connected to a single system and allowing this level of instant information sharing makes it possible to streamline the workflow and reduce wasted time in all the processes of the supply chain. The algorithm of this module is presented in Figure 6.

-Analytics collaboration mode: This collaboration mode includes all of the total collaboration mode features except the automatic decision-making (i.e., order triggering). In this mode, partners collaborate solely by sharing data, allowing better visibility in the supply chain to foster better and more informed decisions. Partners can consider the data shared with them and adapt their processes; however, the system does not trigger orders automatically for them, and they are not expected to act on the shared data by their partners. This mode is specifically useful as a stepping stone towards the total collaboration mode, as the latter can be seen as a big step that companies are most of the time reluctant to take. It allows them to try a lighter level of collaboration, which can encourage them to transition to total collaboration mode later. and indirect purchases. "Ending Inventory" represents the value of the inventory that the corporation still owned at the end of the period.

The amount of inventory consumed over the specified period may be calculated by deducting the value of ending inventory from the total of beginning inventory and purchases. This calculation is useful for evaluating the company's inventory management strategies and can help with decisions about future inventory levels.

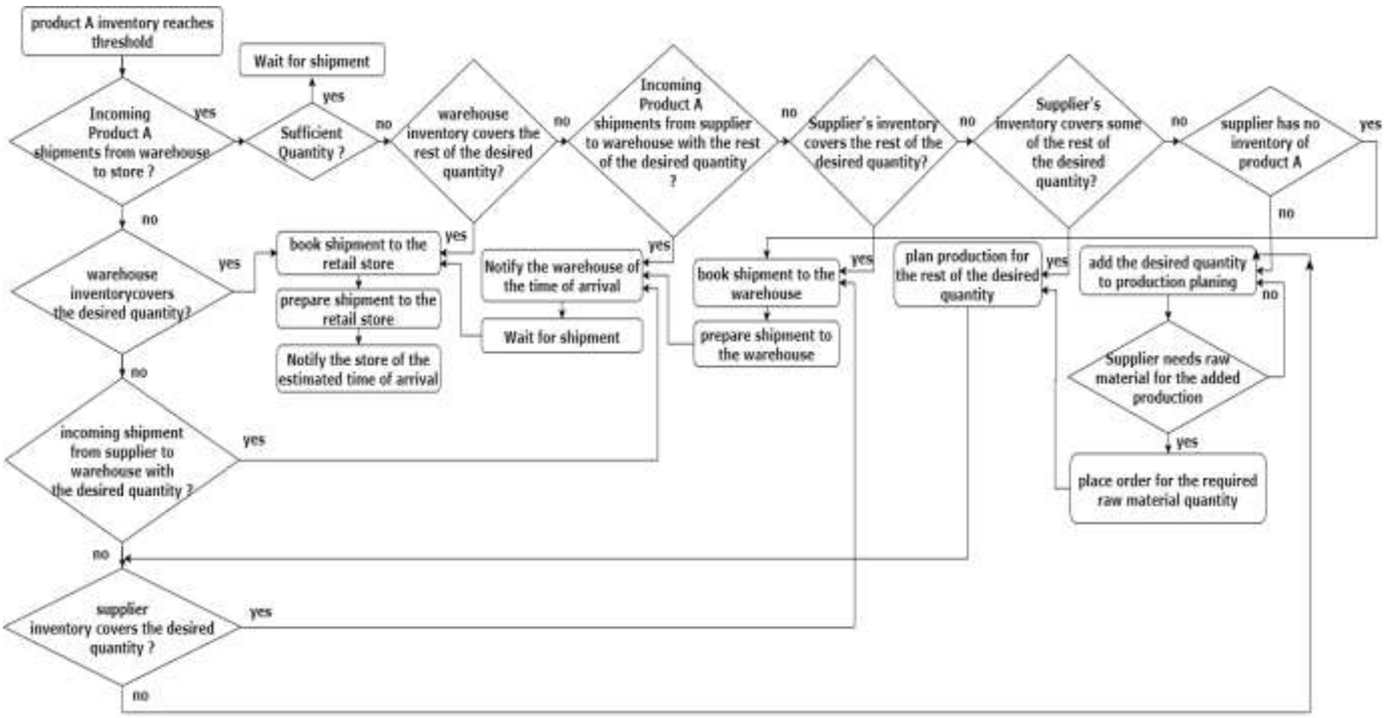

Fig. 6: Total collaboration algorithm

3.3.3 Transport Preparation Module

