UNIVERSITA' DEGLI STUDI DI PARMA

Dottorato di ricerca in Ingegneria Industriale

Ciclo XXIII

ENGINEERING AND DEPLOYMENT OF AN RFID PILOT IN THE APPAREL SUPPLY CHAIN

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Alla mia famiglia…

EXECUTIVE SUMMARY

The project described in the present thesis comes from studies begun in 2008 at the research centre “RFID Lab” of University of Parma concerning the application of RFID technology to the apparel supply chain. The results achieved have helped the members of the Board of Advisors Fashion, composed by various fashion companies, to recognize the benefits and the problems concerning the implementation of a RFID system in the supply chain, obtaining know how, benefits and competitive advantage from the academic technology transfer. One of the studies, conducted by the RFID Lab researchers, have demonstrated significant ROIs both at warehouse and apparel store level using theoretical business cases. In this way, after the formative and practical experience of the *RFID Fashion Store*, some of those companies, and their partners, chose to transfer their knowledge from the lab to the field implementing a project pilot.

The name of the project is “RFID Fashion Pilot” and it is the first supply chain pilot in Italy focused on the evaluation of the impact of RFID technology in the fashion industry. More of 10,000 garments of the spring/summer 2010 season have been RFID tagged at the distribution center and tracked to a store, enabling real time visibility of logistics flows. Project goals are two:

1. measure the quantitative benefits of RFID technology on warehouse and apparel store processes;
2. evaluate the economic impact of more accurate and real time data for the apparel supply chain.

Some of the most important company of worldwide fashion shared benefits and costs of piloting. Although only one of them, Miroglio Fashion, was directly involved in providing the locations and garments, all participants were involved in project engineering, both from a technical and from an operational point of view, in the experimental campaigns, and in the sharing of the resulting know-how.

The supply chain pilot deployed involves two players: (i) the distribution center (DC) of Miroglio Fashion located in Pollenzo (CN) and (ii) the point of sale (PoS) "Elena Mirò" located at the outlet district ‘Fidenza Village’ near Parma. This is an outlet store, that receives garments

of the same season as the previous year. Therefore the garments came back from the normal store, they are reconditioned and, after that, they can be shipped to the outlet store.

An 'As Is' analysis is conducted in order to define the relevant processes, operations and activities currently performed. This phase has revealed the following processes: (i) Labelling and (ii) Shipping regarding the DC, (iii) Receiving, (iv) Replenishment, (v) Fitting, (vi) Check-out and (vii) Inventory regarding the point of sale. Each of them has been reengineered in order to apply the RFID technology and achieve the aims of the projects.

The experimental campaign has involved the products belonging to the spring/summer 2010 season (originally 2009). In regard with the DC, labor efficiency and accuracy has increased by 80% and by 8.6% respectively. That means that the time, and costs, needed to perform the shipping activities can be reduced with a concurrent increase of the accuracy. In regard with the store processes the project has shown the technical feasibility of a five-minute daily inventory process with an accuracy more than 97%. The data provided by the fitting rooms monitoring system can be used to obtain new marketing information and to adapt shop assistant presence to the effective needs. Finally, the project has demonstrated that the more accurate and real time data provided by the RFID technology can help the shop operators to increase the sales by more than 8%.

SUMMARY

1. INTRODUCTION

Radio Frequency Identification (RFID) is an automatic identification technology that is having a great importance. In its simplest concept, RFID is a similar to bar coding. It is considered as a means of enhancing data processes and is complementary to existing technologies. It is a tested technology that has been in use since the first years of '70s. In fact, since the years before the beginning of the current millennium, RFID technologies have been set to complement or substitute barcode technology, which has been adopted in the logistics of the most of the world companies [1]. RFID is expected to enable complete and intensified supply chain collaboration and thus increase process efficiency. However, although considered important for commercial success, RFID standards were still in their immaturity during early RFID pilots in fast moving consumer goods [2], [3], [4] and fashion[5], [6], [7].

The impact of RFID technology is particularly evident in fashion retailing because the fashion business is characterized by a wide assortment of products, high seasonality, high volatility, short life-cycles, high-impulse purchasing and intricate logistics operations [8]. RFID technology can offer fashion retailers a solution to solve a number of issues that are distinctive of their industry. The first problem is the very short product life of fashion products – typically not more of three or four months – it is fundamental to ensure that the garment is delivered to the point of sell as quickly as possible. As RFID provides the capability to track and trace goods, it can increase the efficiency of most of the processes along the supply chain. The second problem is that the garments need space to be displayed because of their variety of styles, sizes and colors, so the management of these items can becomes very complex. "*An RFID-based stock management system can identify the needed items for the customer quickly and correctly*", Moon et al. suggest [9]. The third problem is the reduction of counterfeiting, theft and illegal product used in the grey markets, possible thank to the special identifier given by the RFID. The fourth problem is that the behavior of fashion customers is unpredictable my mysterious. The RFID-based customer cards enables retailers can record how customers shop, interact with items and make purchase decisions. Subsequently, this technology can provide customized marketing strategy for their customers at an individual level. "*RFID technology can manipulate a tremendous amount of stored data and create value*" [9].

In order to test the impact of the RFID technology on the Italian fashion supply chain a pilot project has been arranged. The aims of a pilot is "*to examine the feasibility assessment in the* *field before deciding to roll out*" [10]. In this way, the pilot should point out the technological challenges, human operative issues, security/privacy issues that could potentially affect a potential rollout. The pilot should also provide information about costs and benefits. Overall, the pilot should help to provide the obstacles and opportunities for RFID in the field. It is important remember that the reason of the pilot is to experiment. Often, pilots make known benefits and costs not predicted during the feasibility studies. This is described very well by Gary Cooper, CIO at Tyson Foods: "*There are going to be 'ah-ha' moments when you learn something – the problem is we don't know what these are yet*" [11]. Bottani at all. warm that if the approach of the pilot is too rigid, these 'ah-ha' moments may be missed [10]. The piloting is a critical step in any enterprise wide deployment [12].

The present thesis reports the technical design of the project and the results achieved. The first section provides an introduction to the RFID technology on standard-making. It is followed by an outline of the research methodology. The subsequent section, covering RFID standard-making, describes RFID pilot 'As Is' Analysis to preparation for 'To Be' reengineering followed by a brief description of the web application developed. The two last sections provides a description of the principals key performance indicator (KPI) used and the results of the experimental campaign. A summary concludes the thesis.

2. RFID TECHNOLOGY

RFID Journal defines RFID as "*generic term for technologies that use radio waves to automatically identify people or objects*[1]" [13]. There are several identification technologies, the most common of which is to associate the RFID tag unique identifier with an item or person. An RFID system will typically comprise the following elements (see Fig. 1):

- ✓ an RFID device (tag) applied to the item to be tracked;
- ✓ a tag reader with an antenna and transceiver connected to the tracking system;
- ✓ a host system that controls the tag readers.

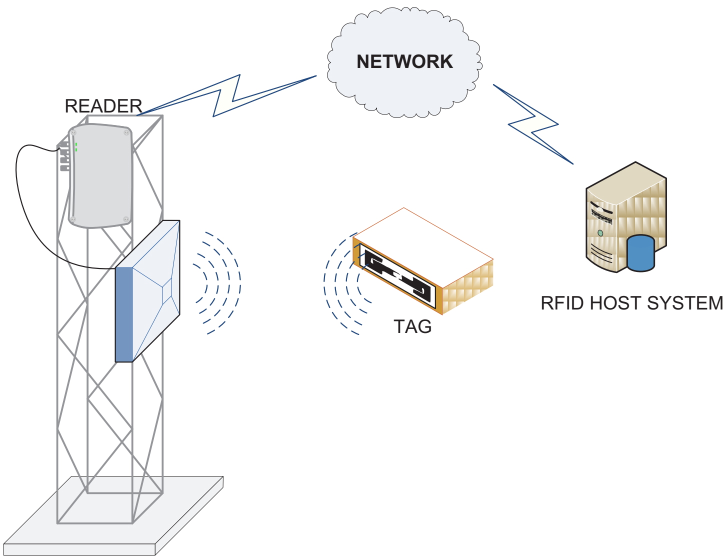


Fig. 1: Typical RFID system.

RFID devices can be classified in two categories: active, with a power supply (for instance a battery) and passive, without power supply. Active devices which communicate with a reader are known as transponders (TRANSmitter/resPONDER). Instead, passive devices are simply known as 'tags'. Active tags are typically also read/write devices and more expensive; conversely, passive tags usually include only reading functionalities and are cheaper. The use of a battery limits the life of the device, although with current battery technology this may be as much as 10 years. Passive tags have an almost unlimited life, are lighter and smaller but they have limited data storage capacity, a shorter read range and require a higher-power reader. There are also semi-passive tags, where the battery runs the chip's circuitry but the device communicates by means of power provided by the reader. Now a day, a lot of type of

[1] RFIDJournal frequently asked questions, http://www.rfidjournal.com

tags are available in the market. In fact shapes and sizes can be different in order to exploit particular electromagnetic properties or protective inlay can be changed in order to provide mechanical and chemistry resistance. Tracking tags used in zootechnics are injected beneath the skin of the animals and approximately have a length of 10mm and a diameter of 1mm. Some tags are converted in credit card sized packages; typical examples include building access cards or sky-pass. Other tags are designed to be used in harsh environments, such as container tracking applications, and can reach 120x100x50 mm. The tiniest tags commercially available measure 0.4x0.4mm and are thinner than a sheet of paper.

2.1. Tags

Tags can incorporate different type of memories: read only memory (ROM), volatile read/write random access memory (RAM) or write once/read many memory (WORM). ROM is used to store security data; in fact, it is an unchangeable, unique device identifier and operating system instructions. RAM is used for data storage during transponder interrogation and response. Data can be stored in the memory which may also include:

- ✓ an operating system;
- ✓ a data storage (volatile or non-volatile);
- ✓ an electronic product code (EPC – the evolution of the bar code).

Passive tags obtain their power from the reader through the electromagnetic field generated. The passive tags will then respond to the enquiry. Active tags usually communicate through propagation coupling and respond to the reader’s transmission using the internal power to communicate.

The individual governments generally manage, through legislation and regulation, the allocation of radio frequencies, thus, although there are international standardizations such as ISO and similar, each geographic area has allocated different frequencies for RFID devices. For example, Europe uses 868 MHz for UHF and the US uses 915 MHz. Currently, very few frequencies are available for RFID applications; as a matter of fact, at the moment three frequency ranges are generally draw on for the real applications depending on the required read range:

- ✓ Low-frequency passive tags have an effective range of about 30 cm;
- ✓ High-frequency passive tags around 1 m;

- ✓ Ultra-high-frequency passive tags from 2 m to 8 m.

Where greater range is necessary, such as in container identification and automotive applications, active tags can be detected to a range of 100 m [14].

When logistics units, palettes, cases and boxes are tagged, they can be tracked through the supply chain from the manufactures to distribution centers, up to the points of sale. In order to identify them, the Serial Shipping Container Code (SSCC) is used. This latter is an international code for logistic units, that allows the unique identification of the transport units. If the tag is applied on item, each individual product can be identified and, avoiding errors, it can be traced along the supply chain, from manufacturer to distribution centre, from this to each store, and up to the sales floor and shelves [15].

2.2. Reader

An RFID reader is an electronic device used to obtain pieces of information stored on the RFID transponder or tag. It emits an electromagnetic field, received by the RFID transponder via its antenna. The signal provides the tag with both the information and the power necessary to operate and transmit its data. The maximum achievable read range depends on the frequency range used for the data transmission.

Different frequency ranges are available for RFID. For the consumer goods industry, two ranges are generally utilized: the high frequency (HF) range of 13.56 MHz which is readable up to 1 meter and the ultrahigh frequency (UHF) range of 860–960MHz readable up to 8 meters. The 13.56MHz frequency has been typically used for RFID transponders at the item level [16]. In addition, the read range is influenced by further variables, such as the composition of the item or the presence of barriers between the reader and the tag. In fact, in the case the item contains water or metals, the maximum reading distance can be reduced; similarly, walls, metal shelves, or material handling device can impact on the performance of the communication. This is why Lahiri [17] suggests that “a typical HF RFID system uses passive tags, has a slow data-transfer rate from the tag to the reader, and offers fair performance in the presence of metals and liquids”.

A reader can perform either inventory reading or access operations on a single tag population. Inventory, as the name suggests, identifies a population of tags through a succession of standardized air-protocol commands [18].Using one of the available algorithms, the reader can isolate a single tag response and receive the memory contents from the tag. Access is used to define the auxiliary operation of communicating with (reading from and/or writing to) other memory areas on a tag. Such as to the inventory protocols, also access encompasses multiple air commands [18].

2.3. RFID Host system

Usually, RFID solutions need a network to work; in fact, they need to communicate with the back-end system in order to interpret reads. The IT support for RFID readers can be spread or closed. In many situations, discovery services and automated configuration of the setting up of the RFID devices are very important (RFID host system) [18]. Once they are set up, RFID system administrators will need to be able to manage and monitor the devices using particular tools. Moreover, health and performance monitoring, firmware management tool will be critical in order to diagnose problems and solve them. The RFID infrastructure may be extend on more players, which satisfy the need for configuration and monitoring tools. In addition, redundancy is necessary to be deployed at each layer for a robust infrastructure.

The RFID Middlware (RFID MW) provides the ability to control and configure readers, and manage and monitor the status of the devices in a deployed system. In summary, the RFID MW allows RFID technologies to be connected with an existing IT infrastructure by making use of standard network protocols. The EPCglobal EPC Information Services (EPCIS) includes a set of interfaces which provides standard event capture and query tools for achieving and sharing data about RFID tagged entities within the supply chain. It supports enterprise resource planning and operating systems and enables functions like track-and-trace, anti-counterfeit, product authentication, quality monitoring across supply chain partners in multiple vertical markets.

2.4. Tag data and events

The tag data obtained and the business events produced by the RFID infrastructure need to be shared for closed-loop, open-loop and cross-enterprise information systems. Many processes and potentially many companies can be involved by this data exchange.

In fact, usually, the combination of RFID and non-RFID events can be necessary to describe the most of the business events occurred during the logistic processes. The exchange of data could move following two flows. Product suppliers could notify retailers that their goods are in transit, and retailers, in turn, could provide suppliers with visibility of goods as they flow through their supply chains, up to the selling floor or point-of-sale. An accurate visibility among the companies of RFID tagged items and the exchange of the related business context data make it possible to have value added response to EPC data and events. For example the supply chain partners of a retail network could work together for a close monitoring of the retailer's inventory, thus reducing the shrinkages and maximizing sales. [18].

2.5. RFID in Fashion

During the last years, the global fashion business has been experiencing a pervasive change, due to two major macroeconomic drivers. First, political conditions and economic changing have requested flexibility and innovation; moreover, recent economic trends have reduced consumer buying power. These phenomena have determined that discount retailers (e.g., Aldi and WalMart) and verticals (i.e. international apparel network with their own production facilities, such as Zara) have obtained an significant market share [19]. To meet these challenges, fashion manufacturers (e.g., Benetton in Italy) and retailers (e.g. WalMart in US) have experimented new technologies such as RFID.

In this scenario, the entire fashion industry faces unprecedented challenges as a consequence of changing market conditions and demanding customers. Two first cases of technology pioneers are Kaufhof Department Stores (Kaufhof) and fashion manufacturer Gerry Weber International AG (Gerry Weber). They have collaborated in verifying the benefits of RFID technology along the fashion supply chain.

Loebbecke et al. [20] report in their study the numbers and the results of the experimentation. Kaufhof Department Store AG is a sales division of the METRO Group and it is one of the principal department stores in Europe. Kaufhof manages 134 stores, of which 116 are department stores (October 2005) in more than 80 cities of Germany, and 15 point of selling in 12 Belgian cities.

More than two million people visit Kaufhof's with a total of 1.5 million square meters of sales area in Germany and Belgium every day. The workforce is composed by 27,000 worker and - in 2004 - generated €3.8 billion in sales, about 35% of those by the fashion department. Kaufhof's

EBIT achieved €56.1 million (1.47%), which gives evidence to the limited gains of department stores and stresses the cost pressures in fashion retailing.

Gerry Weber International AG is a German fashion company with worldwide operations founded in 1973, and at the moment, it owns three brands: Gerry Weber, Taifun Collection, and Samoon Collection. The company manages around 800 shops with their shop-in-shop system. At the ending of October 2005, Gerry Weber International AG earned about €400 million in sales, thank to almost 1,700 workers. With an EBIT margin of more than 8%, the results are above the industry average.

According to Loebbecke et al. [20] "*the Kaufhof and Gerry Weber project shows positive and very promising tests of RFID viability under real-life conditions. While there continue to be technical, data management, and privacy issues for RFID, positive performance impacts on data collection and information management, at both the warehouse and store level offer a strong business case for both retailers and suppliers*".

2.6. Applications

The most important application of the RFID technology in the apparel industry are:

- ✓ Track and trace;
- ✓ Anti-theft;
- ✓ Anti- counterfeit.

Track and Trace

The RFID project can involve all the processes of the supply chain fashion such as tagging, packing, shipping, in the distribution centers, and receiving, replenishment, display, sales, and theft prevention at the stores [20].

For instance Kaufhof personnel used RFID technology for inventory and delivery tracking of the logistic units. Hanger and stackable-good shipments with RFID tags arrived from the distribution centre and passed through the RFID portals of the stores. Kaufhof staff automatically obtain the Serial Shipping Container Code (SSCC) from the tags using a portable RFID reader. The data were automatically stored into a shared database and then compared to the values in the Kaufhof merchandise management system, an application able to collect and manage goods based on amount and value [20].

Anti-theft

RFID can provide real-time item tracking capability improving anti-theft applications. It enables a retailer to know when and which item has been moved. In addition, RFID can enable real-time controls and alarms informing the shop assistants about the theft. For example, by attaching a tag to the value item, such as a Blu-Ray Disc, the on-shelf reader reads the EPC of the RFID tag (passive RFID tags can be the best solution considering the tradeoffs between the cost and benefits) and knows the existence of the item. When the Blu-Ray Disc is picked up by a consumer from the shelf , the reader can determine the EPC of the missing item. The reader then sends an alarm/warning signal to the information system, and enables the other readers installed in the warehouse to start looking for the missing EPC [21].

Anti-counterfeit

Every year, counterfeiting generates a loss of billions of euro of revenue. The most frequently counterfeited products are drugs, currency bills and luxury items. One RFID solution is to associate the tag identification number with any particular prescription bottle so that it can be tracked through the supply chain. For example in [22]. a very tiny RFID tag has been designed for drug bottles tracking usage. The particular characteristics of the item, such as the name, the production site, the expiration date and even the description can be stored in the RFID chip. For example, after scanning, the following information would be displayed on the drug retailer's screen, "The drug is a red liquid inside a 4 inch high bottle, produced by Manufacturer X, in Parma, Italy. Expiration date Nov.4, 2011." In the case the information showed on the drug bottle highlights discrepancies in comparison to the one stored in the container, the counterfeit is immediately discovered. For luxury items (e.g. fashion items), RFID can be exploited to prevent brand counterfeiting. Unique ID can be embedded inside the product, such as fashion clothes. When these clothes are detected in unauthorized selling region, the RFID tag can be used to tell which reseller was responsible for selling it to the gray market [20].

3. RESEARCH METHODOLOGY

The design and the definition of most relevant information to be obtained from the deployment of the RFID technology and the EPC system in the pilot project was supported from the work of a panel of experts, properly arranged to this purpose. Chief logistics officers, supply chain managers and chief information officers of the most important manufacturers and distributors of apparel business compose the panel, which operated following the Delphi technique [23]. This is a structured process that allows researcher to operate systematically with complex or ill-defined problems. The Delphi technique provides an appropriate framework to explore the ideas and recognize the suitable information for a decision-making process. For this reason, adoption of the Delphi technique is suggested in the case of complex, interdisciplinary problems, involving several new concepts [24].

In order to obtain the best results the same methodology of previews researches [25] was applied. Thus, a multidisciplinary panel, composed at least 20 members, was founded. In the case in exam, the panel encompassed:

- ✓ More than 10 members from 8 companies, operating as manufacturers and distributors of fashion, are involved in the RFID Fashion Pilot project developed at the University of Parma. Such companies include Branded Apparel, Dolce&Gabbana Industria (with its logistics partner TNT and DHL), Imax (MaxMara Group), Miroglio Fashion, Trussardi and Norbert Dentressangle. As mentioned, the panel members covered the key business functions where RFID technology deployment can have a significant impact; for instance, participants were chief logistics, procurement, operations and information officers;
- ✓ five researcher from the University of Parma (Department of Industrial Engineering), involved in activities performed at the RFID Lab of the same university. The choice of the academics was based on the studies concerning the application of RFID technology in logistics and supply chain processes;
- ✓ three software developers and two project managers from Id-Solutions, a spin-off company of the University of Parma. They were recruited in the panel because of their specific skills in RFID technology, and also because they were asked to integrate the hardware and software infrastructure.

According to Bottani et al. [10] the development of RFID pilot projects requires five main steps: (i) ‘project definition’, (ii) ‘project team definition’, (iii) ‘feasibility assessment’, (iv) ‘piloting’ and (v) ‘rollout’, (see Fig. 2). Bottani et al. also indicate that, although the steps are presented as sequential, activities of different steps usually overlap and feedback may lead to an earlier step. For instance, outcomes from a step (e.g. ‘piloting’) may suggest either to proceed with the pilot project (i.e. the ‘rollout’ step) or to go back to the ‘Feasibility assessment’ step to change, improve or redefine project design. The present thesis will be focused on the third and fourth phase, and in particular on Feasibility assessment (‘As Is Analysis, ‘To Be’ Re-engineering) and Piloting.

