



An ECR-driven Distributed Retail RFID System

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Abstract

Efficient Consumer Response, commonly referred to as ECR, is being increasingly put at the center of the retail industry strategies. Retailers are now collaborating with all the supply chain stakeholders in order to reach an optimal service level. In this regard, new emerging wireless technologies are currently offering new opportunities to support ECR-driven logistics information systems. RFID is among these technologies, which extends the potential of wireless identification, and represents a potential replacement to old-fashioned identification systems such as the barcode system in retail sales. This paper presents a new RFID-based cost efficient approach for pervasive retail sales. The suggested new system architecture is based on aisle-level scanning and new event management procedures at the level of RFID middleware. It also discusses the impact of deploying such systems in retail stores, such as supermarkets, on the overall supply chain. The motivation behind such approach is not only reducing the number of RFID readers compared to existing RFID based systems, but providing customers with an interactive shopping experience and fast checkout and bill payment, making this new approach transparent, efficient and cost effective.

Key Words

ECR, middleware, RFID, supply chain management.

I. INTRODUCTION

RFID (Radio Frequency Identification) encompasses the collection of information and communication technologies aiming at the wireless identification of objects and individuals [1]. From

supply chain management to kids tracking systems, the domains of application of this technology are in a continuous spread [2]. In the field of retail sales, the current applications use RFID readers embedded in shopping carts, additionally, the products available on the shelves are not being recognized by those systems [3]. The limitations of those systems' approaches prompted a considerable interest in research towards more pervasive information systems in retail sales.

This paper's main contribution to the current state of the art research in the field of distributed RFID retail management systems, [3]-[5], is the presentation of a new architecture focused on the detection and tracking of moving products and shopping carts inside the supermarket or shopping area. This architecture differs from previous research by focusing on aisle-level instead of cart-level scanning, by relying on RFID reader antennas placed at the endpoints of each aisle instead of the shopping carts.

Consequently, customers are able to make their purchases by putting products on their shopping carts, read the corresponding cart items and current bill on the cart's interactive touchscreen, and benefit from directions to specific aisles inside the shopping space.

The checkout is then an easy last step in the purchase process since the customer's bill is already computed and available for payment. The waiting time lost in long checkout queues is hence eliminated. In addition to the highly improved customer experience, the number of RFID readers is lowered and their maintenance costs diminished. The LANDMARC algorithm, which is based on the KNN algorithm, is used to locate the moving products in the shopping space using the received signal strength of the RFID tags attached to them. Products are then assigned to the shopping carts they belong to using clustering algorithms. This paper also discusses the impact of such an approach on supply chain management on the macro-level, and on the retail management at the level of the store.

The present paper is organized in the following manner. The system architecture is presented in Sec. II along with the system design in Sec. III. Sec. IV details the problem formulations and methodology, followed by the obtained simulations and results in Sec. V. The impact of the system deployment on the supply chain is discussed in Sec. IV along with the ECR role in the system's robustness. Finally, Sec. IIV concludes the paper.

II. SYSTEM ARCHITECTURE

The goal of establishing the system's architecture is to construct a bridge between the IP-based domain and the physical level RFID domain. The present architecture's role is to route instructions and data from one layer to the other [6]. This section presents the system architecture in this pervasive RFID retail sales application along with the description of the different layers.

Fig. 1 illustrates the data and instruction flow between the different system layers. As soon as the RFID tags attached to the products are detected (observed) by the reader layer, those signal observations are processed by the device manager, middleware, and event manager in order to maintain the integrity of the data at the information system level.