This module is responsible for transport preparation for orders between the supplier and the warehouse, as well as between the warehouse and the retail store. The transport provider, who is a part of the collaborative system, makes transport available when goods are ready to ship. The transport provider is notified beforehand so that the time between transport availability and merchandise readiness is minimal. In the beginning, this module uses an estimated order preparation time. Afterward, it uses the average order preparation time, which is deducted from the list of order preparation times recorded in the system. Figure 7 presents this module's algorithm.

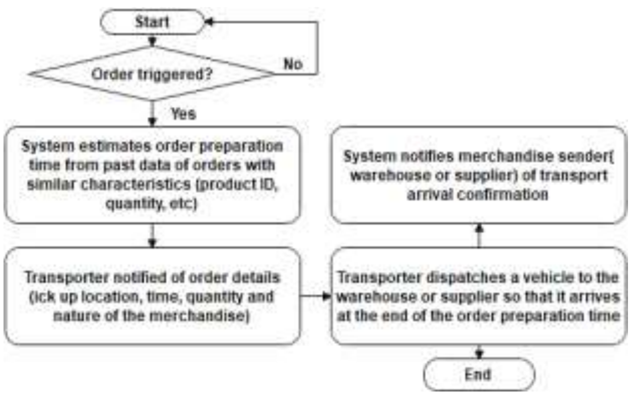

Fig. 7: Transport preparation algorithm

The transport provider is notified of the nature, the volume of the merchandise, the time the transport needs to be ready, and the delivery deadline.

3.3.4 Order Preparation Module

This module is responsible for tracking and calculating order preparation time. Order preparation starts when an order is assigned to order pickers and consists of two phases:

- **Picking:** starts from the order assignment to the reading of the order RFID tags by the packing area's RFID reader, which means delivery of the order to the packing area. The algorithm for the picking submodule is presented in Figure 8 below.

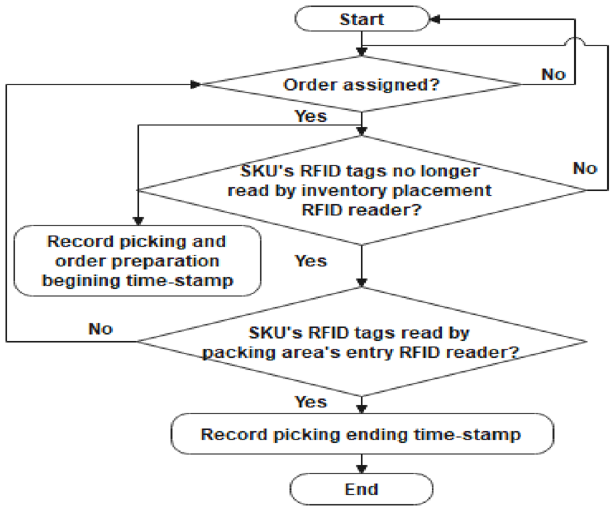

Fig. 8: Picking time tracking

- **Packing**: It starts when an order's RFID tags are read by the packing area's entry RFID reader and ends when they are read by the packing area's exit RFID reader.
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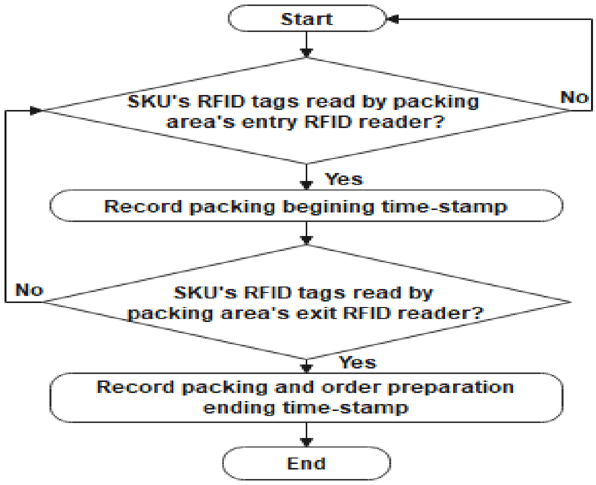

Fig. 9: Packing time tracking

Then, it is concluded that the order is ready for shipping. This procedure is presented in Figure 9.