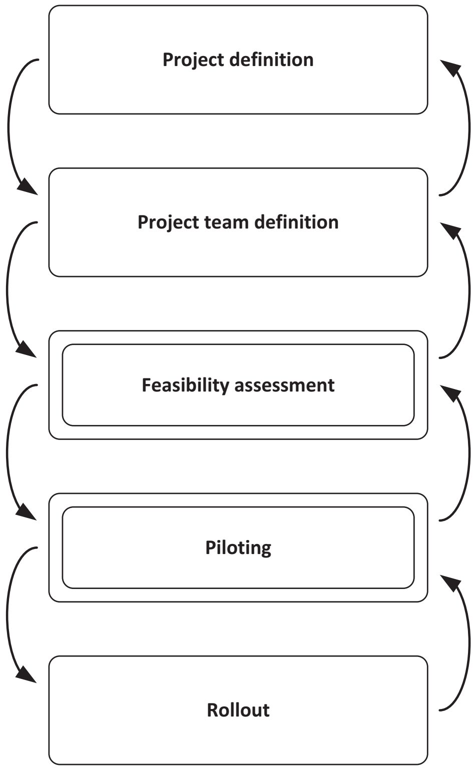


Fig. 2: Proposed methodology. Adapted by Massimo Tizzi from "A methodological approach to the development of RFID supply chain projects," International Journal of RF Technologies: Research and Applications [10]**.**

3.1. Feasibility study

A feasibility assessment basically aims to evaluate the suitability of the project from the technical and operational points of view. To achieve such aim, this phase encompasses two sub-steps, namely ‘AS IS analysis’ and ‘TO BE reengineering’. Related approaches to the feasibility study can be found in literature [26], [27].

3.1.1. ‘AS IS analysis’

Bottani et al. define ‘AS IS’ analysis like “*a systematic data collection phase, concerning relevant processes, operations and activities currently performed and targeted for study within the RFID project*” [10]. It can be performed through visit campaigns, involving, depending on the project, either all players examined or a sample of them, previously identified as representative of related processes. Interviews with one or more representatives of the visited organization are required to collect data and information. To simplify this step, it is favorable that respondents are expert of the processes examined and have a good knowledge about them.

Some pieces of information are required to perform the As Is analysis. Such information refers to (i) physical, (ii) informative and (iii) operation flows. Physical flows are explored by collecting quantitative and qualitative data in relation to processes, operations and activities involving items (i.e. pallets, cases, or assets) handled at the site. Indeed, while manual operations needed for product identification are examples of qualitative data required, the number of product identified every day is an example of quantitative data. In addition, it is important to define (i) input and (ii) output data for each process, information required for process monitoring and any device needed. In fact typical information to be obtained from the interviews refers to the hardware infrastructure currently adopted for product identification and related connection with the company’s backend system, number and location of identification points and item related data and the information flow. Finally, operations flow analysis provides an overview of the tasks to be performed by the personnel to complete the processes examined. Moreover, current performance and potential criticalities of the processes should be analyzed. In this regard, it is very useful and important to pay attention to current performance parameters in order to evaluate the possible benefit achieved by adopting RFID technology.

3.1.2. ‘TO BE’ reengineering

The second phase of the feasibility assessment is ‘To Be’ reengineering. From the AS IS analysis, it is possible to depict new scenarios, hypothesizing, through business process re-engineering (BPR), a new scheduling of activities and operations in order to execute the same processes involving RFID technology [28]. In particular, each process should be described by the To Be model reengineering the technological requirements, the physical flows and the operative activities. Technological reengineering involves the definition of the hardware infrastructure (readers, antennas, gates, etc.) and the software architecture (middleware, network, backend system integration, etc) enabling RFID related to the processes examined. This, in turn, needs that RFID transponder for identification of products (e.g. active, passive or semi-active tags) or assets (e.g. storage locations or pallets), detecting devices (e.g. mobile or fixed device, RFID-equipped forklift truck) to be defined, and the network infrastructure chosen.

A very important and useful step, at this moment, is the development of technological tests. They can be performed in an appropriate laboratory or at the player site in order to select the RFID devices (transponders, readers or printers) and measure their performances in term of reading/writing commands. This can include 'reading accuracy' (number of tags read/ number of tags to be read) and 'read rate' (number of tags read in a second). These data are very important, as both performance and costs may considerably depend on the features of the RFID equipment and the operational conditions.

From the informative point of view, reengineering step should give the new definition of identification points (tracking point) and of the correlated 'item attendant' and 'item related' data to be collected. While the firsts are data collected and stored in the tag, 'item related' data represent information to be obtained by means of tracking points, such as tag EPC, time, location, quantity and process involved. Such data are collected, stored in the company's EPCIS and shared within the supply chain. In this way the definition of the informative infrastructure provide a preliminary design of the data warehouse (DW) or data base (DB) structure, as well as a definition of the business intelligence module (BIM) to be used to derive value added information by the interpretation of the EPC data. Finally, depending on the type of RFID pilot project to be deployed, one or more TO BE hypothesis can be designed. TO BE scenarios developed should be originated from a general agreement on information, operations and technological solutions assumed, as well as from top management commitment. In order to achieve the aims of this phase external competencies and consultants can be involved with the scope of evaluate the suitability and the technical functionalities of the solutions designed.

3.2. Piloting

The AS IS analysis should reveal the most important aspects of the process to be reengineered. However, if previous performance data of the process are not available, they will need to be measure before the pilot begins. Assuming the current metrics are known or have been collected the next step is to deploy the technology. Working closely with the technology providers will be important to achieve the aims of the pilot, because they will know how to improve the performances of their technology. In addition part of the pilot should be an evaluation of the physical installation criticisms (time, skill level needed, best period, hidden costs, etc). Decisions about the location of the technology (e.g. a dock door portal, antennae on one side or on both sides, overhead, etc) should already be made in the To Be phase, but may need to be modified when installation starts (due to previous hidden circumstances). Before or during installation, it is generally useful to conduct a site expertise to evaluate the potential effect of working environment, such as reflecting or absorbing surfaces, on the experimental results [29]. In order to avoid cross-talk between readers [30], dead zones in the reading area where the tag cannot be detected [31], an examination of the composition of electromagnetic waves should be performed with a spectrum analyzer. Using the same equipment, unwanted reads can be prevented. In addition, it is very important to investigate possible interferences from the RFID infrastructure and the existing equipment both RF and not.

Company human resources will need to be trained on the use of the new devices and software application developed during the pilot deployment. The training should also have the aim to dispel any fears people could have about this kind of technology or accompanying changes to their existing jobs. Bottani et al. [10] suggest to change the technology if it doesn't work properly, in line with the purpose of the pilot, which is to experiment; the changed occurred can be considered as 'lessons learned'. In addition, if a new type of technology is released during the pilot, it could be very interesting to test it. If a mobile reader is not giving the requested performance, try a fixed reader. The key of the piloting phase is to experiment, while at the same time controlling as much as possible. The results will provide the key elements of the rollout step. It is possible and probable, however, that the project will have some feedback to the earlier step before proceeding to the next one, rollout phase, because the knowledge from the pilot may determine the project plan to change, possibly designing to additional pilots.

4. ‘AS IS’ ANALYSIS

As previously mentioned, ‘AS IS’ analysis is the data collection phase, concerning relevant information about processes, operations and activities performed and targeted for study within the RFID project [32]. Like Bottonai et al. suggest [33], it was performed through a visit campaign, involving either all sites examined, previously identified as illustrative of related processes. The results of the ‘As Is’ analysis has been approved by the Board of Advisors of the project.

4.1. The company

The company which has been chosen is Miroglio. It is an Italian fashion company, born in Alba in the province of Cuneo. Today it is an international group which has a consolidated turnover of over one billion euro and about 11 thousand employees in Italy and abroad. Now it is present in 34 countries with 59 operating companies. The fashion division has developed in parallel to its network of stores, now counting more than 1,900 one-brand shops.

Miroglio Group currently operates through two separate companies: Miroglio Fashion (fashion business) and Miroglio Textile (specializing in textiles and thread/yarn).The fashion brands are: *Motivi*, ‘fast fashion’ business for young women, created in the 90s with a target age between 20 to 35 years; *Oltre*, founded in 2001 as a natural evolution of *Motivi* for over 30 customers, and *Fiorella Rubino*, fast fashion as a solution dedicated to the generous sizes.

The growing demand for generous garments with a modern and contemporary look, has led to the birth of *Elena Mirò*. They also complied with the ‘generous’ segment *Luisa Viola*, ‘*by Krizia’* (developed in partnership with designer Mariuccia Mandelli from Milan) and *Blue Time Fashion*, aimed at girls. The "regular" business presents the following trademarks: *Caractère*, *Diana Gallesi*, *Claudia Gil*, *Dream and Sym*.

4.2. Supply Chain pilot - overview

The supply chain pilot involves two players:

- ✓ Distribution center (DC) of Miroglio Fashion located in Pollenzo (CN);
- ✓ Point of sale (PoS) "Elena Mirò" located at the outlet district Fidenza Village. This is an out let store, that receives garments of the same season as the previous year. Therefore the garments came back from the normal store, they are reconditioned and, after that, they can be shipped to the outlet store.

A possible schematic representation of the proposed pilot is shown in Fig. 3.

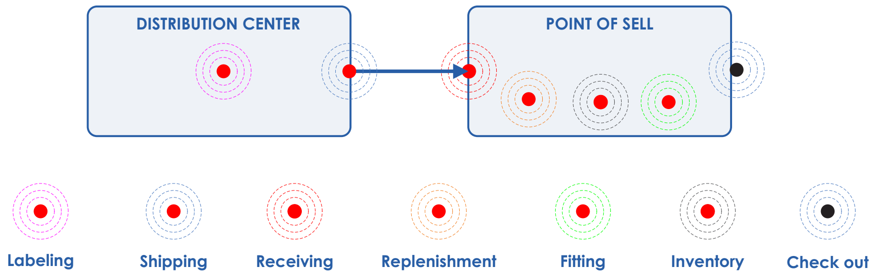


Fig. 3: Representation of the supply chain pilot.

Interviews with the management resulted in a list of logistic processes impacted by RFID technology and analyzed in the project. The following list of the processes impacted is provided:

- ✓ DC logistic processes:
  - ➢ Labelling;
  - ➢ Shipping;
- ✓ Store logistics processes:
  - ➢ Receiving
  - ➢ Replenishment
  - ➢ Fitting
  - ➢ Check-out
  - ➢ Inventory

The following figure show the logical flow of the processes.

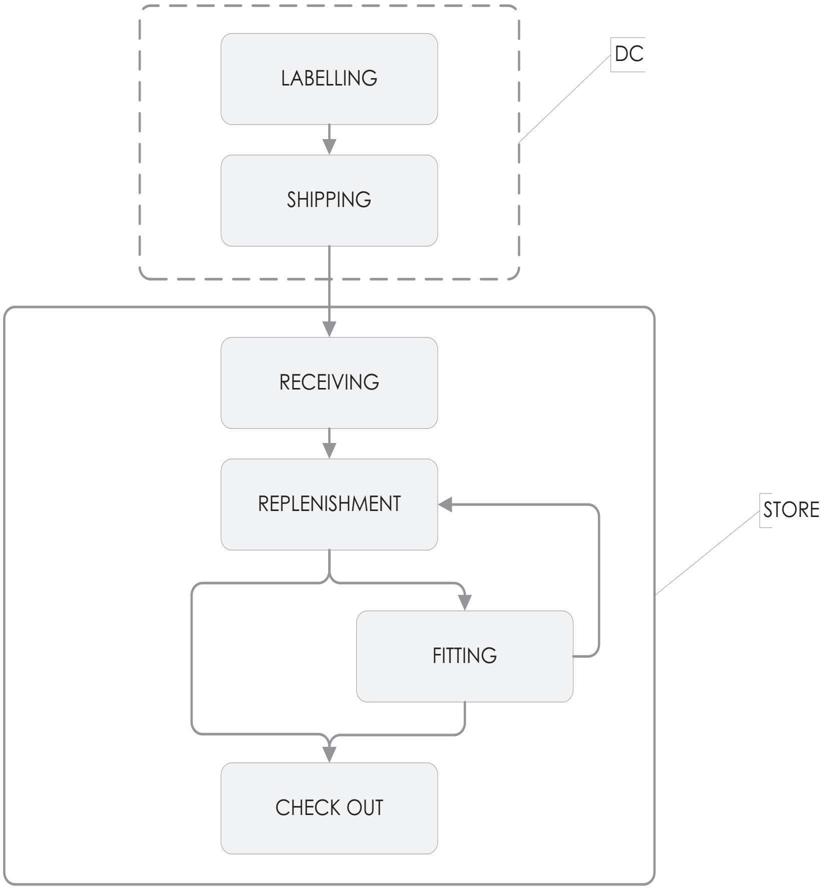


Fig. 4: Processes impacted by RFID technologies.

4.3. The products

The products monitored during experimental campaign belong to the spring/summer 2009 season. They can be divided into two categories: hanging items and folded items. The ‘hanging items’ are products shipped via z-rack and hung in the selling area of the store. This category includes dresses, jackets, pants, shirts, etc. The ‘folded items’ are shipped into a packages and include T-shirts, sweaters, jewellery, scarves, shoes, belts, bags etc.

This categorization is important because the same process could need different activities with different effects on the RFID performance. In fact a different time consuming is expected when hanging items are read compare to items packed into a box.

4.4. The store

The project is mostly focused on the store processes. For this reason an overview of it is reported in the present section (see Fig. 5).

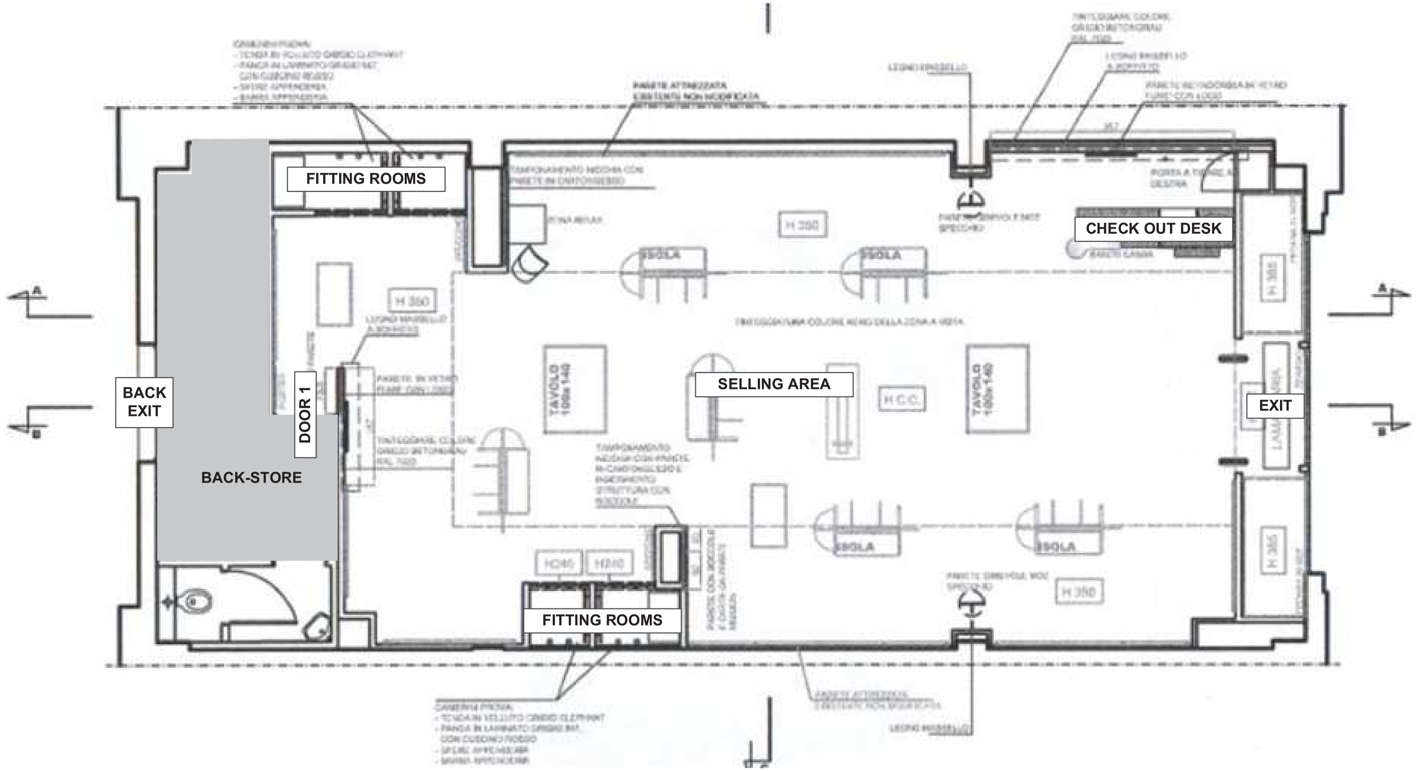


Fig. 5: Fidenza store layout.

The store has only a 25 square meter back-store connected with the selling area by an inner door (DOOR 1). Two couples of fitting rooms are present, for a total of 4 fitting rooms. Near the exit a check-out desk is placed. All the selling area is furnished with displays and tables in order to show the garments.

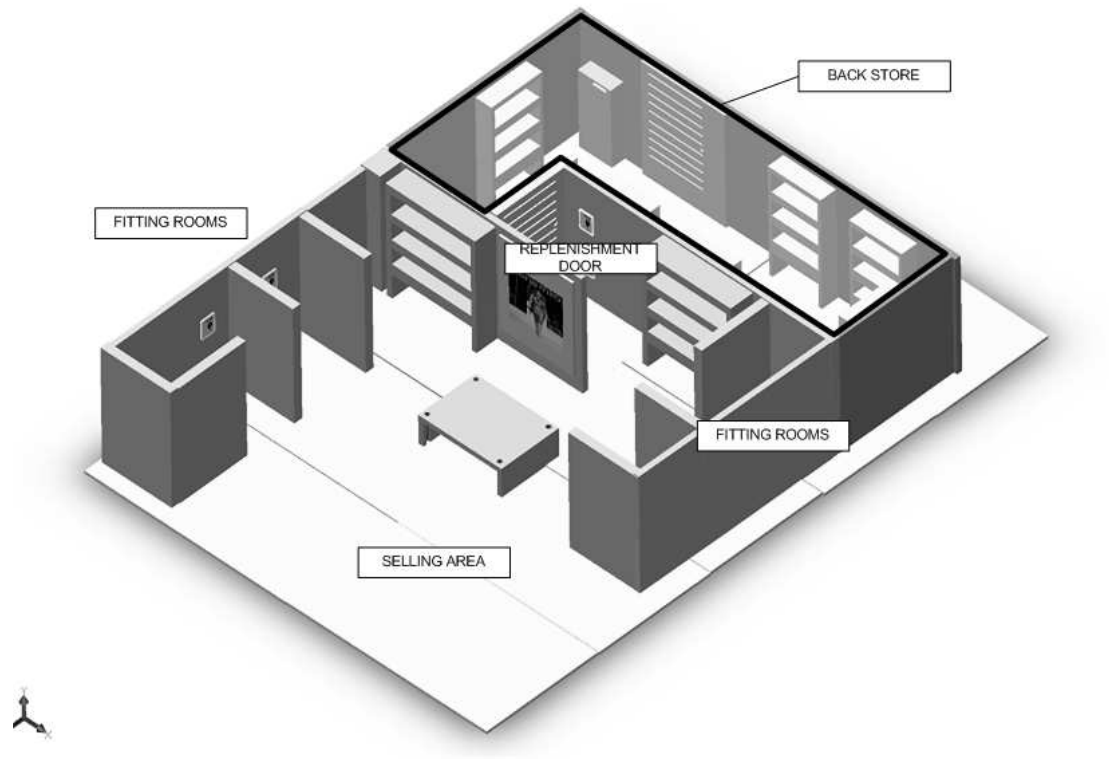


Fig. 6: Fidenza store, 3D model.

4.5. Identification label

Regarding the objectives of the project two types of identification labels will be described:

- ✓ Item-label (price-tag), used to indentify each garments;
- ✓ Case-label, used to identify the packages or a group of hanging items aggregated in a unique virtual box.

The item-label reports the following information:

- ✓ Model number;
- ✓ Color;
- ✓ Season;
- ✓ Client number: the code which identifies the destination store;

- ✓ Incremental number of the item aggregated to the case (virtual or real);
- ✓ EAN 13: reporting national code, company prefix and item reference;
- ✓ Description;
- ✓ Size;
- ✓ Original price;
- ✓ Discount (sometime omitted);
- ✓ Sale price.

Fig. 7: Label information.

The case-label is applied on the packages in order to identify them. The label is the same as the item-label except for graphics, in fact the following information are reported:

- ✓ Client number;
- ✓ Week;
- ✓ Device number;
- ✓ Incremental number of the case (it is reset every day);
- ✓ Number of items in case.

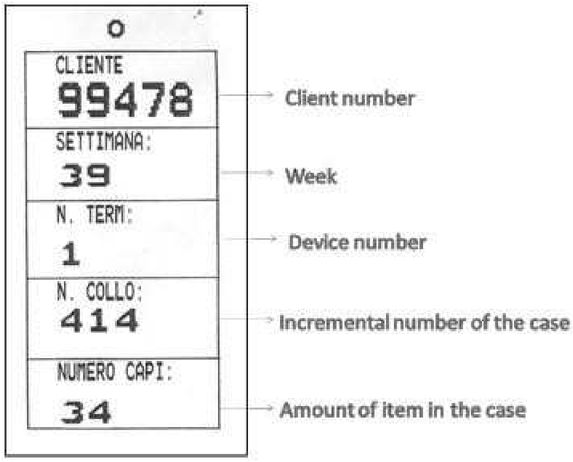


Fig. 8: Case-label.

4.6. The processes

The adoption of RFID technology acts, as a natural consequence, a changing of the activities of the company where it is adopted. This is clearly the case with Miroglio Fashion. To a proper understanding of the reengineered scenario, an overview of current operational procedures it is considered appropriate to present. The results of a previous systematic investigation of all logistic processes are following shown. All processes are describe following the physical and informative flows.