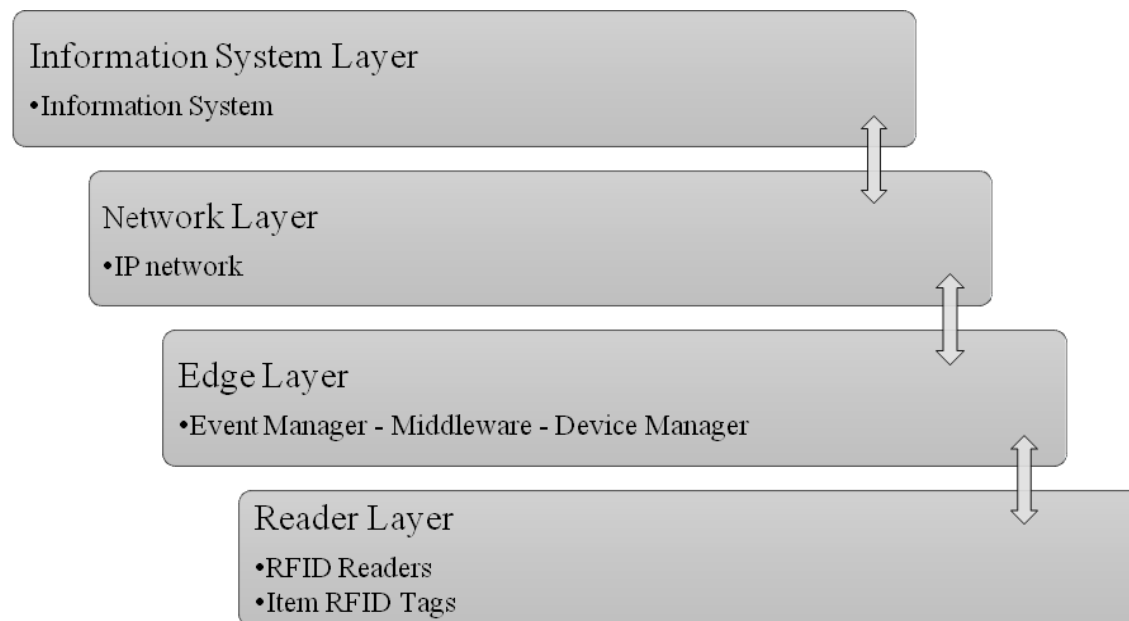


FIGURE 1: SYSTEM ARCHITECTURE.

A. Reader Layer

The reader layer is composed of RFID readers and tags. In this layer, communication takes place following specific protocols presented in the system design. The tags in the shopping carts and on the shelves are detected by the readers, which can identify different parameters concerning the observation of the tags such as tag identity and observation time.

B. Edge Layer

Once an observation is performed using the RFID reader antennas deployed at every aisle, it is necessary to filter the data collected in order to eliminate redundancies and correct irrelevant data. The edge layer is considered as a pre-processing stage where the filtering and smoothening of the data is performed in order to construct events that can be understood by the higher-level layers of the architecture.

The events manager contained in this layer filters the data and transforms it into events that fit in contexts. The innovative added value of this paper lies in the event management and context forming during shopping. When users' carts circulate in the shopping space, the tagged products are detected by the event manager and are identified as part of a context, which is in this case a purchase. This context is formed when tags have the same direction and velocity after a significant number of observations.

C. Network Layer

In order to communicate the purchase context to the system core with the corresponding data, the event manager communicates the events to the IP network. This layer represents the link between the low level data and the higher-level system, i.e., the information system. It ensures identifier resolution in a way that keeps each item recognizable by the system in terms of name, price, description, and others.

D. Information System Layer

The information system layer represents the application or set of applications visible to the administrator or the users. It constitutes the management system where business logic is implemented. It encompasses the database or data warehouse, the desktop, web, or mobile applications for administrators and users. In our context, the carts' touchscreen are also part of the information system so as to interface with the customers.

This system is required to have a constant access to the current transactions being made, to information about users still in the process of purchase, and all other business significant information.

III. SYSTEM DESIGN

In order to implement such a system, its design is required to specifically describe the related components. The focus is being directed towards the components of the system architecture such as the RFID tags and readers, middleware, and network enabled services.

3.1. Tags

Minimalistic RFID systems consist of RFID tags and readers. A typical RFID tag consists of a coil or an antenna and an integrated circuit for memory storage. A wide range of passive, Semi-passive tags, and active tags exist in the market.

Active tags comprise an internal power supply, which creates cost and service time issues. Semi-passive tags include a battery to supply the circuit with a battery in order to broadcast. However, they draw power from the reader to communicate. Passive tags operate with no internal power supply; instead, the reader induces a current in the tag circuit [4], as shown in Fig. 2.