3.4 User Interface Layer

The system is conceived in a web environment. User interfaces are accessible using computers. Users can be either system administrators, managers, team leaders, or operators. The interface displayed for each type of user is different depending on their roles and privileges. System access is granted following authentication. Administrators have reading, writing, and system-modifying privileges. Managers can access process-related information.

4 Simulation and Results

To evaluate the proposed system against the previous works in the literature, we have to define a metric of comparison. Each work in the literature chose a different metric to evaluate their proposed system: inventory turn-over rate, inventory holding costs, order processing costs, etc. In addition, the results for each work are specific to its approach, its objectives, the model of supply chain considered, and the data used, which is in some cases undisclosed. That is why, to compare the previous systems with the proposed system, we first define the supply model as the one shown in Figure 3, and then we estimate, with the help of a time grid, how much time each inventory replenishment step would take. This allows us to have an estimate of how much time each system would take to replenish inventory concerning the others and would help quantify the differences between each system.

Inventory replenishment times vary from one supply chain to another and from one product to another. Depending on the case, it can take days, weeks, or even months. However, to simplify the comparison between the systems, we will consider a control scenario where an inventory replenishment system that does not use RFID or IoT technologies counts inventory by subtracting sales from the existing inventory at the end of the work hours each day. If the new inventory level is lower or equal to the reordering threshold, the store submits an order at the warehouse level and gets the order delivered the next day after work hours. This means that inventory replenishment in this control scenario takes 24 hours.

This means that any improvement in inventory replenishment time can make the order arrive inside or before work hours. This means that the newly available inventory can satisfy the demand that comes after the order arrives at the store.

Table 3 shows the time estimations for each step of the inventory replenishment process based on the scenario mentioned before.

Table 3. Inventory replenishment steps' time durations based on the control scenario

Step	Description	Time (H)
1	The time duration between hitting the reordering point and being aware of it.	3
2	The time of formulating a purchase request	1
3	the time of formulating an order	1
4	the time to get approval and signatures on documents	2
5	the time spent on reviewing the order before submission	0,5
6	time spent on order submission and confirmation	0,5
7	the time between the supplier receiving the order and starting fulfillment	2
8	just in time order and transport preparation (no delays)	1

Table 4 shows the time estimations for each step of the inventory replenishment process for each system type.

Table 4. Estimated inventory replenishment time durations by system type

		Systems Type						
		Control system (h)	**Just in time pick up (h)**	**Easier inventory monitoring (h)**	**Real-time inventory (h) monitoring**	**VMI + IOT & RFID (h)**	**Smart Replenishment (h)**	**The proposed system (h)**
	Previous works		**[14], [15]**	**[10]**	**[11], [12], [13]**	**[16], [17]**	**[18]**	
Inventory replenishment time durations per step	1	3,0	3,0	1,0	0,0	0,0	0,0	0,0
	2	1,0	0,0	0,0	0,0	0,0	0,0	0,0
	3	1,0	0,0	0,0	0,0	0,0	0,0	0,0
	4	2,0	2,0	2,0	2,0	0,0	0,0	0,0
	5	0,5	0,5	0,5	0,5	0,5	0,0	0,0
	6	0,5	0,5	0,5	0,5	0,5	0,0	0,0
	7	2,0	2,0	2,0	2,0	0,0	0,0	0,0
	8	1,0	0,0	1,0	1,0	1,0	1,0	0,0
	Total (h)	**11,0**	**8,0**	**7,0**	**6,0**	**2,0**	**1,0**	**0,0**

Since, in the literature, many systems eliminate the time it takes to do the same steps (Table 1, Table 2), we will group them into one category, estimate the time needed for each step considering the proposed scenario, and calculate how much improvement each system category makes compared to the system that does not use RFID or IoT technologies. This way, we can compare the proposed system against the previous systems in terms of inventory replenishment times optimization.