4.6.1. Labelling

At the end of each season the unsold garments of the standard stores are sent back to the DC in order to forward them in the outlet market. During their permanence in the DC, the garments must be verified and reconditioned. During the reconditioning activities each item is reset to its initial conditions of sale and the price-tag, reporting the original information, is substituted with a new one reporting new information like new price, discount, destination store.

Before to start the process the operator selects, by an assigned PDA, the destination store e begins the process printing a case-label. All the item-label printed after it will be joined together. Subsequently the operator scans the barcode (EAN13) reported on the original label by a PDA with a barcode scanner embedded. The PDA application embeds a local database which links EAN13 code to all the information needed and send the printing command to the thermal transfer printer. In Fig. 9 the cross-functional flow chart of the process is shown.

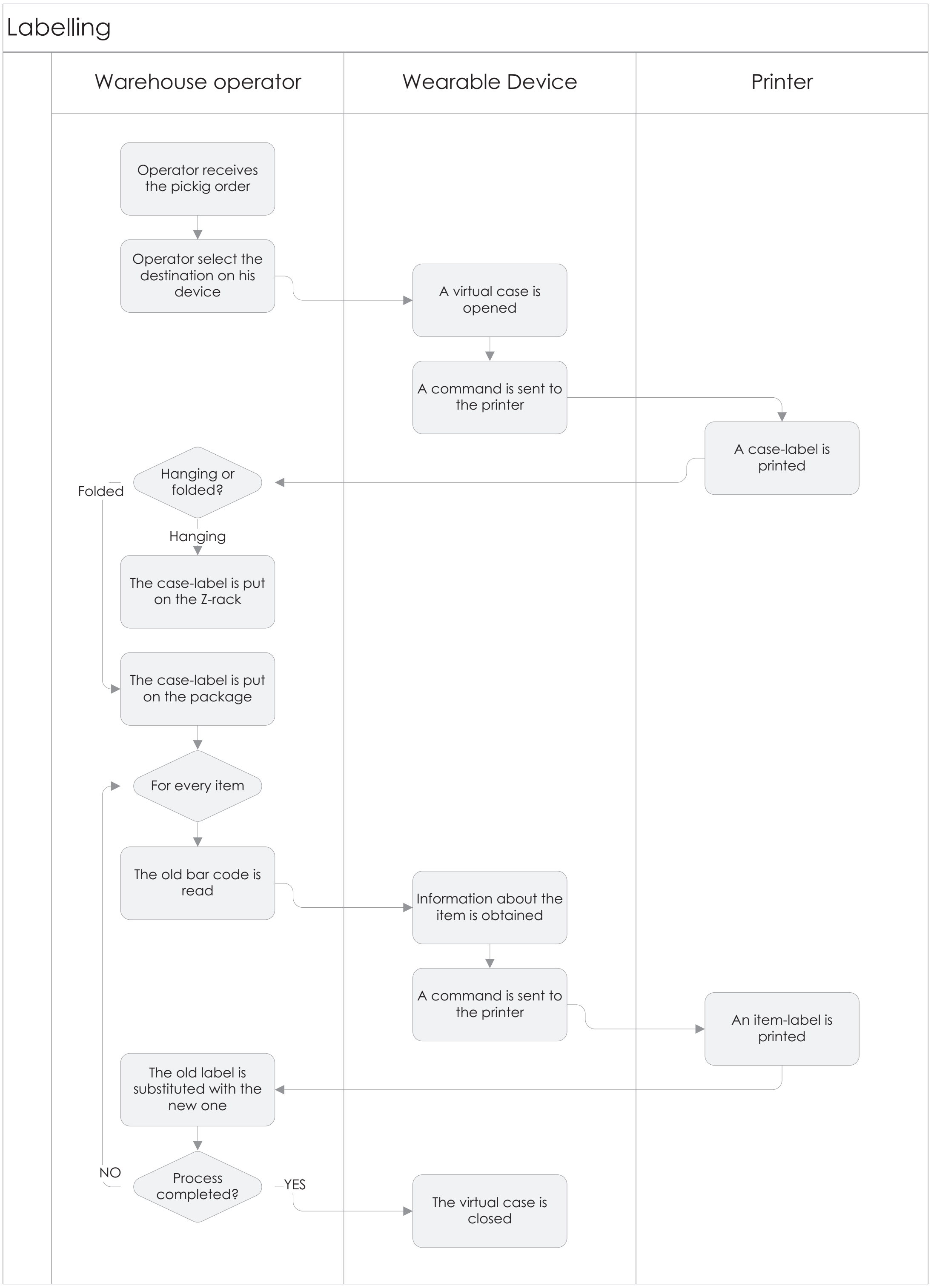


Fig. 9: Cross-functional flow chart of Labelling process.

The hardware devices involved are:

- ✓ Symbol PDA, by Motorola, with barcode scanner embedded, used to scan the barcode on the original label. An off-line database of the product details is installed in and allows the PDA to obtain all the information about the items and the relative labels;
- ✓ Zebra printer, battery powered, connected with the PDA through a Ethernet-WiFi adapter.
- ✓ PDA and printer are connected by a point-to-point wireless network. So the process can work off line without link with the company information system.

4.6.2. Shipping

At the end of the reconditioning activities, the garments are available to be shipped. The warehouse manager provides the assigned operator with the list of the garments to be shipped via paper document. The operator collects the garments and the packages and, after a last visual check, loads them into the courier's trucks.

The number of the items to be sent could be split in more partial shipments in order to optimize the journeys or to respect the particular demand of the destination stores. Each shipment is one-to-one type and it is associated with a Bill of Lading (BOL). The packages are aggregated in pallets of three or four layers each one formed by four packages. The hanging items, instead, are loaded on a returnable z-rack. The Fig. 10 shows the cross-functional process flow.

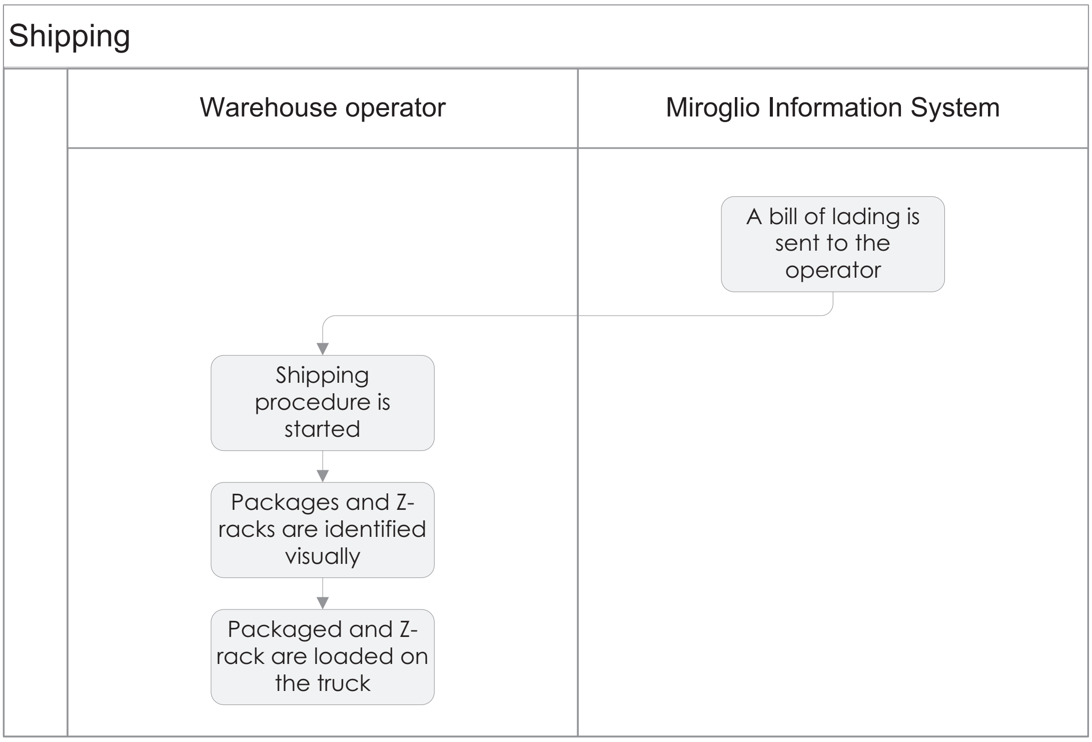


Fig. 10: Cross-functional flow chart of Shipping process.

The Shipping process does not need particular hardware devices. Only a desktop computer is used in order to confirm the shipping details in the information system. The entered information reports the shipping arrangement.

4.6.3. Receiving

The shipment arrives, by courier, to the Point of Sale located into the Fidenza Village, outlet center close to Parma (IT). The receiving area is located in the assigned square on the back of the store. In case of a calm weather, the process is performed at the outside of the store but in case of bad weather it is performed inside of the store. After a quick check of the received items, the couriers is set free and the items are stored inside: a part of them in the selling area of the store, the rest in the back-store. A detailed check of the product is not performed so only evident errors could be detected (e. g. miss shipment).

Subsequently, the shop assistants apply the antitheft pin to the received garments. During this activity a more detailed check is performed, but not sufficient to detect model or size errors. If no errors are detected the BOL is confirmed using an assigned application installed on the check out terminal. The cross-functional process flow is shown in Fig. 11.

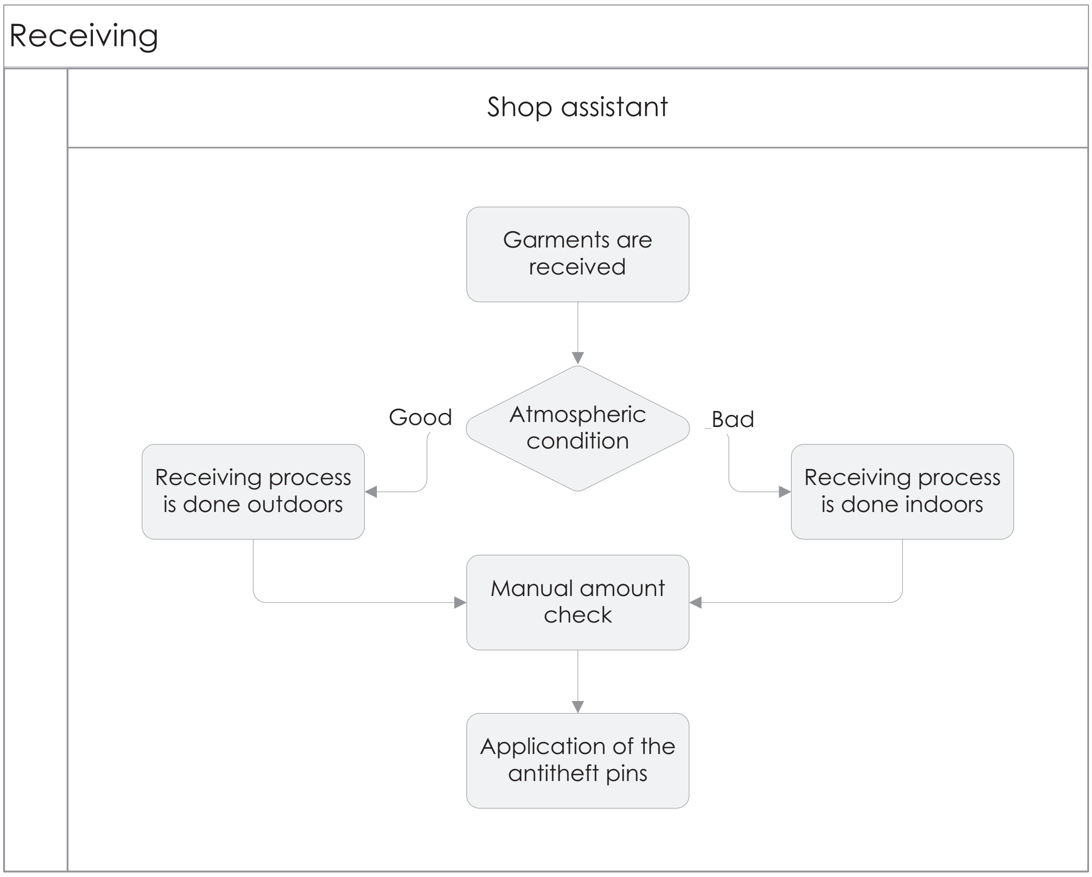


Fig. 11: Cross-functional flow chart of Receiving process.

No hardware devices are necessary to complete the process. The check-out terminal is used to confirm the BOL in order to update the virtual stock of the store.

4.6.4. Replenishment

In accordance with the company's directives and in order to maximize the number of the variants displayed, at least an item for stock keeping unit (Sku[2]) is exposed in the selling area.

When an out-of-stock is detected, during a normal activity or after a customer request, a shop assistant verifies in the back-store the availability of the Sku requested. In case of stock out inform the information system by the check-out terminal. The replenishment activities are not tracked, therefore a different stock management for the selling area and the back-store is not possible. That means the shop assistants have no way of checking the availability of the Sku requested without their experience, increasing the sales loss probability.

The cross-functional process flow is shown in Fig. 12.

[2] Stock Keeping Unit: is an identification of a particular product that allows it to be tracked. In fashion business, an Sku is associated with any purchasable item with a particular style, color and size.

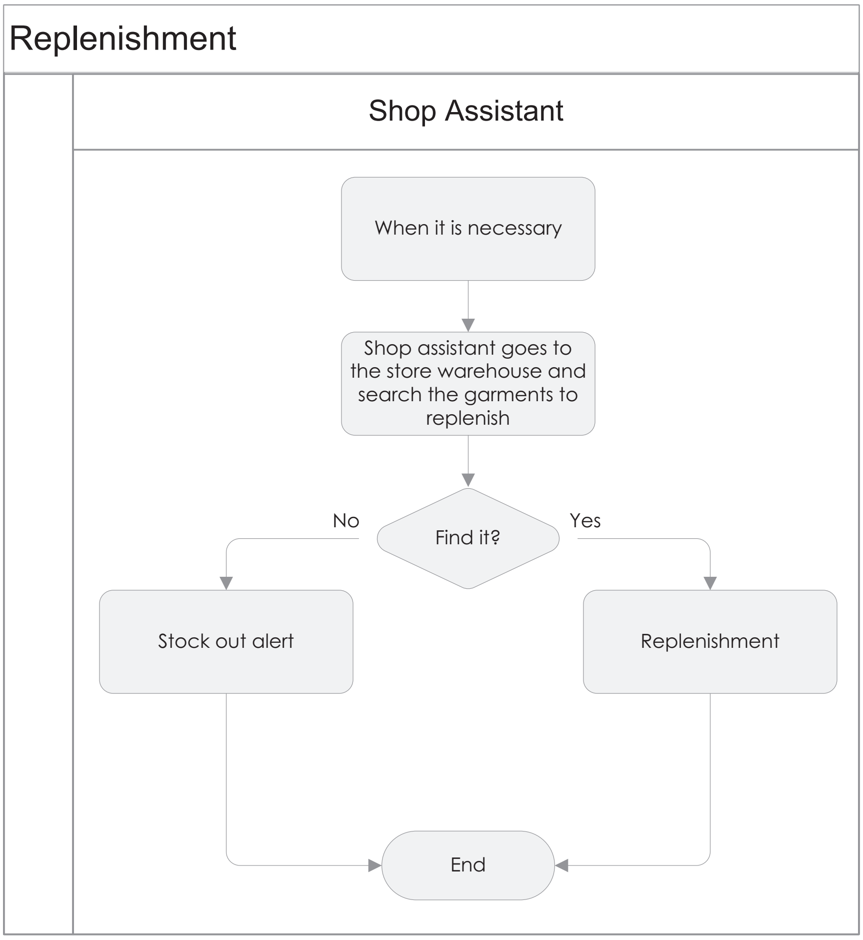


Fig. 12: Cross-functional flow chart of Replenishment process.

No hardware devices are necessary to perform the process.

4.6.5. Checkout

After that all the processes have been placed, a customer who wants to buy one or more garments goes to the check-out desk. The shop assistant checks the items and removes the antitheft pins. Each price-tag is scanned, by bar code scanner, and the data is processed by the check-out terminal in order to obtain relevant information like description, price and discount. Before confirming the receipt, the shop assistant removes the labels and completes the procedure. The pendant removed are stocked in an assigned box for potential cash check, in case of mismatching. The barcode scanner communicates with the check-out terminal using keyboard emulator protocol. The same protocol can be used by RFID system in order to minimize the impact of the RFID software infrastructure on the check out application.

Fig. 13 shows the cross-functional process flow.

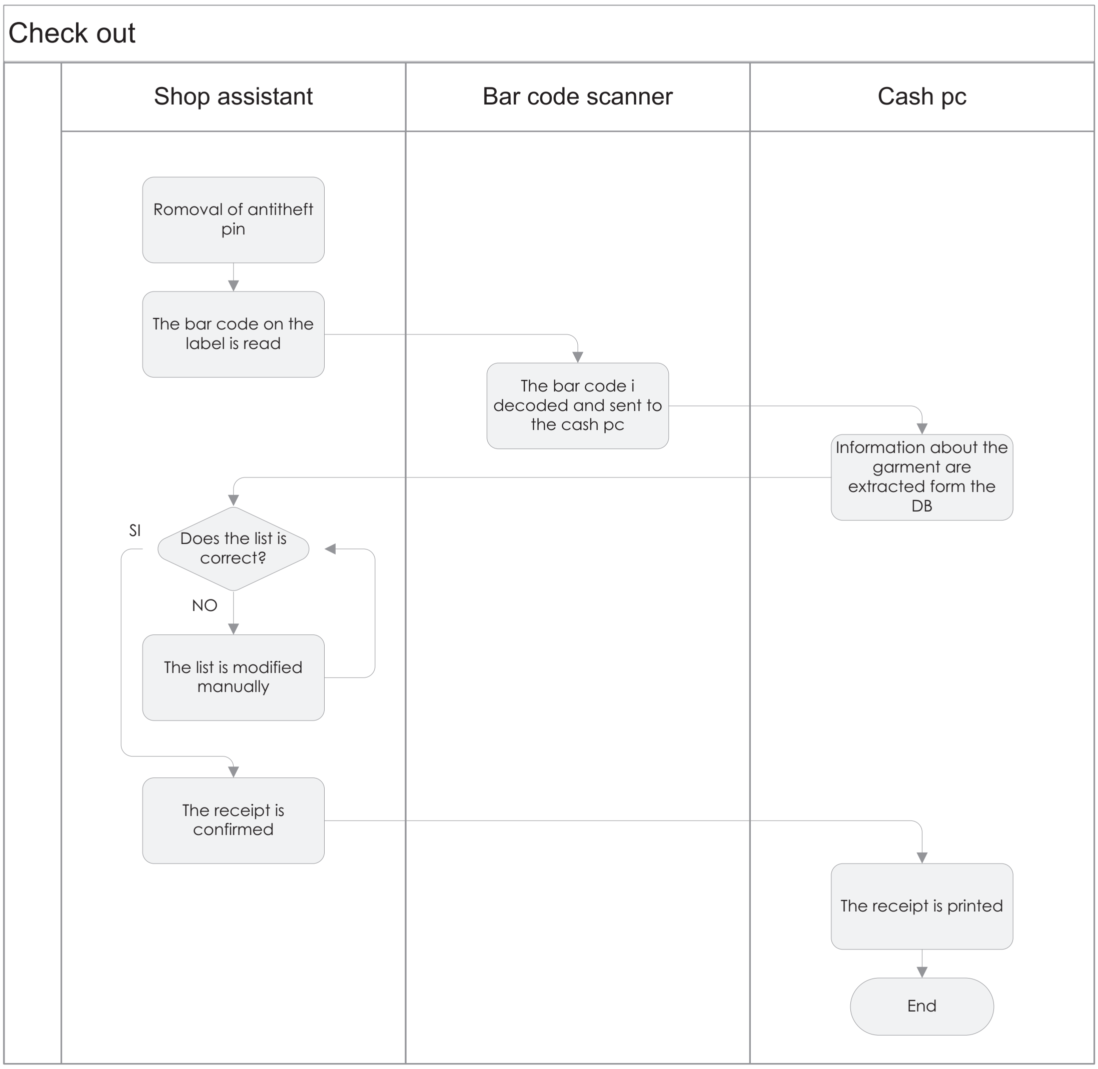


Fig. 13**: Cross-functional flow chart of Checkout process.**

As far as the process is concerned, a desktop computer, with ad hoc application, is used like a check out terminal. In addition the same desktop computer can be used for all the other activities of the store.

5. ‘TO BE’ REENGINEERING

5.1. Introduction

Starting from the AS IS analysis, the feasibility assessment should provide reengineering (‘TO BE’) scenarios, hypothesizing, through business process reengineering (BPR), a new definition of procedures, activities and operations to perform those processes adopting RFID technology [28]. Therefore from the framework described above, a proposal of business process engineering has been developed as a tool for a real-time traceability of each item through the supply chain. In according with the ‘pilot’ nature of the project, the processes have been reengineered minimizing the impact of the new activities on the original ones, even if same integrations, when possible, have been placed.

In detail, at the distribution centre, a specific area was assigned to the experimental activity. In that area, each item destined to the pilot store, is reconditioned and the original price-tag is replaced with an RFID label. The RFID label is very similar to the original one except for some new information written on it and the inner RFID tag, programmed by the RFID Printer. The packages and the hanging items ready to be sent are temporarily stocked in a reserved area where the shipping process is placed. Thanks to this process, detailed data about the shipped garments can be available to the Receiving process in order to improve inventory accuracy. In fact the shop assistant can compare the garments received with the expected garments using the RFID devices and the appropriate software applications provided. This activity allow them to detect misalignments between the BOL and the items actually received. The receiving process updates the status of inventory, split into back-store inventory and selling area inventory. At the same time the information of traceability of the received items are stored in an appropriate DB compliant with the EPCglobal specifications. An application for RFID Replenishment process is provided, designed in order to reduce the activities in PoS. Thank to this application, the transition from back-store to selling area, and vice-versa, can be observed automatically in order to update in real time the two informative stocks.