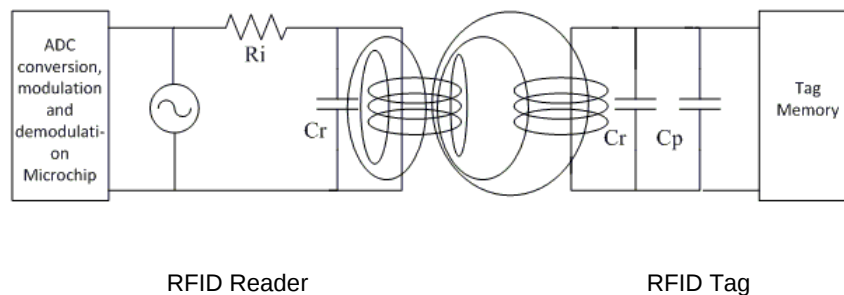


FIGURE 2: RFID READER AND TAG SCHEMATIC.

For this application, due to the considerable amount of tags deployed in the shopping space and to the nature of the products, the RFID tags should be compact-sized and easily embedded in the products packages, with a significant low cost. Additionally, the operating range of the tags should be adapted to the read range of the RFID reader antennas, i.e., to a significant fraction of the standard aisle length for the concerned shopping space.

Passive RFID tags represent the right choice for pervasive RFID system thanks to their compact sizes and the reader's level supplied power. Modern RFID tags operate in the HF and UHF bands, i.e., approximately in 13 MHz and 900 MHz respectively.

When the passive tag encounters radio waves emitted by the reader, the tag antenna forms a

magnetic field. Power is then drawn from the reader by induction of potential in the tag antenna, supplying energy to the tag circuit. The tag then sends the information encoded in its memory to the reader.

The most current and prominent RFID tag technologies that can be used in this application are the Silver Ink RFID tags and EPC Gen2 tags:

- Silver ink RFID tags are becoming a viable option for large-scale applications due to the requirement of low cost tags at large volumes. Tag antennas are being designed specifically for silver ink in such a way that RFID tags made from silver ink have the performance comparable to RFID tags made from copper [7]. For those tags, the 13.56 MHz (HF) band is ideal because reader output power is maximized based on the Federal communications Commission specifications and better range is achieved in metal contaminated environments [8]. However, current advances have suggested the use of silver ink RFID tags in the UHF ranges, meeting the EPC Gen2 standards at 915MHz [9].
- EPC Gen2 tags operate in UHF have a size of 0.46 mm × 0.48 mm and are commercialized in different frequency ranges depending on the geographic location [10]. According to EPC Global, read and write speeds in operation of large tag populations are enhanced, in addition to compatibility with HF and previous versions of Gen2.

Table 1 illustrates a comparison of Ultra High Frequency versus High Frequency tags [11], namely a comparison of the silver ink tags and the EPC Gen2 tags.

TABLE I: COMPARISON OF HF AND UHF RFID TAGS.

	HF	UHF
Frequency	≈13 MHz	≈900 MHz
Spectrum Allocation	Uniform	Fragmented
Range	1 m Max	10 m Max
Memory capacity	4 Kbits	256 Bits

Indeed, the read range of the UHF tags is far beyond the HF tags. On the counterpart, the memory storage capability of HF tags is considerably higher.

3.2. Readers

In order for the tags to communicate with the rest of the system's architecture, RFID readers collect and read the radio frequency signals emitted by the tags at resonance. The main minimalistic components of RFID readers are: internal or external antenna, the RF interface, and a control system to address specific tags.

The readers' antennas are to be deployed at the endpoints of aisles and eventually on their center in order to result in a good readability range as shown in Fig. 3.