For all the system types, we assume that they have automatic document generation capabilities. That is why for all types the time to generate a purchase request and order is 0.

Table 3 serves as a grid to estimate how much each system type optimizes the inventory replenishment process by automating certain steps. These estimations are based on the scenario and parameters described below:

- A retail store that is open to customers 10 hours continuously from 8:00 am to 6:00 pm all days of the month.
- In the control scenario the normal time between hitting the reordering point and inventory replenishment is 24 hours. The delivery arrives at 7:00 pm (after work hours) of the next day which means it cannot be purchased until the day after. This means that in a case of stockout, the demand of the next day is not satisfied and the store incurs lost sales that day.
- The time gap between hitting the reordering point and making an order is estimated to be 11 hours. This means that while using the proposed system the delivery should arrive 11 hours earlier at 8:00 am.
- The time between the order's arrival at the store and the product's availability on the shelf is 0.
- The store's backend starts work at 7:00 am to receive incoming deliveries and place the products on shelves.
- The store reordering point is 300 units and the ordered quantity is 500.
- 3 non-consecutive demand datasets, month-long each with different bursts of demand patterns and strength.
- The store average daily demand not accounting for unpredictable demand bursts is 121 for month 1, 130 for month 2, and 130 for month 3.
- Demand is uniform throughout the day. If a day's demand is 120 units then in each hour out of the 10 hours of work will be 12 units sold.

In the control scenario, the order is made at 7 p.m. after work hours and arrives the next day after work hours at 7 p.m., which means that the inventory can only be purchased the day after. However, for each system type using RFID and IoT technology to reduce the times in Table 3 and Table 4, the order arrives during work hours and can be purchased right away. The bigger the optimization the system offers, the earlier the new inventory will arrive and the lower the lost sales will be in case of a stockout. For example, systems in the real-time inventory monitoring category can make orders arrive 5 hours before the control scenario, which means that the order arrives at 2 p.m.

We simulated with Microsoft Excel and VBA based on the algorithm in Figure 6 for every system type using the 3 demand datasets for each type. Based on the simulation rules, no stockouts occurred on the warehouse and supplier levels, so we will focus on the retail store.

The goal of this simulation is to compare the systems grouped by type against the proposed system in terms of lost sales with 3 different demand datasets. The results of the simulation with dataset 1, dataset 2, and dataset 3 are shown in Figure 10, Figure 11 and Figure 12, respectively.

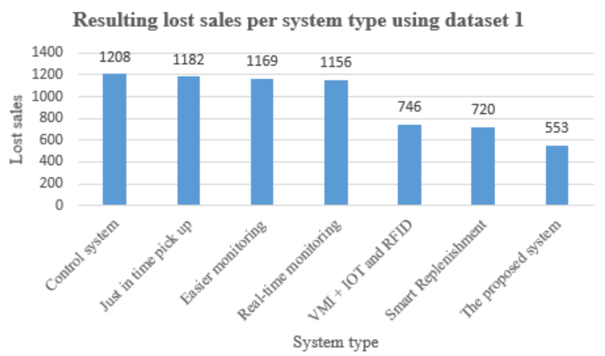

Fig. 10: Resulting lost sales per system type using dataset 1

More technology adoption to optimize the inventory replenishment steps the better the reduction in lost sales.

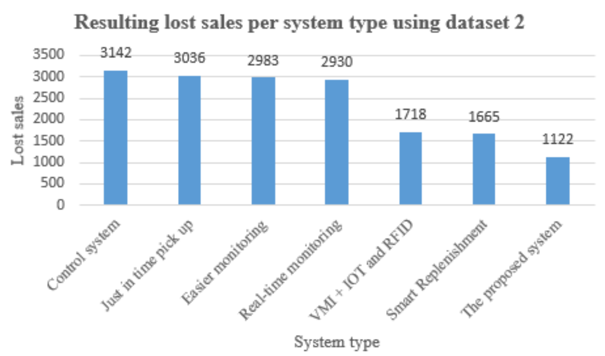

Fig. 11: Resulting lost sales per system type using dataset 2

The control system and the proposed system are two extremes, with the control system using almost no RFID or IoT technologies while the proposed system adopts these technologies in every step of the inventory replenishment process.