In order to solve possible misalignments between the real stock and the informative one, a process, named ‘RFID Inventory’, has been engineered and provided. Using a portable RFID device connected via WiFi network, the shop assistant can read all the garments in the selling area or in back-store updating the informative system.

Finally, the Check-Out process has been reengineered in order to speed up the activities thanks to a reading zone installed into the check-out desk, so the auto-detection of the garments in the reading area has been provided. As in the original process, at the end of the check out, the price-tags, now RFID, are removed and stored in a 'trash container' with an inner RFID antenna embedded. The labels stored into the trash container are periodically removed in order to evaluate the performance of the system.

All data collected from the RFID processes, are stored in a EPC repository compliant with the EPC Global standards. These data are fed into a web applications, called RFID Dashboard, and shared with the companies involved.

5.2. EPC Global Standard adoption

In the present section, after a brief overview, the application of the EPCglobal Standards, in particular about the EPC Information Services (EPCIS) [34] and the Tag Data Specifications [35], is shown.

EPCglobal™

EPCglobal is an organization founded with the aim to achieve worldwide adoption and standardization of Electronic Product Code (EPC) technology. The group is mostly focused on the creation of both a worldwide standard for RFID and the use of the Internet to share data via the EPCglobal Network (Internet of Things). Each player which wants to adopt the RFID technology and wants to be EPCglobal compliant, needs a data warehouse designed in accordance with the EPCIS standard. In this way it is possible to store, to manage and to share data through the supply network. The standard defines five event types: one very generic (EPCISEvent) and four subclasses. These can represent events originated from supply chain activities across a great variety of industries:

- ✓ **ObjectEvent:** event that happened to one or more entities identified by EPCs. For instance when a tagged garments is read during the shipping process, an ObjectEvent occurs;
- ✓ **AggregationEvent:** event that happened to one or more entities identified by EPCs that are physically aggregated together (in the same place at the same time). For instance when some garments are packed into the same box to be shipped, an AggregationEvent occurs;

- ✓ **QuantityEvent:** event concerned with a particular number of items with a common EPCclass, but where the individual identities of the items are not specified, or it is not important. For instance when some garments of same Sku are moved from the back-store to the selling area a QuantityEvent occurs;
- ✓ **TransactionEvent:** event in which one or more entities identified by EPCs become associated or disassociated with one or more business transactions. For instance when a package is shipped, it is associate with a Bill of Lading and a TransactionEvent occurs.

Moreover, EPCIS standard provides the essential parameters to describe consistently each event type and the procedure to add more parameters when necessary.

The essential parameters for each event type are followed reported and described:

- ✓ **ObjectEvent**: *eventTime, recordTime, epcList, action, bizStep, disposition, readPoint*
- ✓ **AggregationEvent**: *eventTime, recordTime, parentID, childEPC, Action, bizStep, disposition, readPoint, bizLocation, bizTransaction*
- ✓ **QuantityEvent**: *eventTime, recordTime, epcClass, quantity, bizStep, disposition, readPoint, bizLocation, bizTransaction*
- ✓ **TransactionEvent**: *epcList, action, bizStep, disposition, readPoint, bizLocation, bizTransaction*

Event Time e Record Time

EventTime and RecordTime provide time information about the event. The first one, EventTime, provide the time stamp at which the EPC event was occurred, while the second one, RecordTime (optional), inform about the time stamp at which this event was stored in an EPCIS Repository. These two fields are completed by an adding field, eventTimeZoneOffset, reporting the time zone. This is useful to compare events occur in different parts of the world. EventTime and RecordTime answer the question "When?".

EpcList, ParentEPC, ChildEPC e EpcClass

EpcList, parentEPC, childEPC and epcClass provide information about the subject of the event:

- ✓ In regards to an ObjectEvent and a TransactionEvent, the EpcList is a list of one or more EPCs denoting the physical objects to which the event pertained. In the case study they are garments or packages.

- ✓ In regards to an AggregationEvent, the objects to which the event pertained are a container (parentEPC) and which it contains (childEPCs). In the case study the association concern a case (parentEPC), both virtual and real, and one or more garments (childEPC);
- ✓ In regards to a QuantityEvent, the objects to which the event pertained is a class, reference, sku or article are indentified by an epcClass.

These information answer the questions "Who?" or "What?".

An EPC (Electronic Product Code) is an universal schema used to identify objects or entities. The schema to use depend on the object or the entity to indentify. In the case study, the followings schemas are necessary:

- ✓ **SGTIN** (Serial Global Trade Item Number) used to identify a vendor unit. The URI schema is *urn:epc:tag:sgtin-96:FFF.PPP.III.AAA* where
  - FFF identify the SGTIN type (depend on the package type, see below);
  - PPP means Company Prefix (company identifier provided by GS1. In the case study, it is obtained by the EAN13 bar code);
  - III provides the Item Reference (Reference identifier unique into the company. In the case study, it is obtained by the EAN13 bar code);
  - AAA is the Serial Number (number wich idendify a prticolar item of the reference III).
  - In the case of an epcClass the schema is urn:epc:idpat:sgtin:PPP.III.*, where * means 'any serial number'.
- ✓ **SSCC** (Serial Shipping Container Code) is used to identify shipping unit which contain different references. The URI schema is *urn:epc:tag:sscc-96:FFF.PPP.III* where:
  - FFF identify the SSCC type;
  - PPP is the Company Prefix;
  - III is the unambiguous number of the shipping unit.

In the case study the FFF code is used to differentiate hanging items from the folded ones. In fact, in according with the standard, hanging items could be interpreted like 'Full case for transport' (FFF = 2), otherwise folded items could be interpreted like 'Point of Sale Trade Item' (FFF=1). Therefore an access to a backend information system is not required to distinguish the two garments type reducing the traffic connection and improving the devices' performances.

BizStep e Disposition

The bizStep parameter describes the business processes in which the EPC is involved, while the Disposition parameter provide a business state of the EPC, subsequent to the event. These information answer the question "Why?". For instance, if a garments is reserved for a particular client or store during the Labelling process, the EPCevent will be having, as Disposition, the value "not_available" or "reserved". This indicates the unavailability of that garment for other stores.

ReadPoint

A read-point, or tracking point, is a logical discretely location that is meant to identify the most specific place at which an EPCIS event took place. Conceptually, the Read Point is designed to identify 'how or where the EPCIS event was detected'. A readPoint can be a physical RFID reader or not. In fact an unique RFID reader could be used to track items trough two different gates, in this case two readPoints will be defined, or more RFID readers could be used to implement a unique gate, in this case an unique readPoint will be defined.

A readPoint could be defined using the EPC schema defined by General Identifier (GID), whose URI is: urn:pec:id:gid:MMM.CCC.SSS, where:

- ✓ MMM: General Manager, in the case study the Miroglio's company prefix will be used;
- ✓ CCC: Object Class, it identifies a class or "type" of thing, It must be unique within each General Manager Number domain (see Tab. 1 below);
- ✓ SSS: Serial Number which indentify a specific read point. It is unique within each object class domain.

Device type	CCC
Mobile Reader	300
Fixed reader	100
Printer	200

Tab. 1: CCC value in the GID schema.

BizTransaction

A list of business transactions that denotes the context of this event. This parameter is obligatory only for Transaction events.

BizLocation

BizLocation field identifies a certain company area where the EPC objects, concerning the event, may be found, until contradicted by a subsequent one. BizLocation parameter can used to identify a branch company, a building, a warehouse, a room or a storage location depending on the company needs. In according with the EPCIS specification the field bizLocation identify the place where the event object will be found at the end of the event. In the case study bizLocations identify different areas of the DC and the PoS.

The EPC schema is defined by SGLN (Serial Global Location Number), whose URI code is urn:epc:id:sgln:PPP.III.AAA, where:

- ✓ PPP: Company Prefix;
- ✓ III: Location Reference, assigned uniquely by the managing entity to a specific physical location (see Tab. 2 below);
- ✓ AAA: Extension Component, assigned by the managing entity to an individual unique Location.

Description	*III*
Labelling Area	102
Shipping Area	103
Back-store	220
Selling area	225
Oblivion	230
Fitting room	225
Check out	500

Tab. 2: Location number (III) definition.

5.3. Hardware solutions

In according with Miroglio company all the garments of the spring/summer 2009 destined to Elena Mirò store are tagged and monitored.

The hardware device chosen are:

- ✓ RFID Tag: UPM Web, UHF GEN 2 with Monza3 chip, embedded into the price-tag;
- ✓ Speedway fixed reader, by Impinj;
- ✓ Handheld device:
  - o Workabout Pro 2 with RFID module by Psion Teklogix;
  - o Skeye with RFID module by Integral;
- ✓ Printers:
  - o RZ400 printer with UHF RFID module, by Zebra Technologies;
  - o B-SA4TP printer with UHF RFID module, by Toshiba Tec.

In agreement with the company, it was decided to tag and monitor all the garments of the spring summer season, approximately 10,000 items for the store 'Elena Mirò'. The new labels are similar to the old ones, with an inner RFID tag. The tags used are 'wet inlay' type, passive, compliant with the UHF EPC GEN 2 standards and a Monza3 chip is embedded. The choice of the tag was based on the dimension of the tag, compliant with the dimension of the original label, and the performance got by previously tests.

5.4. General network infrastructure.

Fig. 14 shows the network infrastructure installed among the players of the supply chain compliant with the EPCglobal standard.

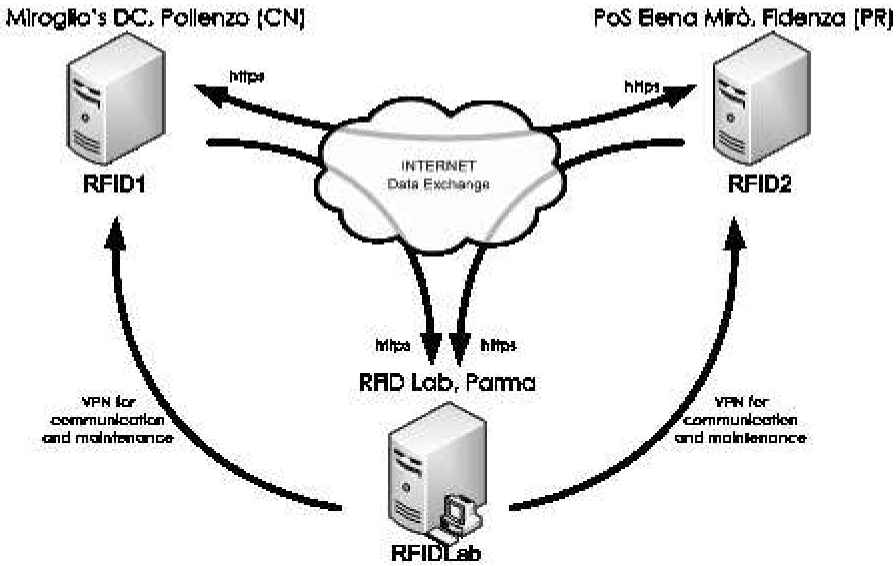


Fig. 14: Network infrastructure

The network infrastructure is set of:

- ✓ A LINUX server for the management of the RFID processes, installed in Miroglio's DC, located in Pollenzo (CN), named *RFID1*;
- ✓ A LINUX server for the management of the RFID processes, installed in the store "Elena Mirò", located in Fidenza (PR), named *RFID2*;
- ✓ Control and data elaboration infrastructure installed in RFID Lab, University of Parma, named *RFIDlab*.

Following the communications between the items of the network infrastructure are described:

- ✓ *RFIDlab* accesses to *RFID1* and *RFID2* by a VPN connection in order to perform remote maintenance activities. Therefore, *RFID1* and *RFID2* are totally open to *RFIDlab*.
- ✓ In order to realize the Receiving process EPCglobal compliant, *RFID1* and *RFID2* must have internet access , in particular, *RFID2* must be able to access to the data stored in *RFID1* by https protocol.
- ✓ *RFIDlab* acceses, by internet network, to *RFID1* and *RFID1* in order to download data necessary to update the web Dashboard.

5.5. Network infrastructure installed in the store

Fig. 15 shows the network infrastructure realized into Elena Mirò store.

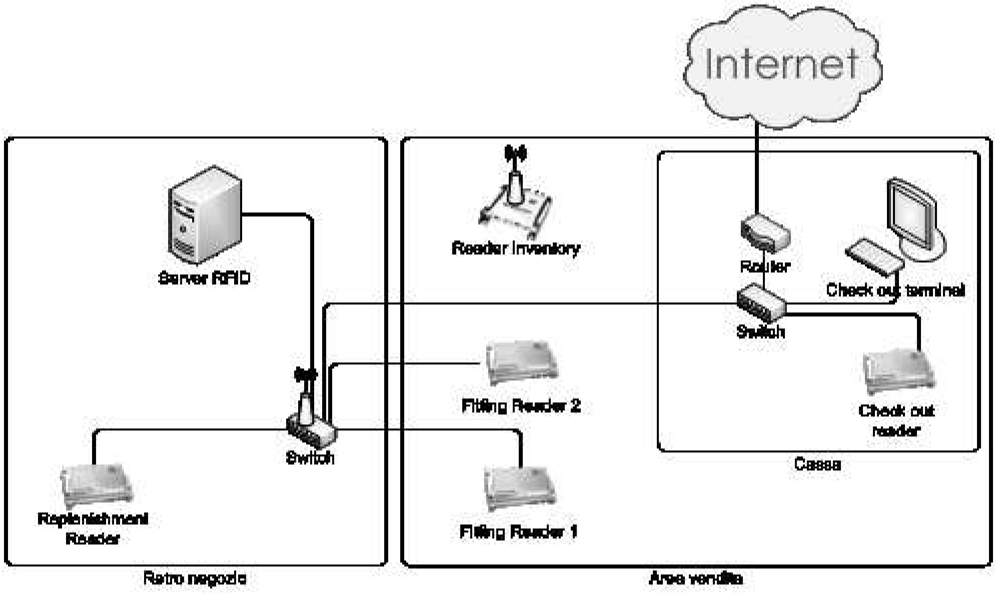


Fig. 15: Elena Mirò Network infrastructure.

A modem is installed to provide internet access and placed near the check out desk. The infrastructure consist of two physical sub-networks, one realized near the check out desk connected by switch to the modem and the check out reader, the other placed into the back-store connected by switch to the server, the two fitting readers, the replenishment reader, the WiFi access point and, finally, the RFID printer. The two sub-networks are able to communicate in order to share internet connection. The WiFi access point allow the communication with the wireless devices: handheld devices and inventory reader.

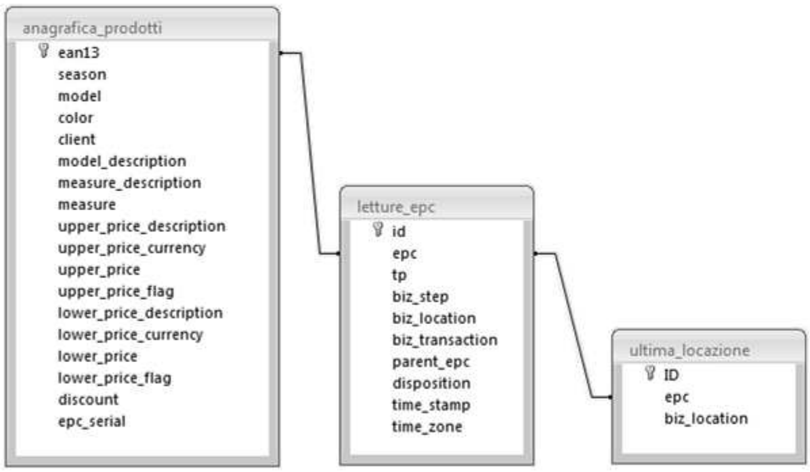
5.6. Database description

The database infrastructure is more complex than that described below, in fact al lot of table are used by the middleware RFID and the capturing application. The description below is limited to the essential tables used by the reengineered processes and necessary for their comprehension.

There are three main tables used by the processes in order to work correctly, in addition the same tables will be used to extract the necessary data for the evaluation of the metrics.

The three tables are:

- ✓ Anagrafica_prodotti (product description): it contains all the information about every Sku (standard keeping unit). In particular the necessary data for the label printing are stored in. The key field is 'EAN13' which represent the barcode;
- ✓ Letture_epc (epc readings): it contains all the EPCIS object events. The key field is 'id' because the field 'EPC' can be repeated in fact more events can involve the same EPC;
- ✓ Ultima_location (last location): it contains the last location for each EPC. The key field is EPC because every EPC can have only one location. The 'location' field is modify by the process executions.



5.7. Business process reengineering

In accordance with the above, in the next sections the reengineered processes are reported. Each process will be described using four sub-sections:

- ✓ **Business Process Reengineering**: description of the process and evolution from a row idea to stable and final procedure. Therefore critical situations and their solutions will be reported in order to provide general rules for an RFID implementation.
- ✓ **Hardware devices**: description of the hardware devices employed on the process.
- ✓ **Data flow**: description of the EPCIS events generated during the process.
- ✓ **Barriers and solutions**: summary of the principal barriers occurred, the solution suggested and implemented.

5.7.1. RFID Labelling

Business Process Reengineering

The new process reengineered needs an integration with the back end system. In fact the access to the database, where all the information about the garments are stored, is necessary in order to print an RFID label similar to the previous one.

One of the mobile devices (PDA with bar code scanner embedded) used by the operator to create the price tags has been assigned to the new RFID process. The previous application has been adapted in order to communicate with the RFID server which controls the printer.

Therefore, when the operator needs to work on pilot garments he/she uses the mobile device assigned. By the application installed, he/she chooses the point of sale and the process can start. Subsequently, by the same application, the operator 'opens' a new case, that means the application generates a virtual, or informative, box and all the garments printed after this are aggregated with it, and the case-label is printed by the RFID printer. In fact a command is sent to the RFID server which generates the correct EPC (SSCC type) and forward the data to the printer. After that, the operator can start labeling garments and scans the bar code of the original label of the first item. The device obtains, from its off-line DB, the information to print and send the data to the RFID server. This, by assigned web service, elaborates the data just received, generates the EPC code (SGTIN type) and forward the command to the printer which prints the new label writing, at the same time, the EPC code. After that the operator can substitute the old price-tag with the RFID one. In Fig. 16 the cross-functional flow chart is shown.

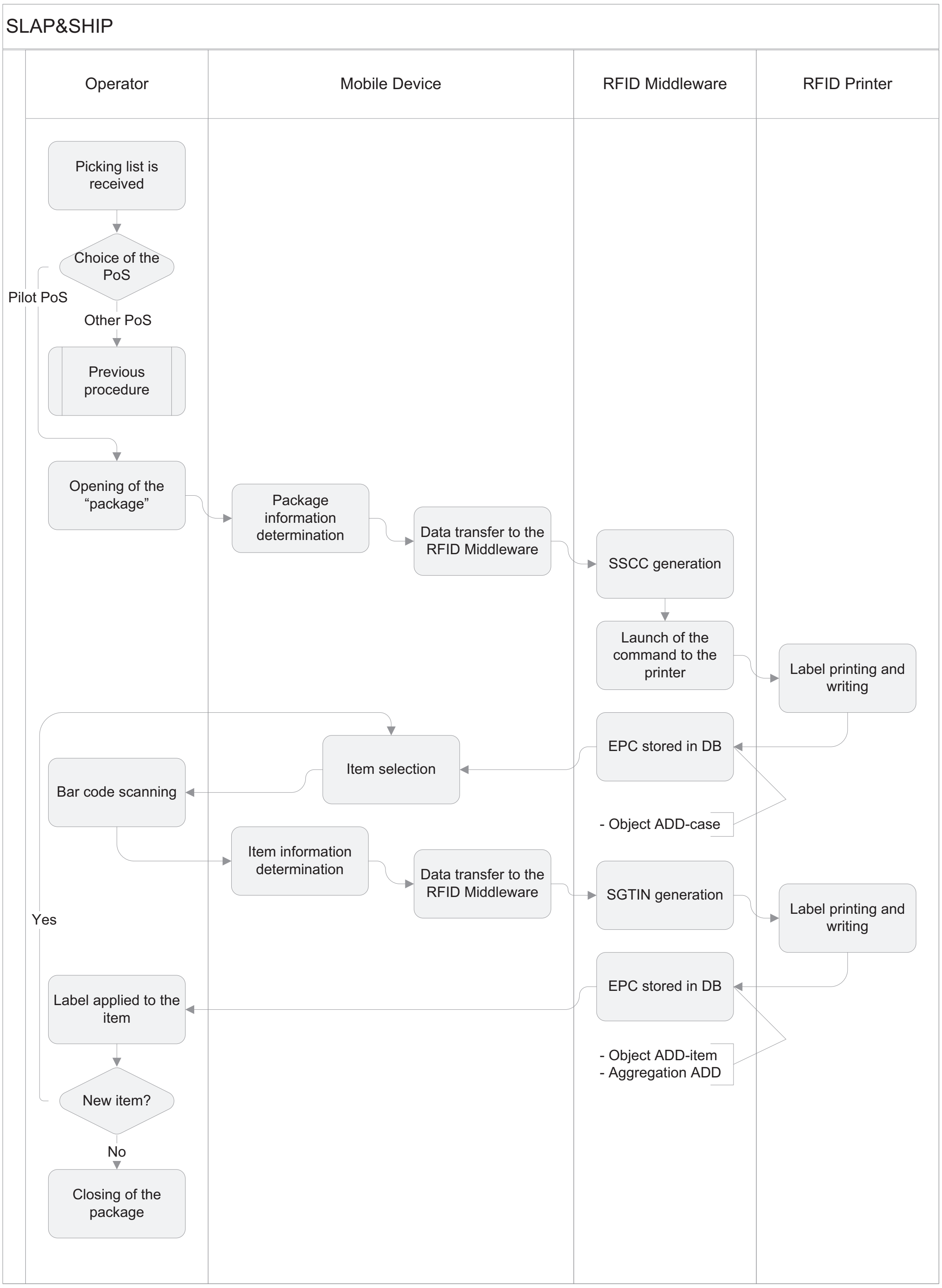


Fig. 16: Cross-functional flow chart of RFID Labelling.