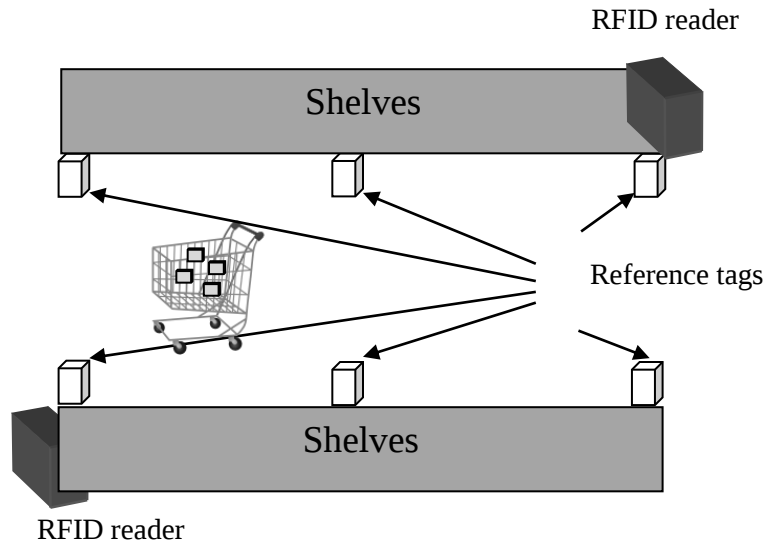


FIGURE 3: AISLE-LEVEL SCANNING OF RFID TAGS.

Since this application requires a relatively high efficiency and effectiveness in RFID scanning, in addition to the capability of detecting a dense RFID tag environment along with single and precise scans for detecting shopping carts, RFID readers capable of switching scanning modes are the best choice in this regard. In this application EPC global Gen2 RFID readers offer the above functionalities. The particularity of these readers consists in their 3 reader modes: dense, multiple and single. These modes will make the detection of the products and carts separate for an increased detection efficiency and mapping of products to unique shopping carts. Older versions of EPC global RFID readers such as EPC global Class-0 readers and Class-1 readers presented issues in recognizing and addressing specific tags [12].

Among-readers collision is also an issue that is solved by the EPC global Gen2 capability of having the 3 reader modes. Additionally, there is a problem of collision between readers due to the large offset between their corresponding signals and the tag's signal. In Class-1 Gen2, a reader can address single tag, so these problems are solved [13].

3.3. Middleware

The role of RFID middleware is to bridge between the low-level tag observations and the enterprise-level applications that operate in an IP-enabled network. The middleware permits a suitable event management by reporting events such as the detection of a customer (shopping cart), the purchase of a new product, the arrival to the payment zone etc. Depending on the nature of the events, the reporting process can be periodic or single-shot, synchronous or asynchronous [11].

In this application it is necessary to interpret events such as purchases, moving customers or a removal of products from shopping carts. Thus, the edge layer is employed to run the following procedures using specific algorithms presented in the perspectives section: localization, clustering along with statistical filtering. The direction of arrival of the RFID signals for both products and shopping carts will enable the localization of the tags, providing coordinates for every element. Using multiple scans with respect to time, those sets of coordinates, are provided as input to the clustering

algorithms and statistical filters in real time. By using those steps we will be able to map products to shopping carts, and thus be able to form application-level significant events and contexts relevant to pervasive retail. Consequently, the system will have a contextual view as depicted in Fig. 4.

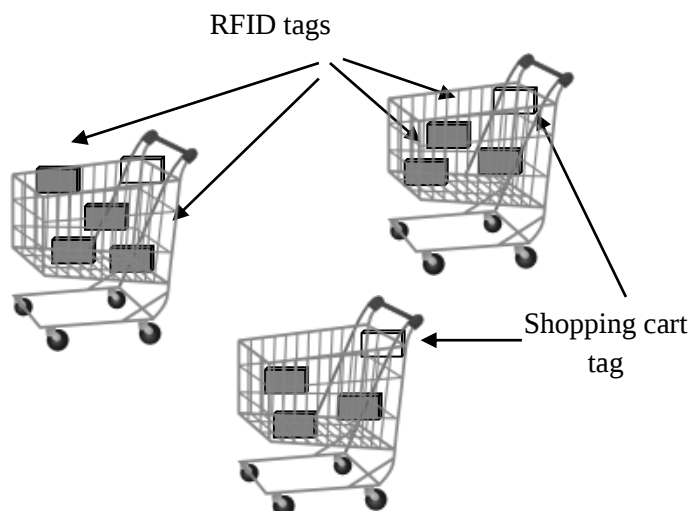


FIGURE 4: SYSTEM CONTEXTUAL VIEW.