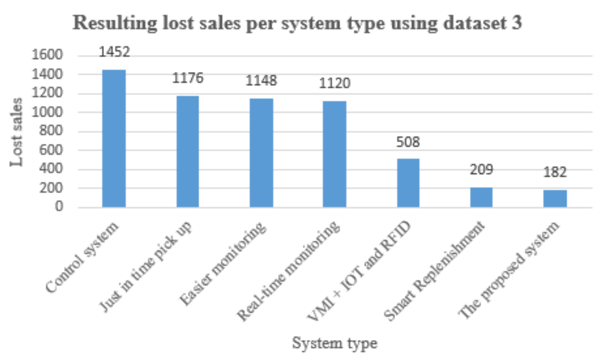

Fig. 12: Resulting lost sales per system type using dataset 3

The 3 datasets used in this simulation have random demand spikes with different magnitudes. However, the results show consistency in how the use of RFID and IoT technologies optimize the inventory replenishment process and reduce lost sales.

5 Discussion

The graphical representations in Figure 10, Figure 11 and Figure 12 show a clear connection between the duration needed for replenishing inventory and the effect on lost sales. The incorporation of technology in inventory replenishment plays a crucial role in decreasing inventory replenishment durations and, as a result, lowering lost sales.

Among the discussed works, the smart replenishment approach, as described in reference [18], is notable for being the second most efficient technique in reducing lost sales. This methodology has notable efficiency, but, it is surpassed by the proposed solution, which surpasses it by fully eradicating the periods linked to each stage of the inventory replenishment process.

The adoption of the proposed system produces compelling outcomes, demonstrating its superiority in optimizing inventory replenishment. Compared to the control system, it shows a significant average reduction of 68.66% in lost sales. This highlights the significant influence of integrating RFID and IoT technology into the supply chain, simplifying procedures and guaranteeing a more prompt and adaptable system. In a direct comparison with its closest competitor, the smart replenishment system, the suggested solution shows a significant 22.9% reduction in lost sales. This margin of improvement highlights the edge of the proposed system, positioning it as an efficient frontrunner in inventory replenishment within the context of unpredictable demand patterns.

These findings confirm both the effectiveness of the suggested approach and the practical advantages of adopting sophisticated technology in the supply chain. The deliberate elimination of time-consuming inventory replenishment steps results in a notable decrease in missed sales, hence improving the overall efficiency of the supply chain.

6 Conclusion

While material flows are of the highest importance in a supply chain, they are controlled by information flows. That is why, companies and researchers alike are looking for methods and ways to increase visibility and collaboration in a supply chain.

IoT and RFID technologies are two of the main technologies adopted to enhance visibility between supply chain partners. However, visibility and collaboration are hardly quantifiable. For this reason, we chose to evaluate the proposed system's inventory replenishment capabilities in terms of lost sales when faced with unpredictable demand.

After dissecting the inventory replenishment process into 8 steps that take significant time when not adopting IoT and RFID technology. It became clear that the more steps done with the help of IoT and RFID technologies the lower the inventory replenishment time. To compare the proposed system with existing works in the literature. We grouped the works that used these technologies to optimize the same steps into one category and then compared them against the proposed system.

Inventory replenishment is a process that includes many steps (Table 1, Table 2 and Table 3). These steps can be eliminated or done automatically if RFID or IoT technologies are adopted. The more steps done with the help of these technologies the quicker the inventory replenishment process. While the proposed system optimized all the steps in the process of inventory replenishment (Table 1, Table 2 and Table 3), the previous systems in the literature only optimized some of them

The results showed 22.9% less lost sales on average using the proposed system compared to its closest competition and 68.66% less lost sales on average compared to the control case in which IoT and RFID technologies are not adopted.

From a future perspective, we will work on the development and employment of the system to collect real-world data, as well as adjust the system to the challenges that we might face in the deployment phase if needed.

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Conflict of Interest

We hereby certify that this manuscript is an original work and is not currently under review by any other publication. No substantial part of this work has been published or is under review elsewhere.