The graphics of the new label is quite similar to the old one. Some new information has been added in order to recognized each item and distinguish it from the others. In fact, with the implementation of the RFID system, the management logic switches from the management of the Sku to the management of the single item. Therefore two new information are printed:

- ✓ Filter: could be 1 or 2, depending on the garment type (hanging item or folded items).
- ✓ Serial: it is the serial number of the SGTIN. All the serial number printed by the Labelling process end with '0'. In order to distinguish them from the label printed in Elena Mirò store which end with '1'.

In Fig. 17 an example of a label is provided.

Fig. 17: RFID Label.

Hardware devices

The equipment installed is:

- ✓ Mobile device (already used by operator) connected to the network by a WiFi connection. In the 'As Is' scenario the mobile device was connected directly to the printer, in the 'To Be' process it is connected to the network in order to communicate with the server;
- ✓ Portable trolley with RFID printer and batteries embedded, connected by WiFi connection to the RFID server;

Data flow

EPCIS OBJECT ADD- case Event

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SSCC
Action = "ADD"
BizStep = urn:rfidlab:bizstep:fashion:Labelling
Disposition = "ready_to_ship"
ReadPoint = urn:epc:id:gid:95100046.200.1,2 (printer's GID)
BizLocation = urn:epc:id:sgln: 95100046.102.1
BizTrans = "null"

EPCIS OBJECT ADD-item Event

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN generated
Action = "ADD"
BizStep = urn:rfidlab:bizstep:fashion:Labelling
Disposition = "ready_to_ship"
ReadPoint = urn:epc:id:gid: 95100046.200.1,2 (printer's GID)
BizLocation = urn:epc:id:sgln: 95100046.102.1
BizTrans = "null"

EPCIS AGGREGATION ADD Event

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
Parent EPC = SSCC
ChildEPCList = SGTIN generated
Action = "ADD"
BizStep = urn:rfidlab:bizstep:fashion:Labelling
Disposition = ready to ship
ReadPoint = urn:epc:id:gid: 95100046.200.1,2 (printer's GID)
BizLocation = urn:epc:id:sgln: 95100046.102.1
BizTrans = "null"

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 3.

Barrier	Description	Issue	Solution
Network infrastructure:	Point-to-point communication between PDA and printer, off-line updating of the data store in PDA's memory.	EPC uniqueness cannot be guaranteed. If more PDAs work in same time on the same Sku (item reference), they cannot know the last serial number used.	Shared Wifi network has been deployed in order to share the EPC generator, guaranteeing the uniqueness of the EPCs generated.
Visual recognition of the item-label	The original label do not allow the distinguishing of each item of the same Sku because only the EAN13 code is written.	No information on the item-label can be used to distinguish each item of the same Sku.	New information (filter and serial) are printed in order to recognize each item and identify manually the EPC code.

Tab. 3: Barriers and solution of the Labelling process.

5.7.2. RFID Shipping

Business Process Reengineering

The RFID process is performed in a assigned staging area and involves only the tagged items (packages and hanging garments). From the 'As Is' analysis it is clear that an accurate check of shipment is not performed and this could increase the error rate, unknown at the moment. The new RFID process wants to evaluate and solve this issue.

The Labelling process provides the aggregation information (virtual or real box with items), so it possible to verify if all garments previously prepared are correctly shipped comparing the aggregation information with the actual readings.

The Shipping process can be split into sub-processes involving each single box, virtual or real. By this procedure the amount of data to elaborate is reduced in order to improve the computing power of the device. Each sub-process can be performed using two different devices, the RFID Handheld device or the RFID cage (see below).

An RFID Handheld device (industrial PDA with RFID reader and antenna embedded) is provided and an assigned application is installed. The operator starts the application and can select one of the cases to be shipped from the list downloaded from the RFID server via WiFi Network. He/she types in the BOL number and starts the reading. Automatically the device downloads the EPCs of the items aggregated and compares them with the EPCs actually read.

Three possible cases can happened about each EPC:

a) Expected EPC is read. Best situation, one of the EPCs belonging to the expected list is correctly read and it is shown on the application interface;
b) Expected EPC is not read. One of the EPCs belonging the expected list is not read by the device. The gap is shown on the application interface. The operator can decide to confirm it or ignore the alarm.
c) Unexpected EPC is read. It is ignored by the application in order to reduce the device computing stress.

After a variable time, the operator can decide to stop the reading in order to check the status of process (number of missing items) and if he/she is satisfied he/she can decide to terminate the process. In this case the list of the EPCs read, or manually confirmed, is sent to the RFID middleware in order to generate the EPC events. The data about the process are, in this way, stored in DB.

During the fine tuning activity, a particular behavior was observed: with a great quantity of garments the device was not able to complete the check algorithms. After some tests it became clear that the computing power of the handheld device was not sufficient to check all the EPC to be detected. A new installation was, therefore, necessary and RFID cage was designed, made and installed (Fig. 18).

Fig. 18: RFID Cage installed at the DC.

The RFID cage is composed of a metal cage (aluminum chassis and steel cloth), a RFID fixed reader and four circular polarized antennas. The metal cage provides the RFID shield and confines the read area into the cage, therefore the outer tags cannot be read. In addition the reflection of the signal, obtained by the metal surfaces, increases the probability of reading every single RFID tag. Moreover the fixed reader provide a 2 Watt signal (instead of 0.5 Watt provided by the HH device) and the four antennas expand the reading area to all the cage. Finally all the computing activities are trusted to the RFID server which has a higher computing power.

Obviously an RFID cage is not a solution for a real implementation (too expensive and too time-consuming), but it can deemed as a proof of concept of an RFID tunnel or shielded gate, more suitable for a real implementation.

Basically, the new RFID system does not change the process activities, even if the unexpected tag can be managed in order to identify all the packaging errors.

In Fig. 19 and in Fig. 20 the cross-functional flow chart is shown.

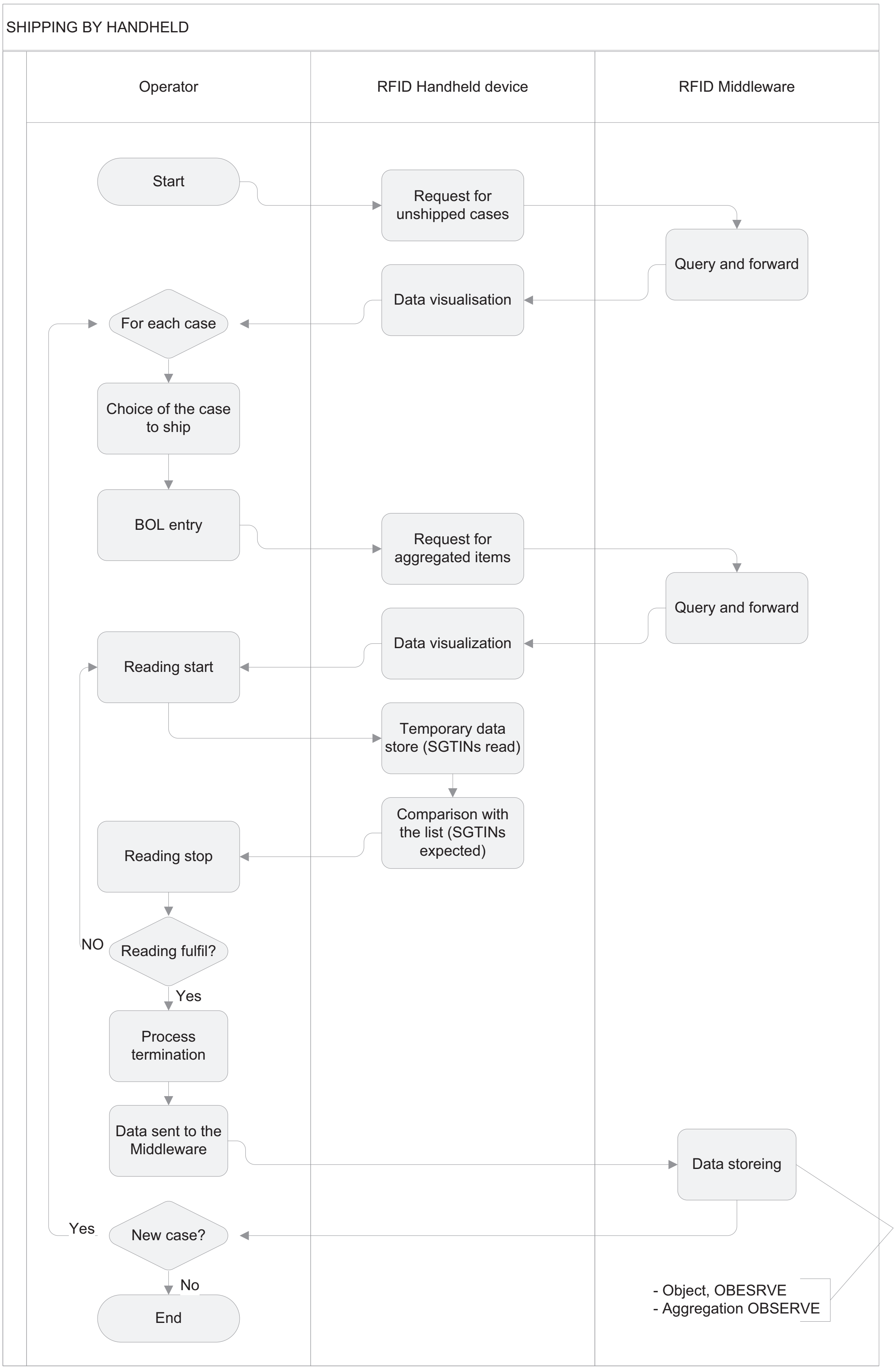


Fig. 19: Cross-functional flow chart of Shipping process performed by HH RFID.

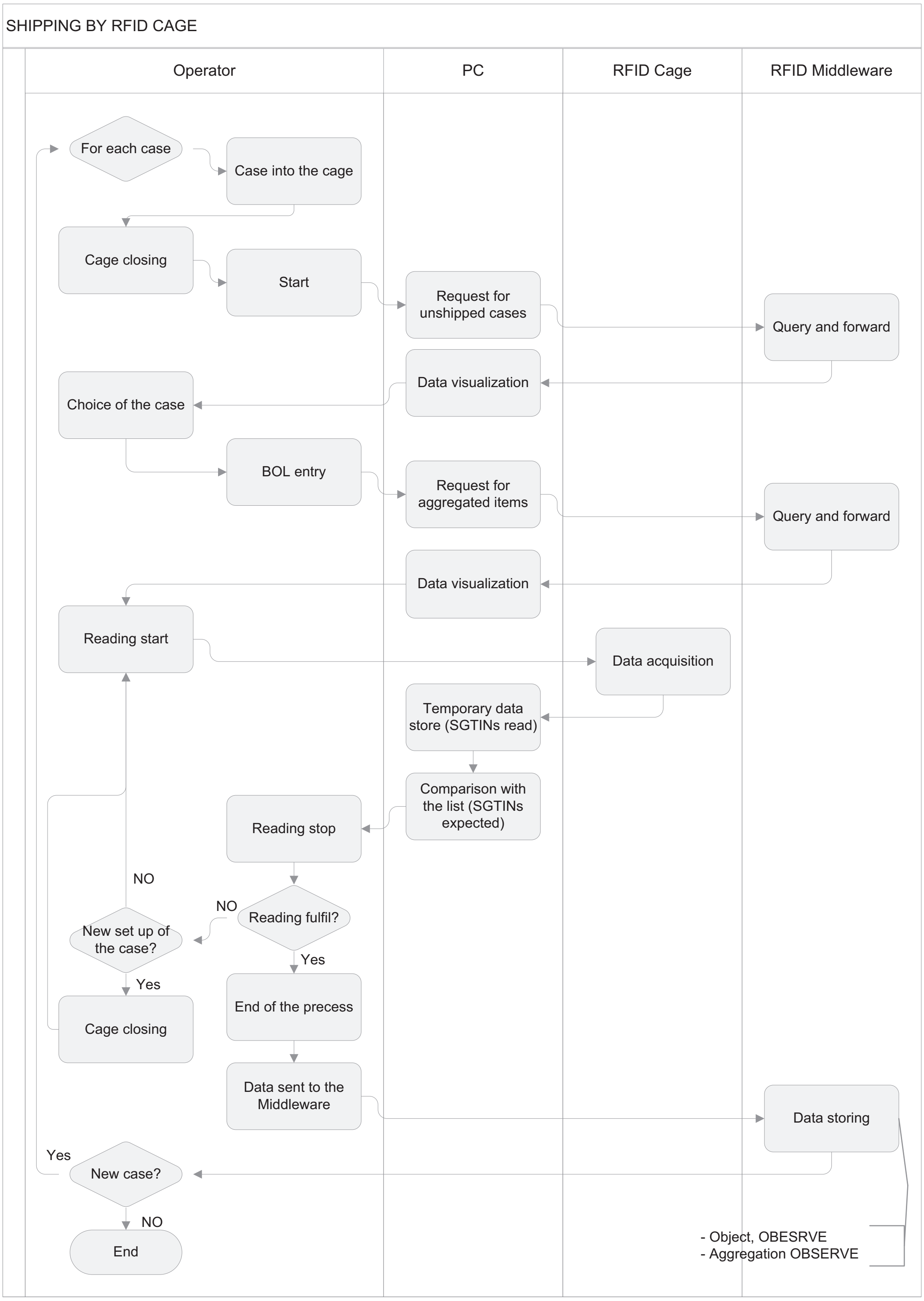


Fig. 20: Cross-functional flow chart of Shipping process performed by RFID cage.

During the experimental campaign some non-RFID friendly garments, named 'critical garments', were recognized. These kinds of garments have the property of being made with metal yarn or metal ornament. These create a shield that reduce the reading performance and the accuracy of the process. In fact not only these kind of garments cannot be read, but also the garments closer them. At the moment more tests are being performed in order to find a more performing tag. However, these kinds of products can be managed using special procedures. For instance it is possible to move the box into the cage in order to read all the items, or open the box in order to separate them. Specific time measurements are performed in order to compare the read time with normal items and with 'critical' ones.

Hardware devices

To perform the process, the following hardware devices and equipments are necessary:

- ✓ RFID Handheld device with WiFi connection (Skeye Integral);
- ✓ RFID cage, composed of
  - Metal cage, 2.20h x 1.20 x 3.30 meters, aluminum chassis and steel cloths;
  - RFID application installed on an assigned PC;
  - One fixed reader (Impinj Speedway Revolution) with Ethernet connection;
  - Four circular polarized antennas (Impinj), two for each long side mounted at a height of 0.70 and 1.40 meters.

Data flow

Item reading: event type object observe

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = "OBSERVE"
BizStep = urn: rfidlab:bizstep:fashion:shipping
Disposition = "shipped"
ReadPoint = urn:epc:id:gid:95100046.300.1/100.6 (HH device/cage)
BizLocation = urn:epc:id:sgln:95100046.103.1
BizTrans = BOL number

Case-reading: event type object observe

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SSCC
Action = "OBSERVE"

BizStep = urn:rfidlab:bizstep:fashion:shipping
Disposition = "shipped"
ReadPoint = urn:epc:id:gid:95100046.300.1/100.6 (HH device/cage)
BizLocation = urn:epc:id:sgln:95100046.103.1
BizTrans = BOL number

Relationship between Bill of Lading and Items: transactionEvent

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = "ADD"
BizStep = urn: rfidlab:bizstep:fashion:shipping
Disposition = "shipped"
ReadPoint = urn:epc:id:gid:95100046.300.1/100.6 (HH device/cage)
BizLocation = urn:epc:id:sgln:95100046.103.1
BizTrans = BOL number

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 4.

Barrier	Description	Issue	Solution
Low HH device computing power:	The HH device computing power is not enough to complete all the check algorithms needed when more than 100 tag are present.	The process cannot be successfully completed.	An RFID cage was designed and made in order to trust the computing to the server and improve the transmission power.
Low HH device read accuracy	The HH device cannot read all the critical garments into a box.	The process cannot be successfully completed.	The box needs to be open, or the process is performed by RFID cage that is more powerful.

Tab. 4: Barriers and solution about Shipping process.

5.7.3. RFID Receiving

Business Process Reengineering

'As Is' analysis has shown a major problem: there are not accurate controls of the garments received from the store. The shop assistants just count the garments and the boxes, but they don't check the mix, therefore errors can happen. A more accurate and effective control can identify shipping errors reducing misalignments between real inventory and informative one. An RFID implementation can provide a solution for this problematic behavior.

The last version of the process is subsequently described. The shop assistant can choose between two procedures to perform the process using two different RFID systems. In fact the shop assistant can decide to use the RFID handheld device provided and/or the RFID replenishment gate (described in section 5.7.4, p. 65).

The double possibility has been provided since the RFID handheld device performances were not, at this time, sufficient to complete all the operations. For this reason an application has been developed and installed on an all-in-one pc in order to control the RFID replenishment gate. Fig. 21 describes the decision flow regarding the choice of the correct procedure.

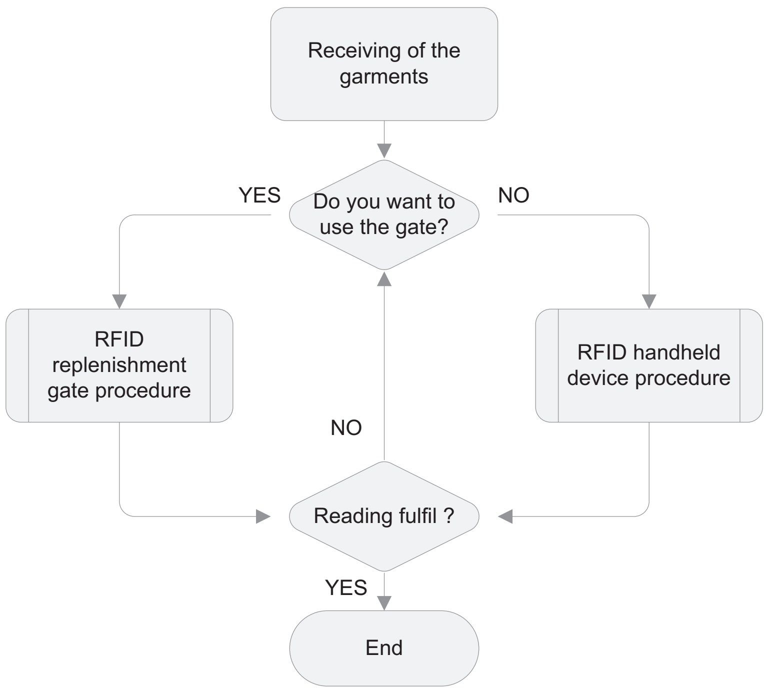


Fig. 21: Receiving decision flow.

As the decision flow shows, the shop assistant can break off the process anytime and change device. For instance she/he can start the control using the RFID replenishment gate identifying one or more missing items in a package. She can decide to stop the operation and no longer check the box in order to carrying on with other activities. In the same way, during the application of the anti-theft pins, for example, she can use the Handheld device to find the missing items reading them after the opening the packaging.

Both the procedures are based on the data transfer from the DC database to the store one. Thus this the receiving application can be aware of all the expected items and compare them with real readings. Therefore the shop assistant, after have chosen the store area, types in the BOL code and the boxes associated are shown by the application. She/he selects the case number she/he want to check and start the reading. At this moment the two procedure are different. In fact the handheld device application will ignore the unexpected readings, while the RFID replenishment gate will not. Since it ignores the unexpected readings, the handheld application needs less computing resources and can increase the elaboration rate, but it cannot detect every kind of error.

When all the items are read, or the shop assistant think more readings are not possible, he/she stops the reading and forward the data to the server in order to update the expected list and the informative stocks.

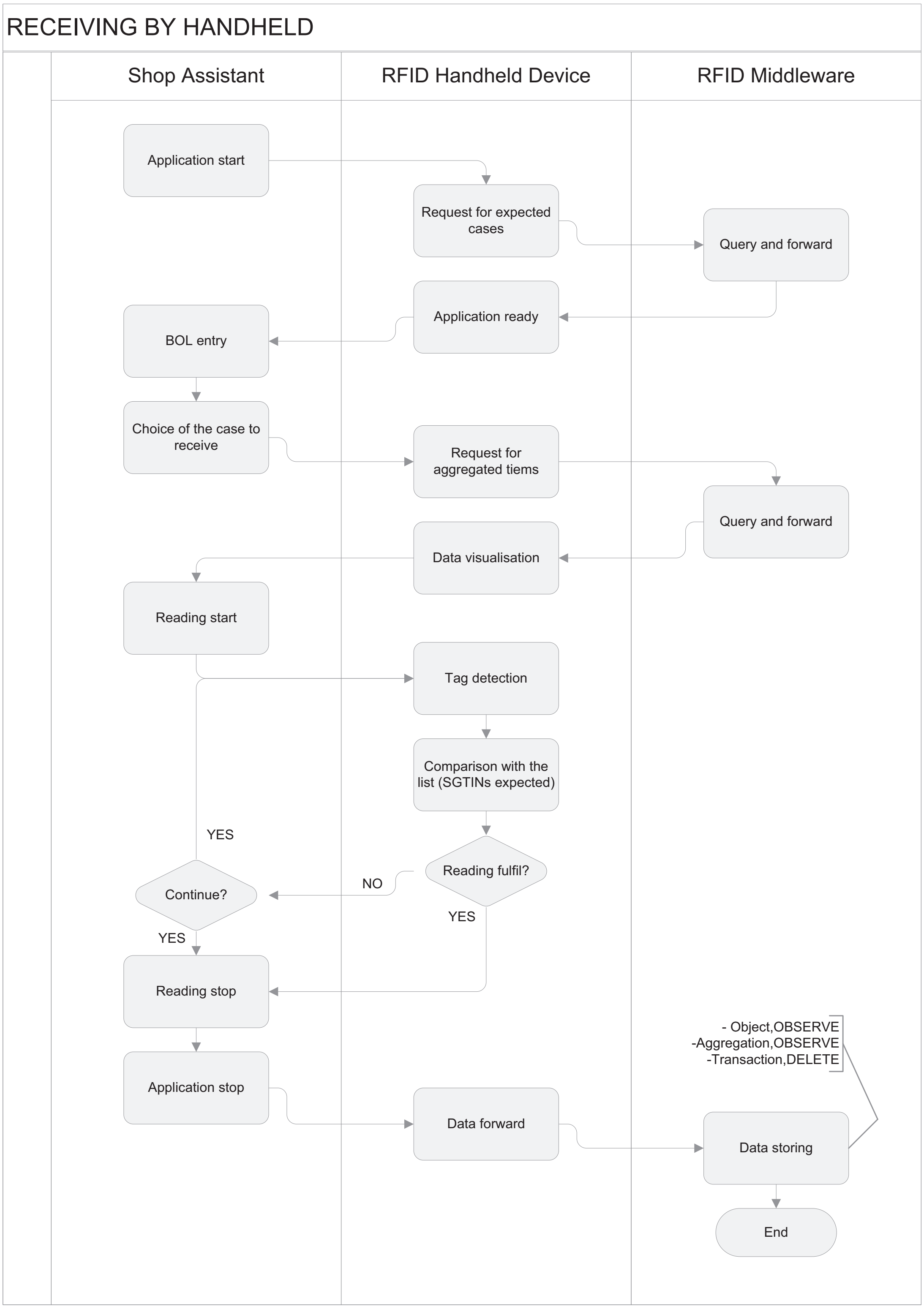


Fig. 22: Cross-functional flow chart of Receiving process performed by RFID handheld.