Every shopping cart will be uniquely identified using its RFID tag and the corresponding products will be associated to it each time the customer passes by a reader antenna.

3.4. Network services

Network services to be deployed are essential to the functioning of this RFID system for pervasive retail sales. The most essential service provided in the network is the Identifier Resolution Service implemented as ONS (Object Naming Service), which is a specification overlaid on top of the DNS (Domain Name System) used in Internet architectures. The main function of the ONS is to map EPC identifier of a certain tag in the network to a unique URI (Universal Resource Identifier), that specifies the location of the information related to this code.

IV. PROBLEM FORMULATION AND METHODOLOGY

The main complexity in developing such a system resides in the accurate scanning, localization, and clustering of the product tags. The indoor environment contains various materials, which represent obstacles and interferences with other devices that can hinder the propagation of the RF signals. In addition, the association of the right products to the right shopping cart has a direct effect on the reliability of the system. Thus, the clustering step is essential to the performance of the system.

The methodology followed in this paper tackles those challenges by designing a localization system based on the received signal strength of reference tags deployed on the shopping space, then the moving tags are associated to single shopping carts, whereas stationary tags will be assigned to inventory on shelves.

4.1. LANDMARC

LANDMARC (LocAtioNiDentification based on dynaMic Active RFID Calibration) is an indoor localization technique based on RFID technology. LANDMARC introduced the concept of reference tags in order to reduce the number of deployed RFID readers (cost) with the accuracy of the localization guaranteed at the same time. In a complicated indoor environment it could be difficult to estimate the distance between reader and tag by detecting the signal strength only. With the use of reference tags, they are subjected to the same effect in the environment as the tags that are to be located; hence the estimation is more accurate and reliable. With each reader measuring the received signal strength indication (RSSI) readings from a tracking tag (new tag) and the reference tags, the RFID readers can coordinate their readings of the tracking tag in order to identify the nearby reference tags. Based on the known locations of the reference tags, the location of the tracking tag can be estimated.

In the context of this application, we will make use of the benefits of LANDMARC by deploying passive RFID tags, which are of low cost.

4.2. The K^{th} Nearest Neighbor algorithm

In machine learning, the k-nearest neighbor algorithm (k-NN) is a method for classifying objects based on closest training examples in the feature space. K-NN is a type of instance-based learning, or lazy learning where the function is only approximated locally and all computation is deferred until classification. The k-nearest neighbor algorithm is amongst the simplest of all machine learning algorithms: an object is classified by a majority vote of its neighbors, with the object being assigned to the class most common amongst its k nearest neighbors (k is a positive integer, typically small). If $k = 1$, then the object is simply assigned to the class of its nearest neighbor.

The neighbors are taken from a set of objects for which the correct classification (or, in the case of regression, the value of the property) is known. This can be thought of as the training set for the algorithm, though no explicit training step is required. The k-nearest neighbor algorithm is sensitive to the local structure of the data.

4.3. Fingerprinting

The fingerprinting process or training phase of the k-NN machine learning algorithm consists in identifying the reference tags in the signal space and mapping those signals to the physical distances set up in the environment setting. The goal is to render possible the interpretation of Received Signal Strength lying in the signal space in order to be able extract a statistically significant output in terms of distances in the physical distance space, i.e., estimated coordinates of the tags.

4.4. Coordinates Estimation

Since the location of a certain tag is continuous, the in algorithm can be adapted in an approach incorporating weights for each and every reference tag. Here is the procedure: Given n number of RF antenna, m number of reference tags, and u number of new tags to be localized, we define the signal strength of the new tag to be localized as $S_k = (S_{1k}, S_{2k}, \dots, S_{nk})$ where S_{ik} denotes the signal strength of the new tag k perceived by the antenna with $i \in (1, n)$, and $j \in (1, m)$. The signal strength values at the reference tag j are denoted by $\theta_j = (\theta_{1j}, \theta_{2j}, \dots, \theta_{nj})$, where θ_{ij} denotes the signal strength of reference tag j perceived at reader i .