Thanks to the application interface, each read tag is highlighted in order to differentiate these from the unread ones. When all the expected tags are read, automatically, the application stops the reading and informs the user, and also he can stop it any time he wants without losing the information.

The EPCIS events are:

- ✓ ObjectEvent, action OBSERVE, because some items are read;
- ✓ AggregationEvent, action DELETE, because an aggregation between case and its items, existing before, is terminated;
- ✓ TransactionEvent, action DELETE, because, once received, the connection between items and Bill of Lading is canceled.

The cross functional diagram of the receving process performed by the RFID replenishment gate is shown in Fig. 23.

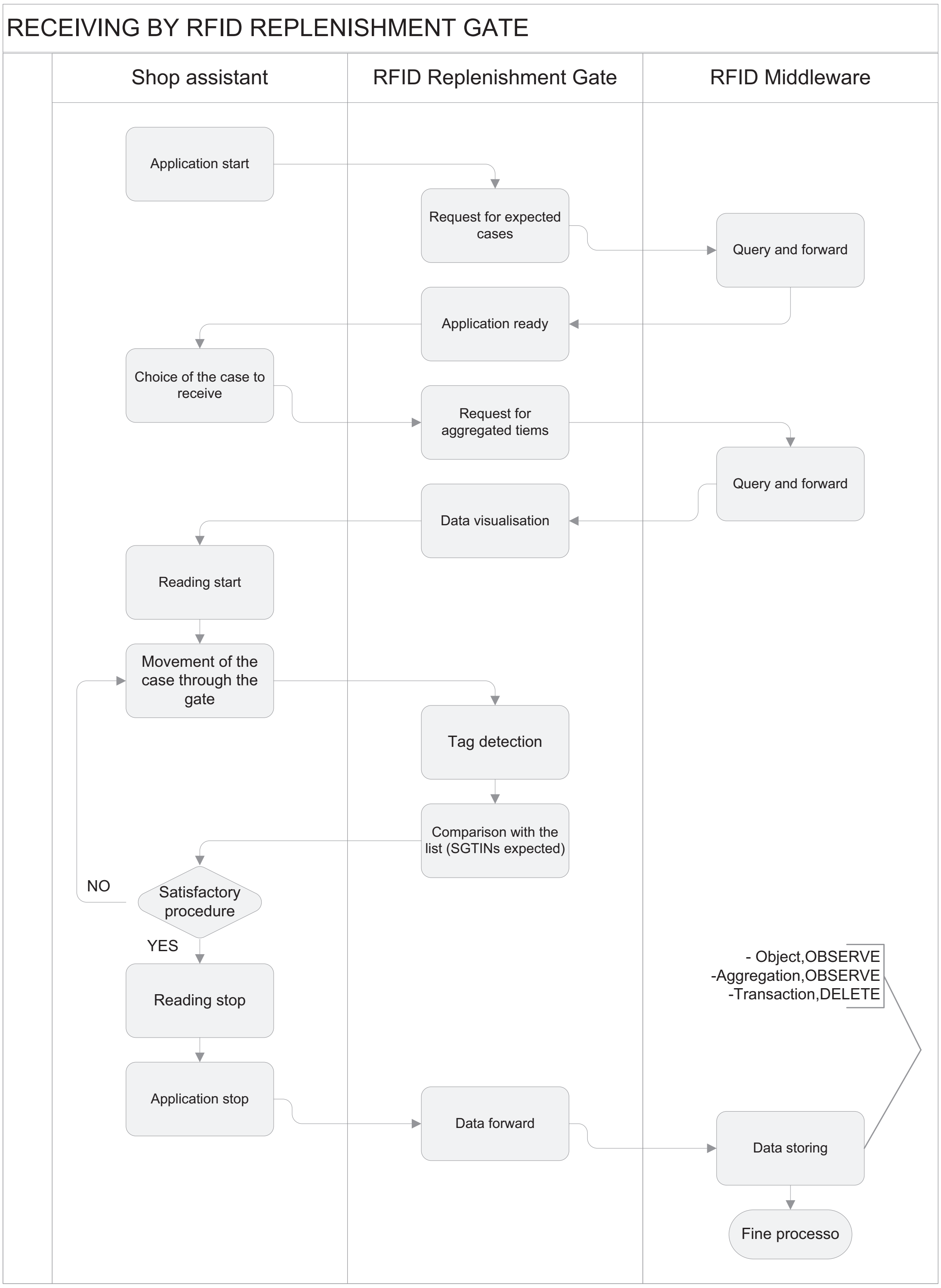


Fig. 23: Cross-functional flow chart of Receiving process performed by RFID replenishment gate.

Hardware devices

In order to perform the process the following devices have been provided:

- ✓ RFID Handheld device (Psion Workabout Pro2), connected by WiFi Network.
- ✓ RFID replenishment gate, composed by (for more details regarding the gate design see section 5.7.4, p. 65):
    - RFID fixed reader (Impinj Speedway);
    - Four Near field antennas, two for each side;
    - RFID shield (quantum sufficit);
    - All-in-one pc for control of the software applications.

Data flow

Item reading: event type object observe

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = “OBSERVE”
BizStep = urn: rfidlab:bizstep:fashion:receiving
Disposition = “received”
ReadPoint = urn:epc:id:gid:95100046.300.2/100.1 (HH/gate)
BizLocation = urn:epc:id:sgln:95100046.220.1/225.1 (back store/selling area)
BizTrans = BOL number

End of the relationship between Items and case: aggregationEvent

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
Parent EPC = SSCC
ChildEPCList = SGTIN generated
Action = “DELETE”
BizStep = urn:rfidlab:bizstep:fashion:Labelling
Disposition = ready to ship
ReadPoint = urn:epc:id:gid:95100046.300.2/100.1 (HH/gate)
BizLocation = urn:epc:id:sgln:95100046.220.1/225.1 (back store/selling area)
BizTrans = BOL number

End of the relationship between Bill of Lading and Items: transactionEvent

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN

Action = "DELETE"
BizStep = urn: rfidlab:bizstep:fashion:shipping
Disposition = "received"
ReadPoint = urn:epc:id:gid:95100046.300.2/100.1 (HH/gate)
BizLocation = urn= urn:epc:id:sgln:95100046.220.1/225.1 (back store/selling area)
BizTrans = BOL number

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 5.

Barrier	Description	Issue	Solution
Low HH device computing power:	The HH device computing power is not enough to complete all the check algorithms needed when a great amount of tag is present.	The process cannot be successfully completed.	A new software application is developed in order to use the RFID replenishment gate as receiving gate (signal and computing capability more powerful).
Low HH device read accuracy	The HH device cannot read all the critical garments into a box.	The process cannot be successfully completed.	The box needs to be open, or the process is performed by RFID cage that is more powerful.
Time consuming	Sometime, the process needs too much time to be completed.	Shop assistant cannot dedicate so much time to the process, so it is not complete.	Integration between HH device and replenishment gate. The results of the two way can be added together.
Replenishment gate fine tuning	see section 5.7.4, p. 65	see section 5.7.4, p. 65	see section 5.7.4, p. 65
Low power of replenishment gate	As result of the fine tuning activity of the replenishment process , the power of the replenishment gate has been reduced.	The accuracy of the gate is enough for the purposes of the receiving process.	The software application can change the reader power depending on the active process.

Tab. 5: Barriers and solution about Receiving process.

Upgrade: Management of the garments without label

The experimental campaign has highlighted a particular issue underestimated at the beginning: unwanted detachment of the price tag from the garments and their loss. This common event represent a source of error for all the subsequent processes. It can happen during the load and unload processes involving, specially, the hanging items (folded items are put into the box so they do not need to be handled), or during the handling activities in the shop.

The first case can greatly impact on the labor time of the receiving process, due to the time necessary to identify the missing item. In fact, the shop assistant may have to check all single hanging garments in order to find the missing label.

In order to eliminate the impact of this issue on the consequent processes a new application has been developed which allows printing a new RFID label. The application consists of two sub-applications, one running on the handheld device, the other one running on the server integrated with the RFID Middleware.

By the handheld application the operator can chose between two option:

- ✓ **Ristampa semplice (Basic Printing)**: this mode requires the barcode scanner embedded in order to obtain the necessary information automatically, for this reason another label of a garment with identical characteristics is needed. So this mode is used when other similar items are present or when the label is, even if not missing, not working.
- ✓ **Ristampa avanzata (Advanced Printing)**: this mode doesn't require the barcode scanner embedded. The operator has to type in some known information, for instance the model, and the application returns the other available characteristics. From this list she can select the right Sku and print the label. This mode is used when the characteristic of the garment are unknown or when no other garment of the same Sku is present in the shop.

After that the shop assistant can startup the printing sending data to the server application which generate the new EPC, compliant with the requests, and controls the printer. In Fig. 24 the cross-functional diagram is shown.

In order to assure the uniqueness of the SGTIN created in the store (store server and DC server are not, in fact, real time updated), it was established to end the serial number with '1' if the SGTIN is generated in the shop, with '0'if it is printed at the DC.

When the printing of a pre-existent label is performed during the receiving process the operator must:

1. Read also the new label;
2. Flag manually the new EPC read (unexpected list) and terminate the process.
3. Now the case is still in the expected list because the operation is not complete, so it need to be manually delete by an assigned interface developed.

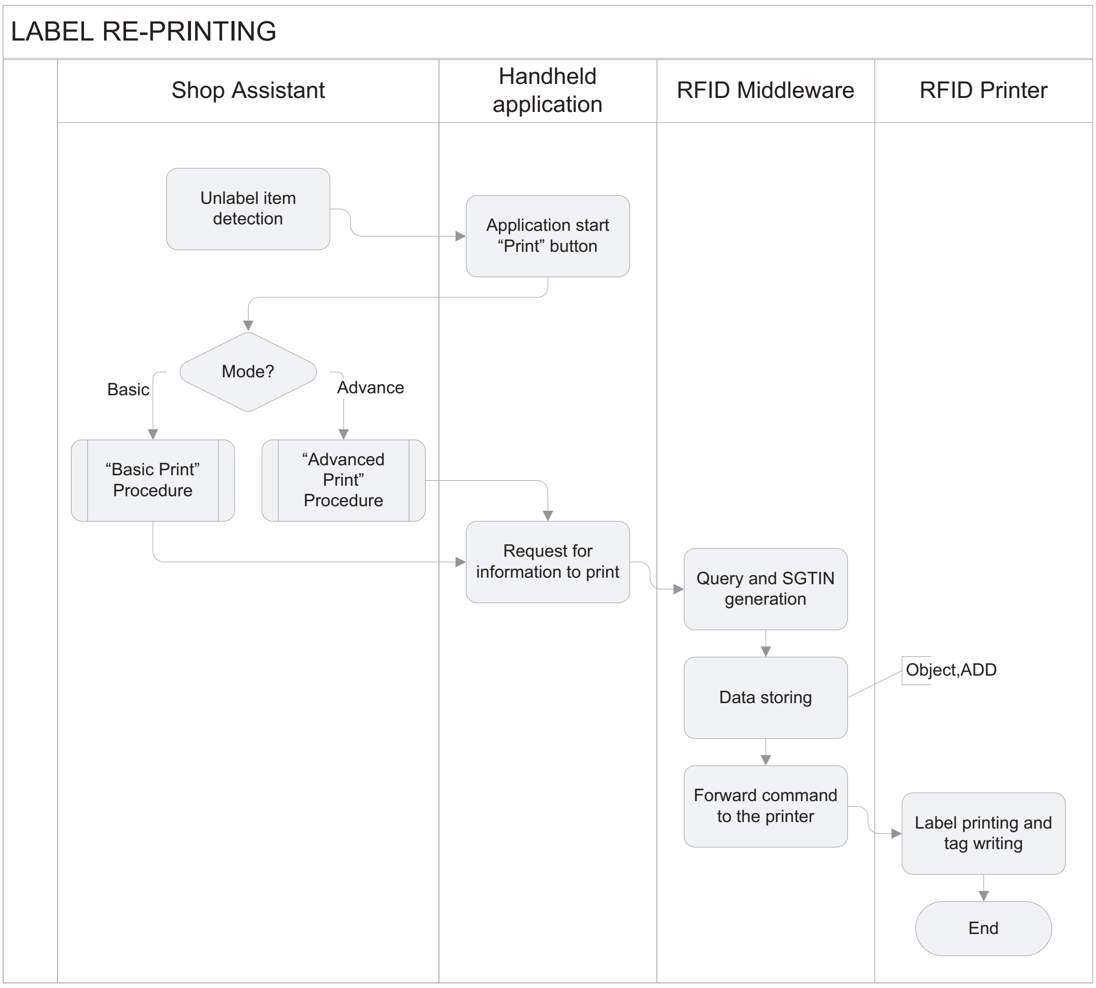


Fig. 24: Cross-functional diagram of the Label reprinting procedure.

The suggested procedure is justified as beneficial by reducing of the labor time. In fact the operator needs about 15 seconds the perform it, instead of about 2 minutes necessary by the previously procedure[3], actually a 87% time reduction.

Data flow

Item writing: event type object add

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN (ending with ‘1’)
Action = “ADD”
BizStep = urn: rfidlab:bizstep:fashion:Labelling
Disposition = “received”
ReadPoint = urn:epc:id:gid:95100046.200.2
BizLocation = urn:epc:id:sgln:95100046.220.1/225.1 (back store/selling area)
BizTrans = Bill of Lading code.

[3] Previously, the operator had to find the information using an assigned software application installed on the checkout desk.

5.7.4. RFID Replenishment

Business process reengineering

From the ‘As Is’ Analysis it is clear that the existing process does not need either technological supports or devices. In fact the shop assistants are free to decide how to manage the exposition following the company directives, hence they have not any system to detect out-of-stock in the selling area, which can lead up to a sale loss. In addition, possible shrinkage is unknown and the informative inventory is not correctly updated, so generating order errors. For this reason, the process reengineering aims to prevent these issues by managing two different inventories: back store inventory and selling area inventory. In this way it is possible monitor the stock of the garments in the selling area and to send alarm when a stock out occurs, or to create a new module able to help shop assistant during the purchase process helping their customers. In addition the new process should have the minimum impact on their activities in order to reduce the labor time, necessary to help the customer during his decision process.

For these reason an RFID gate, with a all-in-one pc, was installed near the door which connects the back-store to the selling area. The system automatically starts and detects all the garments passing through and, based on the history of each of them, determines the new location updating the inventory. For instance, if the shop assistant needs to replenish a shirt, she goes to the back store, brings the correct shirt and comes back in the selling area. The reader read the shirt label and determines the present location associated (back store). The application shows the shirt and the new location (selling area). After a set time the new location is automatically confirmed and the two inventories updated. During the set time the shop assistant can pause the application, restart it or forced the new location regardless of the suggested one.

Moreover, it is clear that the RFID gate is installed where a lot of tags are present, so unwanted readings can happen, or previous errors can lead to mistaking the right location. For these reasons the application allows the shop assistant to enter the location manually. In the following table (Tab. 6) some critical situation are shown: the first column report what the shop assistant is doing, the second one report the correct application response, the third one a possible error, the fourth one the cause of error, the last one the solution.

In Fig. 25 a basic cross-functional diagram is shown.

Physical situation	Wanted response	Critical response	Causes	Solution/Procedure
Item X is moved from location A to location B	Item X is detected, it is in location A and it is moving toward location B	No items are detected	✓ The shop assistant's body shields; ✓ Tag damaged; ✓ Item shields the tag.	Repeat the procedure being careful the tag is detached from the item surface or the shop assistant's body. If it doesn't work check the tag with a mobile reader.
		Wrong location: item X is detected but it is located in B and it is moving toward location A	✓ Inventory inaccuracy. A previous process has failed the location update.	Shop assistant substitutes the right location by the interface. Now the item is in the right location.
		Unwanted readings: items X and Y are detected.	✓ Other garments are too close to the RFID gate	Pause the application, check the other garments, and restart it, repeat the procedure.
		Item X location is Oblivion	✓ Inventory inaccuracy. A previous process has failed the location update	The application is automatically in pause waiting for a shop assistant choice.
Items X and Y are moved from location A to location B	Items X and Y are detected, they are in location A and they are moving toward location B	Item X or item Y is not detected	✓ The shop assistant's body shield; ✓ Tag damaged; ✓ Item shield the tag.	Repeat the procedure being careful the tags are detached from the items surface or the shop assistant's body. If it doesn't work check the tag with a mobile reader
		Items X and Y are both detected, but they are located in B and they are moving toward location A	✓ Inventory inaccuracy. A previous process has failed the location update.	Shop assistant substitutes the right location by the interface. Now items are in the right location.
		Items X and Y are both detected: item X is correct, but item Y is in location B and it is moving toward location A, or one of their location is oblivion.	✓ Inventory inaccuracy. A previous process has failed the location update.	The application is automatically in pause waiting for a shop assistant choice. After a set time the application assume location = oblivion.

Tab. 6: Most frequent critical situazione and errors.

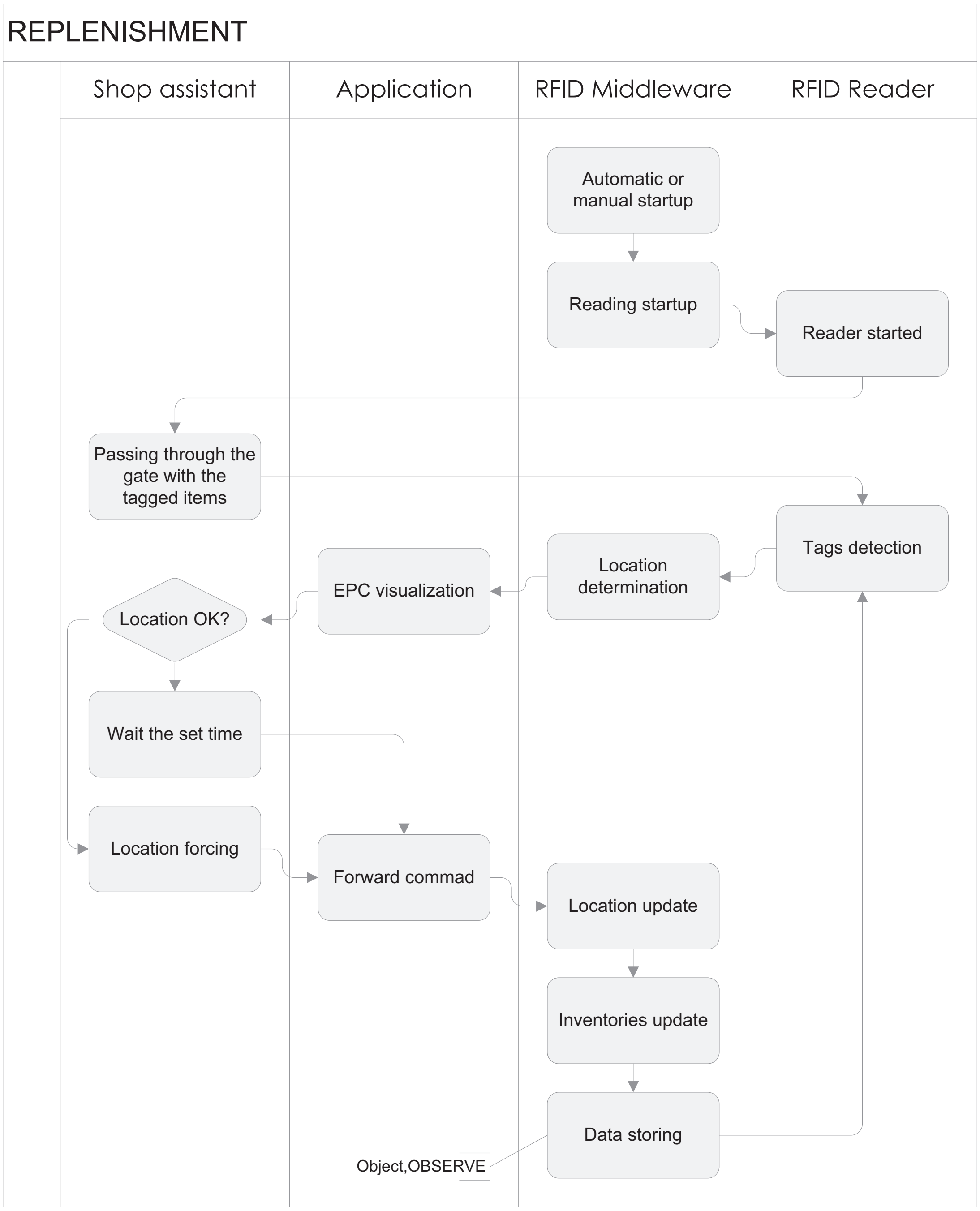


Fig. 25: Cross-functional diagram for the replenishment process.

Hardware devices

The necessary equipment is composed by:

- ✓ Reader RFID Impinj Speedway;
- ✓ Four near field MTI antennas (MT-249567/NCP) installed near the access door between selling area and back store;

- ✓ All-In-One Pc Asus eeeTop 1610;

The antennas have been installed two on each side of the passage (see. Fig. 26) with staggered heights in order to cover all the reading area (see Fig. 27). In order to confine on the reading area only in the passage reducing the probability of unwanted readings, Nikitin et al. propose some approaches [36]:

1. install an UHF RFID system with standard (far-field) antennas and low reader output power in order to reduce the reading area. This solution has lowest cost (no new special reader antennas or tags are required), but, because of lower reader output power, reading performance (long range, material insensitive) should be inadequate with RF non-friendly objects such as critical garments;
2. short range UHF tags combined with standard (far-field) antennas transmitted in full reader output power mode. The tags should be designed with a magnetic antennas or they can be intentionally mismatched by tuning in order to be activated only near the antennas where the fields are strong. Such a system does not need ad hoc detecting device (reader and antennas) but a particular tag needs to be designed (high costs) in order to achieve the wanted aim;
3. use special near-field reader antennas and tags. Such system will have the best performance but also the highest cost regarding the reading system, although these technologies are now enough common.

Even if more expensive the best choice is the third one: near filed antennas. The most important coupling mechanism in the near field UHF RFID can be either magnetic (inductive) or electric (capacitive) [36]. Inductive coupling systems, where most transmitting energy is emitted in a magnetic field, are mostly influenced only by objects with significant magnetic permeability. Such materials are not common in fashion business, which is why this coupling is used in systems that are able to operate in close proximity to metals and liquids (for instance the human body). Capacitive coupling systems, where most transmitting energy is emitted by the electric field, are jammed by objects with high dielectric permittivity.

On the right side (coming out from the back-store) an all-in-one pc has been installed and connected via LAN to the other devices. The PC controls the devices and shows the application developed.

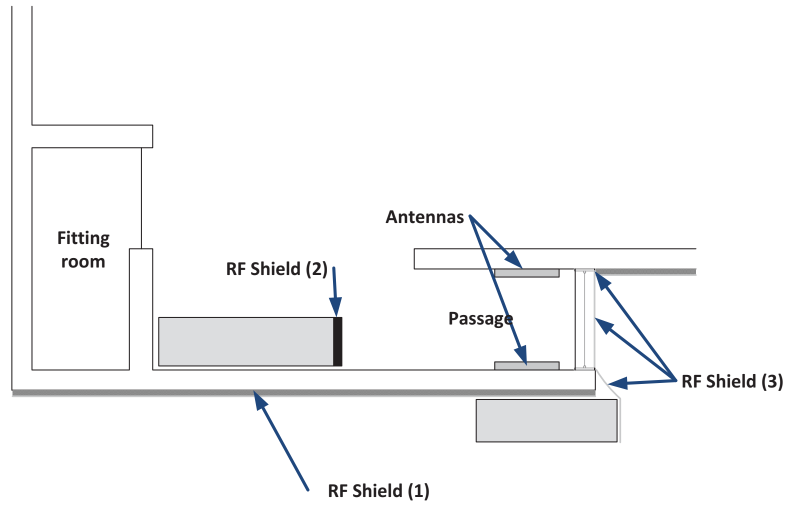


Fig. 26: RF shields implementation.

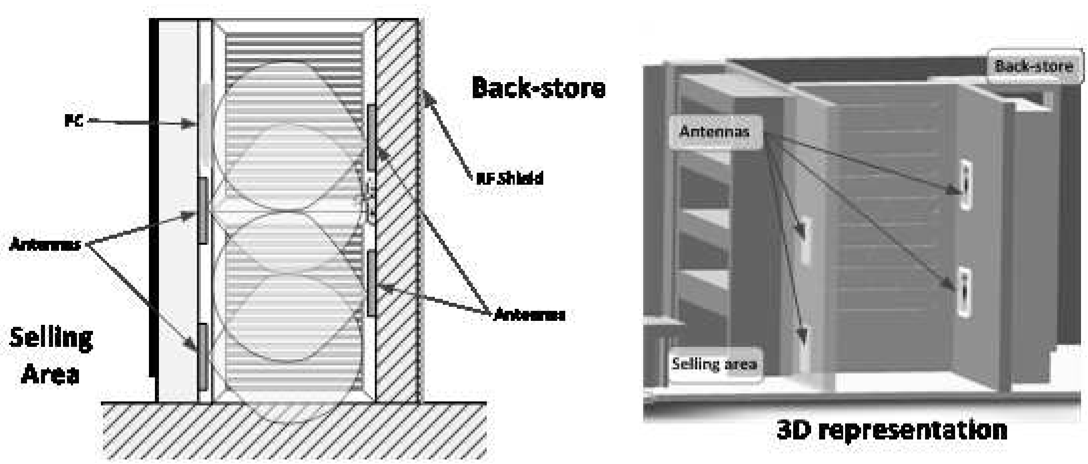


Fig. 27: Representation of the RFID replenishment gate.

The initial installation phase has proved that only the near-field antennas are insufficient to prevent unwanted readings. For this reason RF shields are installed near the gate, in particular:

- ✓ sheath shielding sticker attached to the inner wall of the back-store. It not only prevents the detection of the garments stored in the back-store (plasterboard wall is RFID permeable) by replenishment gate but also by mobile devices used to perform other processes, such as Inventory (see Fig. 26 (1))
- ✓ shielding plate installed next to the exhibitor near the gate in order to prevent the detection of the items displayed (see Fig. 26 (2));
- ✓ wire metal mesh applied to the inner face of the door in order to prevent the reading of the items placed close to it (Fig. 26 (3))

In addition to passive shielding, reader power was reduced (65%) in order to trade off between the efficiency (read the moving items) and effectiveness (read only moving items).

Data flow

Reading event

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = “OBSERVE”
BizStep = urn: rfidlab:bizstep:fashion:replenishment
Disposition = “replenishment”
ReadPoint = urn:epc:id:gid: 95100046.100.1 (gate)
BizLocation = urn:epc:id:sgln:95100046.220.1/225.1 (back store/selling area)
BizTrans = ‘null’

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 7.

Barrier	Description	Issue	Solution
Selectivity	The gate must read only the items that are passing through..	This can cause unwanted readings and inventory inaccuracy	✓ Near field antennas ✓ RFID shields; ✓ Reader power tuning;
Detection errors	Some unwanted items can be read	Inventory inaccuracy.	Application with human interface which allow the user to stop, restart or correct the readings.
Localization errors	Historic data errors can mistake the determination of the new location.	Inventory inaccuracy.	Application with human interface which allow the user to stop, restart or correct the readings..

Tab. 7: Barriers and solution about Receiving process.

Upgrade: inventory management application

The fine tuning phase has provided useful directions to the development of a new application able to help shop assistants to increase customer services. Indeed this application provides the inventory stock of a certain item model. This is useful, for instance, when a customer is not able to find a certain size (or color) of a certain model. In this case the shop assistant can check the inventory and verify if the requested size is present in the store and where. In Fig. 28 the procedure is described: on client request, the shop assistant goes, with an item of the same model, to the replenishment gate, the item label is shown and the replenishment application is paused. On selecting the right line, relative to the requested item, the application shows the stock for each size and color of the same model split for location (back-store, selling area, DC). In this way the shop assistant can quickly check if the requested size is present in the shop and where it is. If the size is not present she can suggest an alternative minimizing the risk of loss of sale. The customer has not to wait for long researches and customer satisfaction increases.

In addition, if no items is present, the shop assistant can inform the DC in order to request it and reduce the out of stock level.

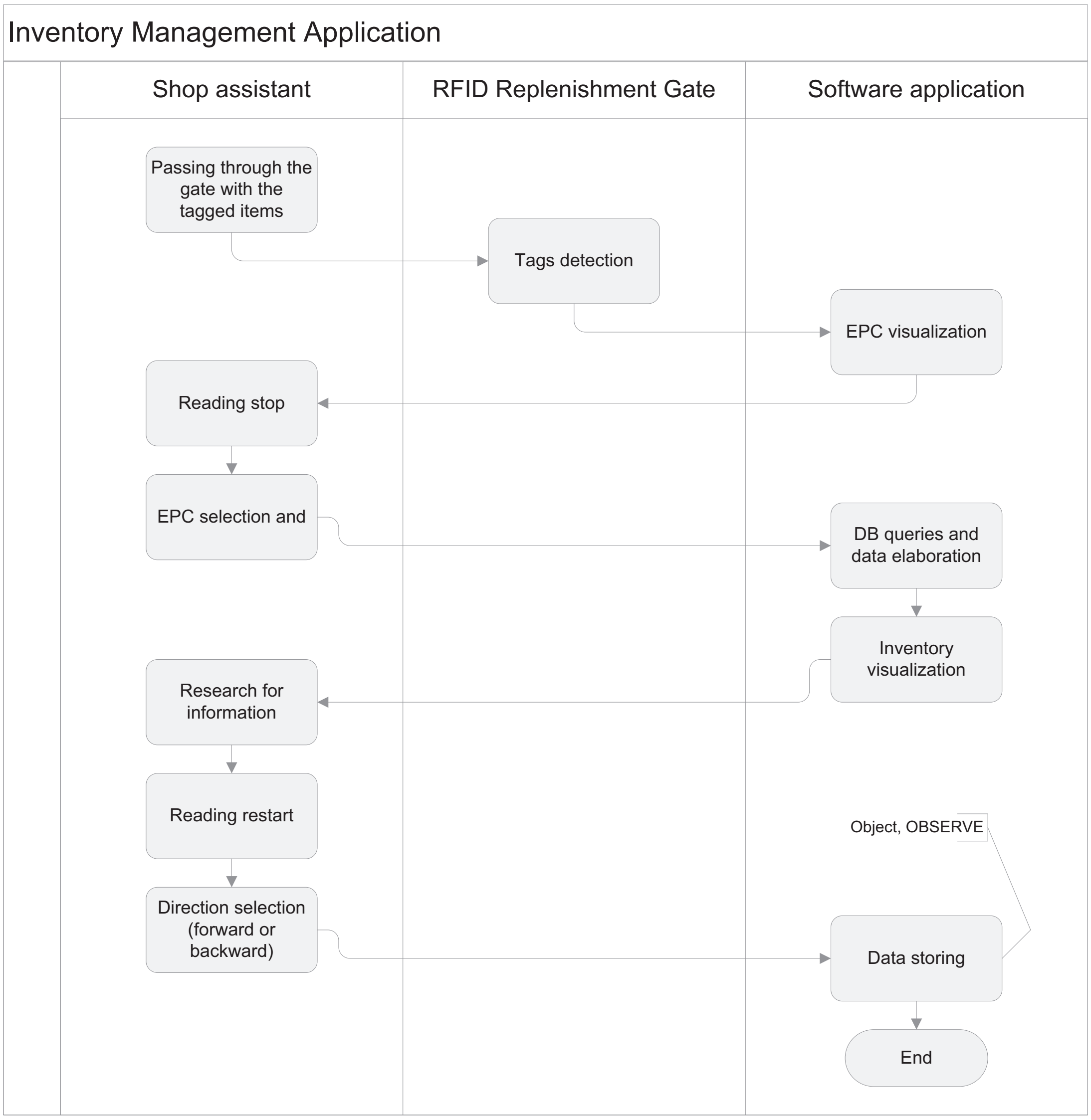


Fig. 28: Cross-functional diagram of the inventory managment application.

5.7.5. RFID Fitting

The RFID fitting is one of the most easy process reengineered. In fact it is totally automatic and it doesn't need any human intervention, a part from maintenance activities. In addition this process is totally new in the fashion scenario and represent a new and unknown source of information. In fact the RFID fitting is able to provide information relatives to the garments appeal, fitting frequency also in relation to the sales. In this way departments such as marketing, style, design and store management can have access to interesting information in order to increase its appeal increasing the sales. For instance it is possible identify garments often fitted but seldom bought, probably because unsuitable. This kind of garments represents a loss for the shop because they take up space that can be used by other more productive items. Or it is possible determine when, during the work-day, the maximum need of personnel occurs in order to provide the best service.

In compliance with the management requests some constraints are defined in order to minimized the impact of the new technology on the customer behavior:

- ✓ RFID antennas must be hidden, the customers shouldn't recognized they are being monitored (no privacy information is obtained);
- ✓ RFID antennas must read just the fitted garments;

On the base of the constraints reported above, the process is engineered in the following way. The application automatically starts in the morning and stops in the evening, after the closing time. Of course an interface enables the user to start and stop monitoring manually each fitting room.

During this time all garments which are brought into the fitting room are read and stored in the DB for successive analysis (see Fig. 29). The readings are filtered in order to reduce the amount of data. The rule is to ignore the readings of an item if less than three minutes are passed from the last readings. In addition the RFID fitting process is able to update the location of the garments detected. For instance, if the location of a garment is back-store and it is seen in a fitting room, it means that that garment is in not still in the back-store but in the selling area, therefore its location must be modified.

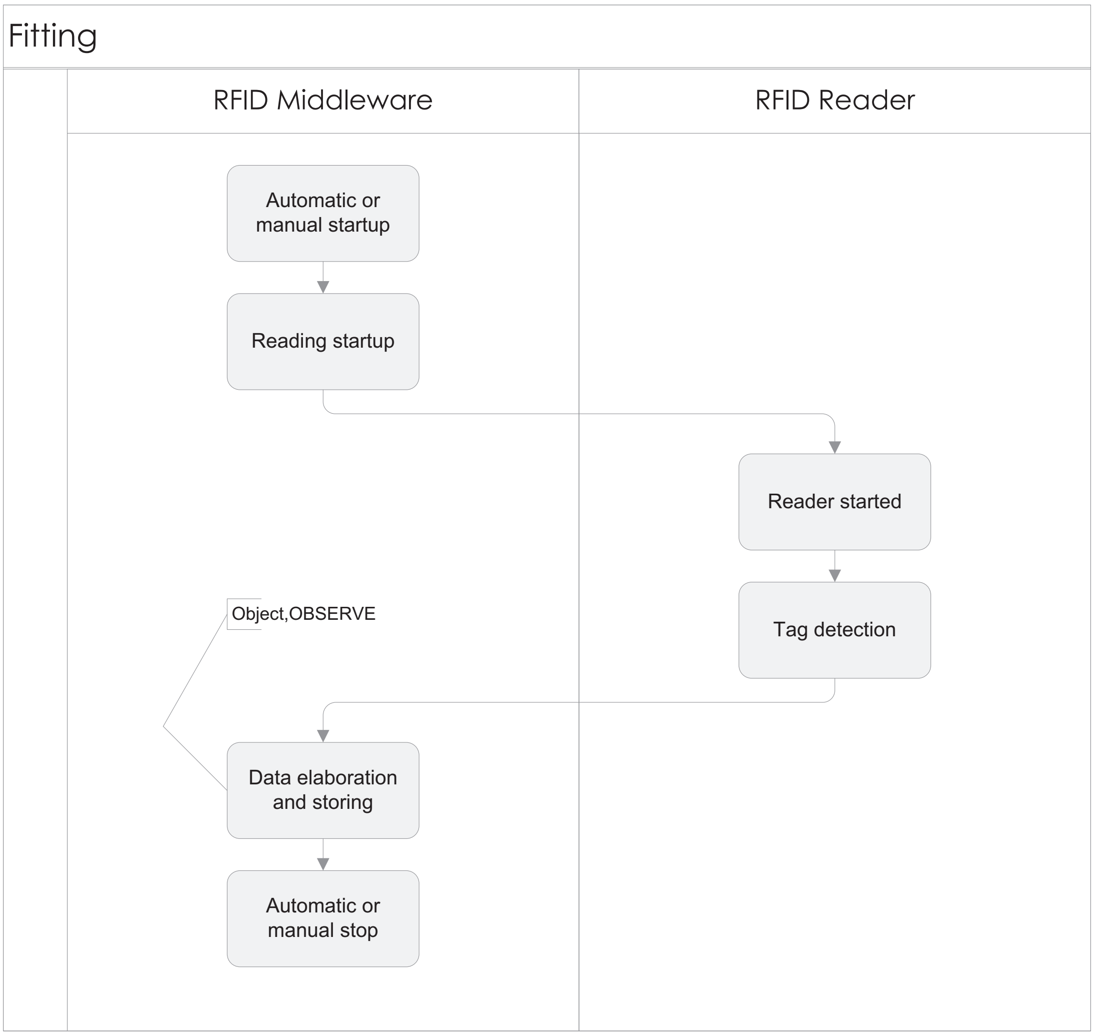


Fig. 29: Cross-functional diagram for the Fitting process.

Hardware devices

About the fitting room the follwing equiopment has been installed:

- ✓ Two RFID Readers Impinj Speedway
- ✓ Four (two for each reader) near field antennas by MTI (MT-249567/NCP), each one installed in one fitting room;

In according with the company requests the antennas have been hidden into the plasterboard wall (RFID friendly material). The fitting rooms can be organized in two couples, each of which are monitored by a reader and two antennas. In order to force the reading area into the each fitting room, some RF shields have been installed (see Fig. 30). In

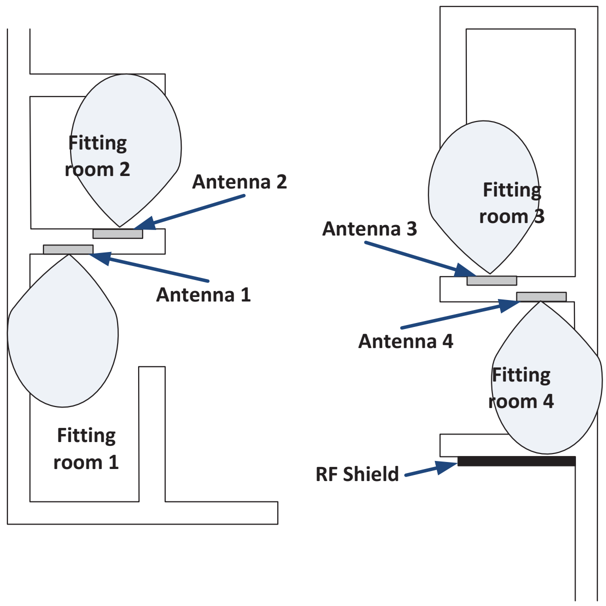


Fig. 30:Installation schema of the RFID antennas into the fitting rooms.

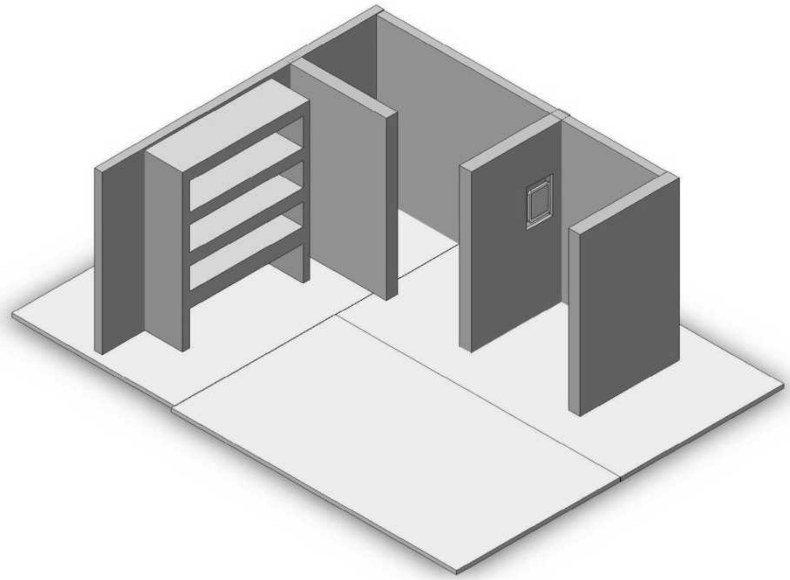


Fig. 31: 3D representation of the fitting room 1 and 2.

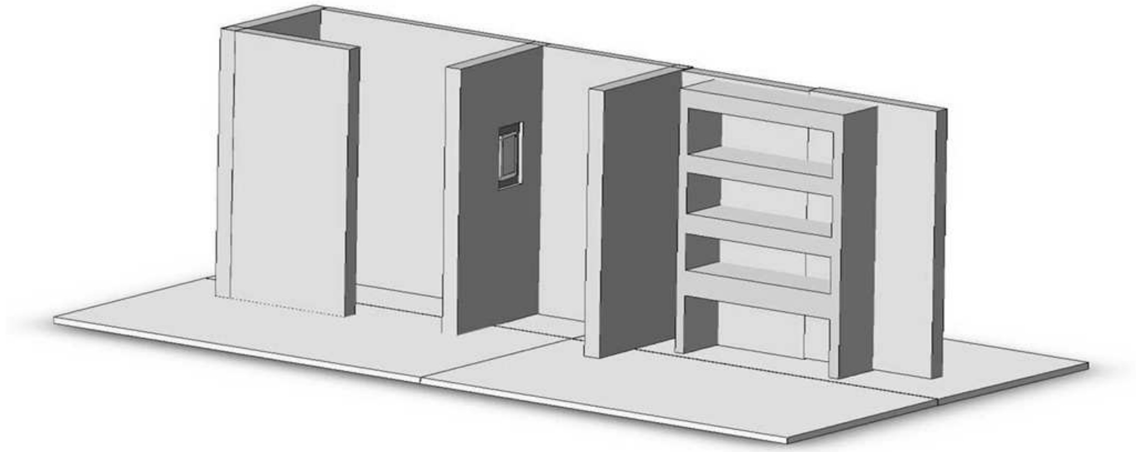


Fig. 32: 3D representation of the fitting room 3 and 4.