For each new tag (including item and cart tags), the difference between the signal strengths (between a reference tag j and the new tag) is represented by:

$$E_k = \sqrt{\sum_{i=1}^n (\theta_{ij} - S_{ik})^2} \quad (1)$$

where $k \in (1, u)$, and $j \in (1, m)$. In this case, an Euclidean distance in signal strength is to be calculated, and the closer the reference tag is to the new tag, the smaller is the value of E_k .

Compute for each reference tag a single w_k :

$$w_k = \frac{E_k^2}{\sum_{k=1}^u \frac{1}{E_k^2}} \quad (2)$$

Compute the estimated coordinates of the tag by multiplying the reference tag coordinates (x_k, y_k) by the w_k scalar computed earlier, where $j \in (1, m)$:

$$(x_k, y_k) = \sum_{j=1}^m w_k (x_j, y_j) \quad (3)$$

4.5. Clustering

In order to identify different tags as belonging to a unique shopping cart, clustering all tags in one cart is essential. Indeed, clustering will ensure uniformity and isolation of elements in terms of cart of origin. In order to cluster the RFID tags and thus identify the fact that a collection of products has been put in the shopping cart by a certain client, we use the KNN algorithm to find the nearest neighbor to those tags and map the product to a unique client. The procedure is iterative and is presented in Fig. 5.

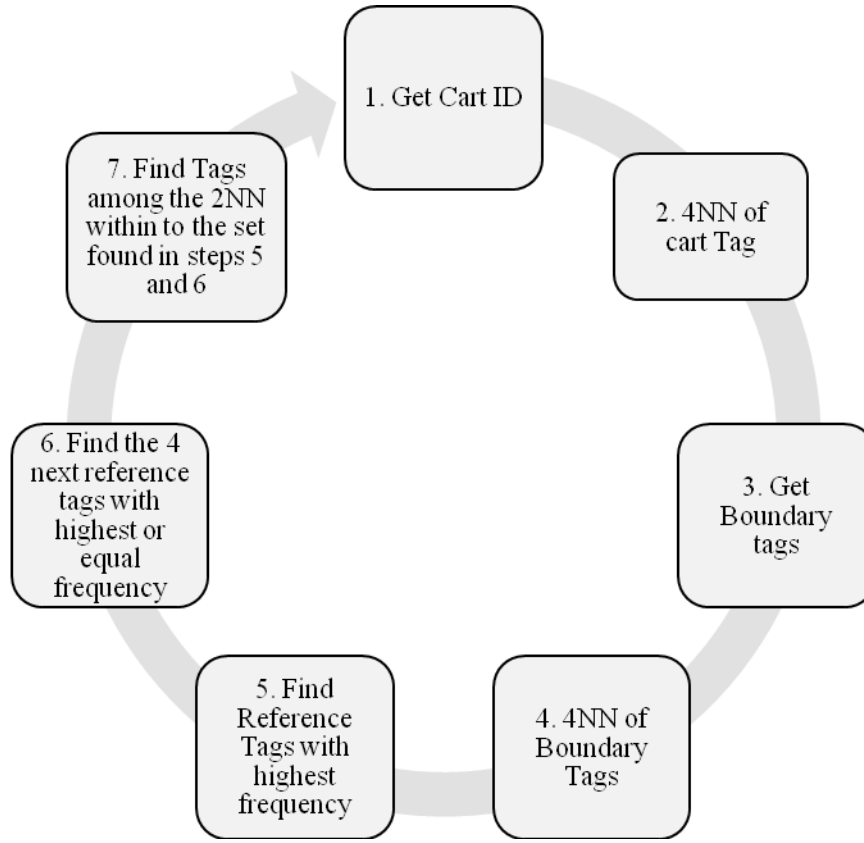


FIGURE 5: CLUSTERING PROCEDURE.

4.6. Context building

Once the individual tags are mapped to specific carts, the changes in the contents of the carts over time give an insight of the transactions carried out by the customer. When a set of tag ID or UIDs are attributed to a given customer, changes in the UID set indicate whether there is a withdrawal or purchase of a given product.

V. SIMULATION RESULTS

In the simulations, the considered reference tags are deployed as a grid on the ground of the shopping space, with a spacing of 1m [4]. The propagation model used involves a log-distance path loss model for RF signal, taking into consideration the Gaussian noise and the multiple reflections caused by the challenging store environment. Then the fingerprinting step aims at learning the coordinates of those reference tags. The learned reference tags' coordinates are then used by LANDMARC, an algorithm based on the KNN algorithm. Thus, the estimated locations of the moving and stationary tags can be gathered.

Fig. 5 shows a typical scenario of a sample shopping cart containing products. The green crosses refer to the predicted boundaries of the shopping cart, which will make the association of the products to a unique shopping cart [6].

From the results of the simulation we notice that the errors have approximately the same mean of

RMS of the error, that is, 17 cm approximately as presented in Fig. 6 and Fig. 7.

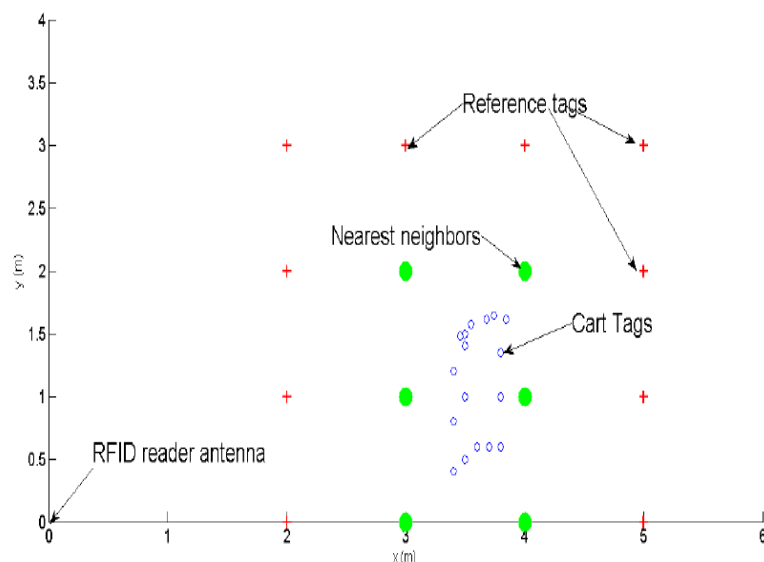


FIGURE 6: IDENTIFICATION OF A SHOPPING CART.

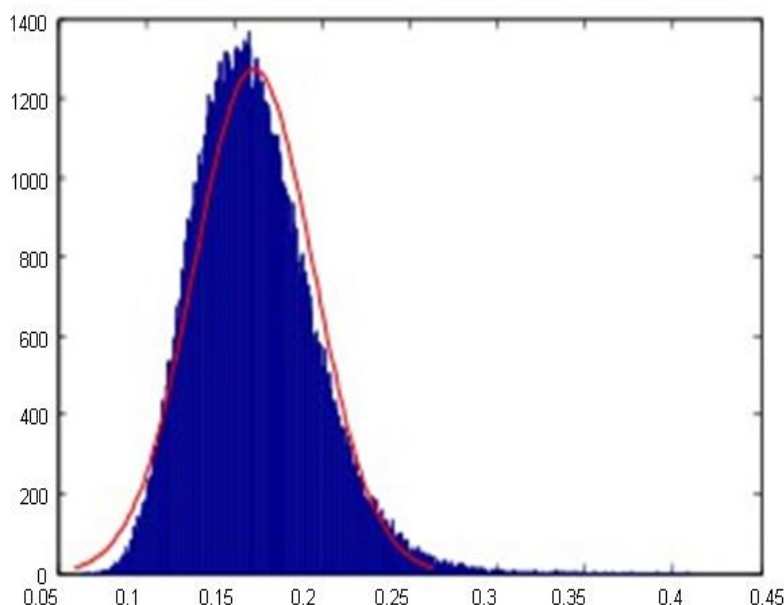


FIGURE 7: ERROR DISTRIBUTION WITH $K=4$.

VI. IMPACT ON SUPPLY CHAIN MANAGEMENT

Following the current adoption of agile supply chain management by an increasing number of retailing firms, the need for real-time transactional data has increased [14]. Indeed, the benefits presented by the RFID technology have opened the possibility to sense and store the purchase data, and have more insights on consumer behavior. This new approach in RFID retail sales ensures a good level of flow of products and information within the business and extends to the wider supply chain. It enables them to better anticipate and react quickly to the changes in demand for specific

products.

The information system layer constitutes an interface for the wider supply chain to which the store belongs, through the internal enterprise resource planning systems already in use in the store. The data related to the different purchases such as the products purchased, respective quantities, date and time, location can serve both internally and externally.

6.1. Interface with the store's ERP

This new approach in RFID retail sales ensures the availability of context-relevant data about purchases. Thus, the internal day-to-day replenishment activities and modifications in products positioning in the different aisles would have a significant impact on sales.

Indeed, the added value of real-time data contributes to the migration from old-fashioned sales, towards new context aware interaction. For instance, in case of product unavailability on a certain shelf, alternative products can be presented to shoppers using the interactive touch-screen. In addition, the real-time data is essential to undertake effective congestion management by guiding customers and assisting them to reach the products they want to purchase.

Additionally, store managers can access real-time and visible analysis of the performance of each individual aisle, customer, or product line [14]. The historical data collected can be stored in data warehouses and spatial data mining techniques can be applied to construct consumer-purchasing models. All those different uses of the data would have a significant impact not only on the aggregate sales, but also on the customers' shopping experience.

6.2. Relationship with the overall supply chain

This system provides relevant information, which is essential for scheduling transport and determining the appropriate levels and locations of product warehousing. It has the potential to approach a 'Just-In-Time' system by linking directly the distribution center to the store.

Retailers' role in reacting to the changes in demand, and thus, their contribution to the overall operation of the supply chain is ever more important. Indeed, their permanent communication with their suppliers and other supply chain intermediaries would add more significant impact to the value created by the flow of products along the chain.

Using the collected data, they can predict the appropriate quantities to be delivered by the distribution centers in order to avoid stock-out, and ensure a high availability level of the products offered in the shopping space. Consequently, suppliers should be chosen according to their speed, flexibility and quality in order to decrease the time to serve and the time to react to volatile responses in demand.

6.2.1. Demand management

The accurate item-level real-time data provided by this new RFID approach in retail sales will enable retailers to avoid costly buffer stocks and perform a meaningful and enhanced aggregate planning.

6.2.2. Order fulfillment

The system will allow an optimized cross-docking, picking, shelving, and an avoidance of sending items to wrong aisles. This will directly impact the customer order fulfillment by increasing the reactivity to changes in demand for specific products in specific aisles, and will render possible the re-shelving of alternative products.

6.2.3. Returns management

In the framework of the proposed system, downstream visibility can be easily achieved through the identification of returned items. The system allows the association of tagged items to specific sales. Thus, the retailers would know whether the returned item was indeed sold, consequently limiting the fraudulent returns [15]. The returns would count as negative demand, consequently increasing inventory levels.

6.2.4. Impact on the supply chain

Valuable competitive advantage can be drawn by implementing the proposed system and synchronizing the change across the supply chain. Shifting towards a versatile, effective, and efficient supply chain is facilitated through the improved demand management, order fulfillment, and return management. Firms can also adapt their internal processes to maximize the added value of implementing this system, by guaranteeing a level of process interdependence and suitable integration using adequate RFID standards. [16].



FIGURE 8: VALUE OF RFID INTEGRATION.

6.2.5. Role of Efficient Consumer Response

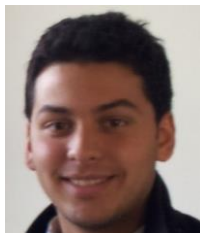
In the presented system, consumer behavior has a significant driving force, bringing solid insights and increased accuracy to the supply chain processes. ECR's main areas; namely replenishments, promotions, and technologies; are driving the well-functioning of the system. Accordingly, Replenishments can be predicted and scheduled in a timely fashion. Promotion campaigns and new product introductions can be organized and rendered effective through the interaction with the users' touchscreens. The technological robustness of the system layers supports and maintains an adequate service level in the aforementioned activities. Thus, the Efficient Consumer Response creates a strong need for collaboration between the chain's stakeholders [17].

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