Data flow

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = "OBSERVE"
BizStep = urn: rfidlab:bizstep:fashion:fitting
Disposition = "fitted"
ReadPoint = urn:epc:id:gid: 95100046.225.1/2 (fitting rooms 1,2/fitting rooms 3,4)
BizLocation = urn:epc:id:sgln:95100046.220.1
BizTrans = 'null'

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 8.

Barrier	Description	Issue	Solution
Selectivity	The readers must read only the items brought into the fitting rooms..	This can cause unwanted readings and inventory inaccuracy	✓ Near field antennas ✓ RFID shields; ✓ Reader power tuning;
Great amount of data	Each time a garment is detected data is stored in DB	Calculation hard and complex.	Data filetering.

Tab. 8: Barriers and solution about Fitting process.

5.7.6. RFID Inventory

Business Process Engineering

Some studies demonstrate how the RFID technology can improve the inventory process performances [37], [38], [39]. For this reason the process has been engineered and an important experimental campaign has been performed. In addition, according the management, some errors can occur during the other processes so a system to fix informative inaccuracy is necessary. In fact thanks to this process it is possible read all the garments in a certain area and modify their locations. The process is very easy and requires only a mobile device.

The operator starts the application and selects the area to control and the mode option. In fact there are two options: standard or complete. There are no differences in term of operations, but just in term of data storing. At the beginning the application download from the RFID server all the SGTIN expected and compare them with the readings. When an expected SGTIN is read its location is confirmed, when a new one is read, its location is updated, when an expected SGTIN is not read a decision is needed. The reason for a lack of reading can be due to:

- ✓ a real lack of the garments, owing to shrinkage;
- ✓ a real lack of the garments, because it is located in the other location;
- ✓ technologic limits.

The issue is that the real reason is unknown so a human interpretation is needed. If the garment was stolen the system must be able to show its lack, if it is in a different location, it will be probably read during the another one and its location will be updated. But, if some technological limit has occurred its location should not be changed. For these reasons two inventory modes have been developed. By the 'standard' mode, the loss readings are viewed such as a technological inaccuracy, so the locations are not updated. In addition the shop assistant can use this modality in order to fix a restricted group of items, without trying to detect all the garments in the location. In the 'complete' mode the unread items are consider stolen so their location is fixed with the value 'oblivion'. In this case, the shop assistant must try to detect all the garments in the area with the best possible accuracy. In Fig. 33 the cross-functional diagram is shown, while in Fig. 34 the data storing diagram is explained in base on the mode option.

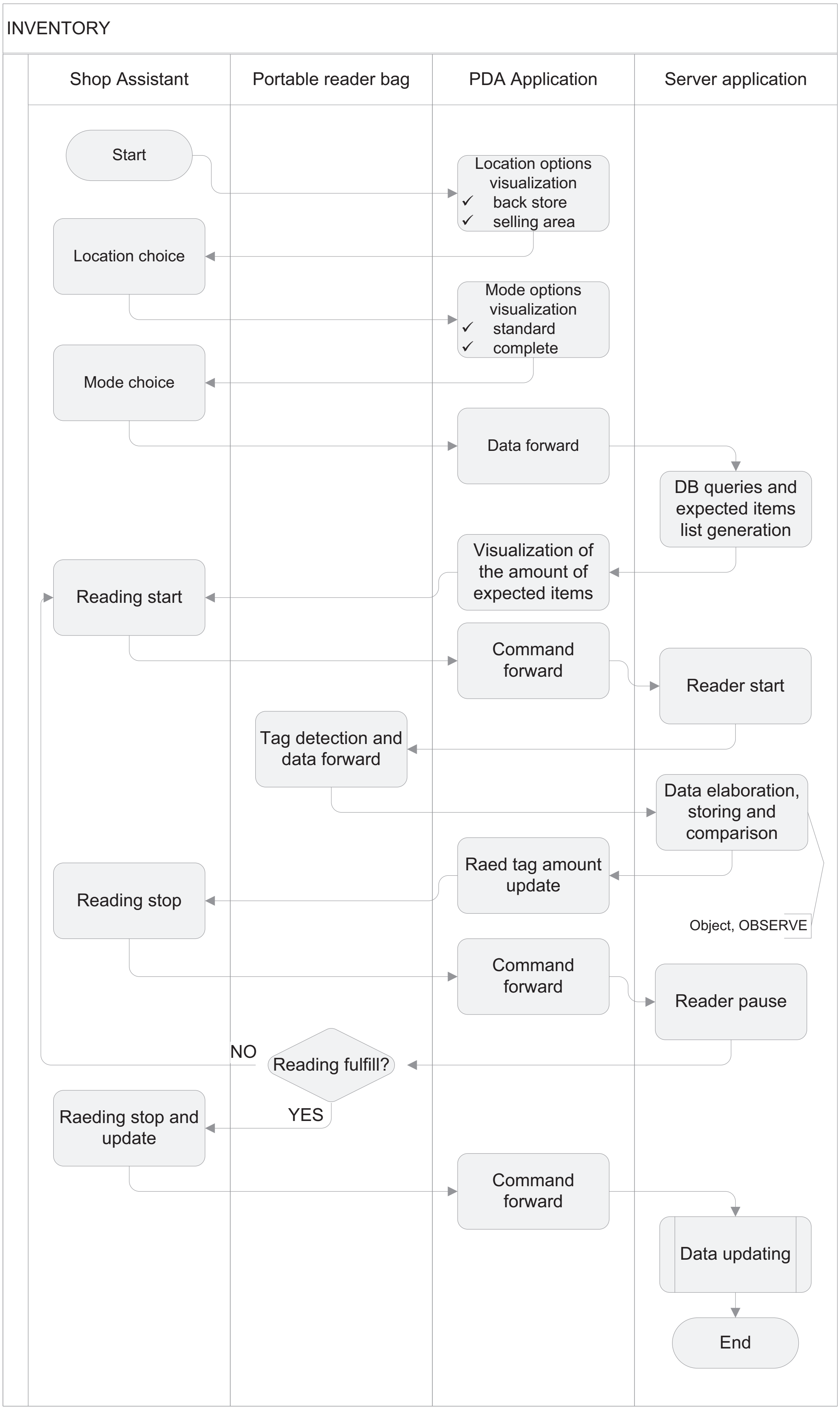


Fig. 33: Cross-functional diagram of the RFID inventory process.

Data updating algorithm

The principal objective of the inventory process is to check and update the location of each item. During the development of the process five locations have been defined, they are:

- ✓ selling area: when a garment is detected in the selling area by a process (receiving, replenishment, inventory, fitting);
- ✓ back-store: when a garment is detected in the back store by a process (receiving, replenishment, inventory);
- ✓ sold: when a garments is sold and seen by the check-out process or trash process.
- ✓ oblivion: location is unknown. The inventory process is not able to define a sure location;
- ✓ lost: all the labels found in the store without the item are stored and manually processed in order to remove them from the informative inventory.

The inventory process involves three of the five locations in accordance with the algorithm reported in Fig. 34. From this diagram it is clear that the inventory mode influences the location updating.

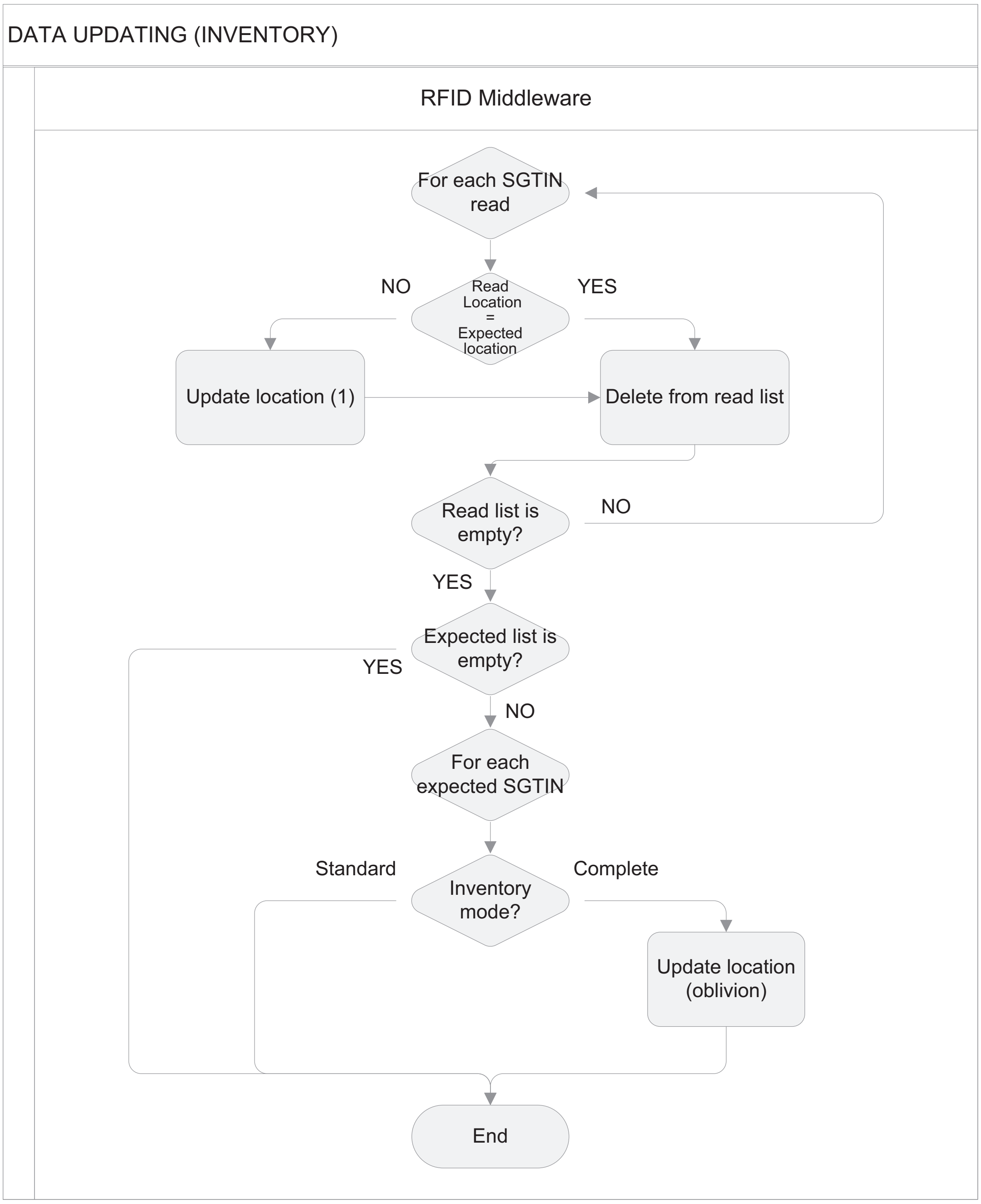


Fig. 34: Data updating procedure in base on the mode options.

For instance, suppose the following situation is provided before the execution of the process. Each item has its own location (see Tab. 9).

EPC	Location
EPC 1	SELLING AREA
EPC 2	BACKSTORE
EPC 3	SELLING AREA
EPC 4	SELLING AREA

EPC	Location
EPC 5	SELLING AREA
EPC 6	SELLING AREA
EPC 7	BACKSTORE
EPC 8	SELLING AREA
EPC 9	BACKSTORE
EPC 10	BACKSTORE

Tab. 9: Initial inventory state.

At the beginning of the process the shop assistant selects the location where the process should be performed, suppose 'selling area' (see Tab. 10)

EPC	Location
EPC 1	SELLING AREA
EPC 3	SELLING AREA
EPC 4	SELLING AREA
EPC 5	SELLING AREA
EPC 6	SELLING AREA
EPC 8	SELLING AREA

Tab. 10: Initial inventory state filtered by location.

The shop assistant execute the process in 'complete' mode. The result of the process is shown in Tab. 11.

EPC	Location
EPC 1	SELLING AREA
EPC 3	OBLIVION
EPC 4	SELLING AREA
EPC 5	SELLING AREA
EPC 6	SELLING AREA
EPC 8	SELLING AREA
EPC 9	SELLING AREA
EPC 15	SELLING AREA

Tab. 11: Result of the inventory process, changes highlight.

The following observation can be done:

- EPC 3: it was expected but it was not read. The new location is 'oblivion';
- EPC 9: it was expected in back-store, but it was read in the selling area, so its location was changed.
- EPC 15: it was an unexpected items, both in selling area and in back store. But since it was read in selling area, its location was changed.

Now suppose that the shop assistant had chosen the ‘standard’ modality. In Tab. 12 the changes are shown.

EPC LETTI	LOCAZIONE
EPC 1	SELLING AREA
EPC 4	SELLING AREA
EPC 5	SELLING AREA
EPC 6	SELLING AREA
EPC 8	SELLING AREA
EPC 9	SELLING AREA
EPC 15	SELLING AREA

Tab. 12: Result of the inventory process, changes highlight.

The following observation can be done:

- EPC 3: it was expected but it was not read. In this case its location is not modified;
- EPC 9: it was expected in back-store, but it was read in selling area, so its location is changed.
- EPC 15: it was an unexpected items, both in selling area and in back store. But, since it was read in selling area, its location is changed.

Hardware devices

In order to achieve the aim of the process the hardware selection is very important.

At the beginning of the experimental campaign an RFID handheld device was used, but the performance wasn’t sufficient. The principal reasons are the low power reader embedded into the handheld device (0.5 W) so the computing power is limited and sometime the handheld is not able to elaborate the data in real time. For this reason a new device has been designed and made.

In order to increase the reading power (2.0 W) a fixed reader has been chosen. But it should be light and portable. The smallest and lightest fixed reader available is Speedway Revolution® by Impinj®. In order to make it portable a proper battery and an Ethernet-WiFi adapter have been used. All the components have been installed into a bag in order to make the system portable. Finally an antenna equipped with a handle is connected to the reader.

Using this configuration, the RFID server considers the portable reader exactly like a normal reader which has been installed, for instance, in a gate. For this reason a portable application is needed and, therefore, developed. It has been installed in a PDA, but all the computing is transferred to the RFID server. The application is just an easy and light software interface.

The equipment is composed of:

- ✓ Portable reader: Speedway Revolution fixed reader by Impinj, batteries, Ethernet-Wifi adapter, battery charger, far filed antenna
- ✓ PDA with software application installed in.

Data flow

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = “OBSERVE”
BizStep = urn: rfidlab:bizstep:fashion:inventory
Disposition = “inventoried”
ReadPoint = urn:epc:id:gid: 95100046.300.5
BizLocation = urn:epc:id:sgln:95100046.220.1/225.1 (back store/selling area)
BizTrans = ‘null’

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 13.

Barrier	Description	Issue	Solution
Low HH device computing power:	The HH device computing power is not enough to complete all the algorithms needed when a great number of tags is present.	The process cannot be successfully completed.	A new portable device is engineered. The computing activities are performed by the RFID server

Barrier	Description	Issue	Solution
Low HH device read accuracy	The HH device cannot read all the garments and the labor time is too high.	The process cannot be successfully completed or it needs too much time.	A new portable device is engineered. The reading power is four times more powerful and the antenna gain is higher. The read accuracy is increased.
Different interpretation of the inventory process	The inventory process can be seen as a counting activity or as a photo of the current state.	The readings must be interpreted in a different way.	Two modalities are available. At the beginning of the process the shop assistant must chose the inventory modality.
Read errors	The walls between the back store and the selling area are RFID permeable.	When the process is performed in a certain location, the garments stored in the other one can be read generating inventory inaccuracy.	An RF shield has been installed in the inner wall of the back store in order to block the radio waves and isolate the two locations.

Tab. 13: Barriers and solution about inventory process.

5.7.7. RFID Checkout and RFID Trash

The RFID check-out process represents the outbound tracking point, and it is necessary in order to update the informative inventory, in fact all the garments sold must be read in order to remove them from the inventory.

The process is very easy: the shop assistant put the products to be sold on the check out desk, equipped with a RFID antenna and presses a button. The RFID reader detects the garments and sends the readings to the server application. Here, the software extracts the EAN13 and sends it to the application installed on the check-out computer using the keyboard emulation protocol.

In order to reduce the impact of the pilot on the check-out computer, keyboard emulation protocol was chosen. In this way the current check-out application does not need any interventions, because the current barcode scanner uses the same protocol. In addition the barcode scanner remains available in case of failure of the RFID system.

In this case the RFID tracking point substitutes the barcode scanner, so the subsequent operations are maintained. Therefore, after a visual check of the shopping list reported in the check-out application, the shop assistant remove the labels and print the receipt.

From the ‘As Is’ analysis it is known that sometimes the customer can change the shopping list after checking the total cost of its purchasing. In this case the shop assistant changes manually the list on the check-out application without any RFID event. This can generate inventory inaccuracy because the RFID system consider all the read garments sold.

Moreover the check-out application does not manage the items’ serial number but only the EAN13, so a substitution of a garment of the same Sku but with different serial number generates further inventory inaccuracy (the RFID system does not exchange the first item with second one, while it is needed).

Finally, some system problems must be considered during the experimental campaign, this means that, if the RFID system is not available during the check out operations, the shop assistant are able to use the previous procedure (barcode scanning) generating inventory inaccuracy (the RFD system cannot remove the garments because it does not know they are sold).

For these reasons, the lack of a strong integration between the check out application and the RFID system represents an error source and can generate inventory inaccuracy. In order to solve these issues, a new process has been developed.

The new process, called ‘RFID trash’, exploits the ‘As Is’ operation of removing the label from the item before printing the receipt. The removed RFID labels are stored in metal container with an inner RFID antenna. In this container only the labels from garments actually sold are stored so the readings from this process can be used in order to solve some inventory inaccuracies.

However, periodically, the trash container is emptied out and the labels in it brought in RFID lab where they are checked to verify the process accuracy and fix possible misalignments.

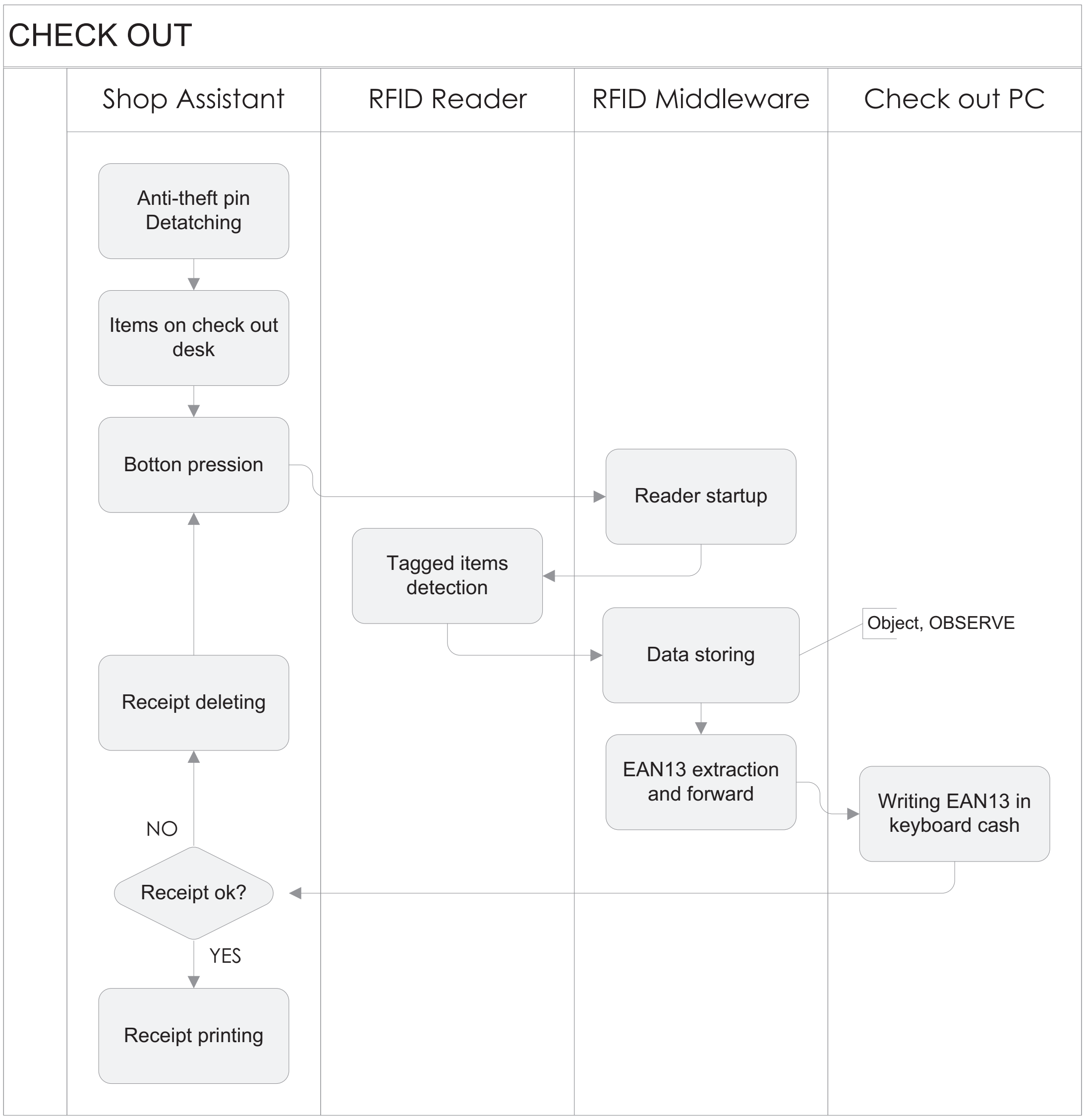


Fig. 35: Cross-functional diagram of the check-out process.

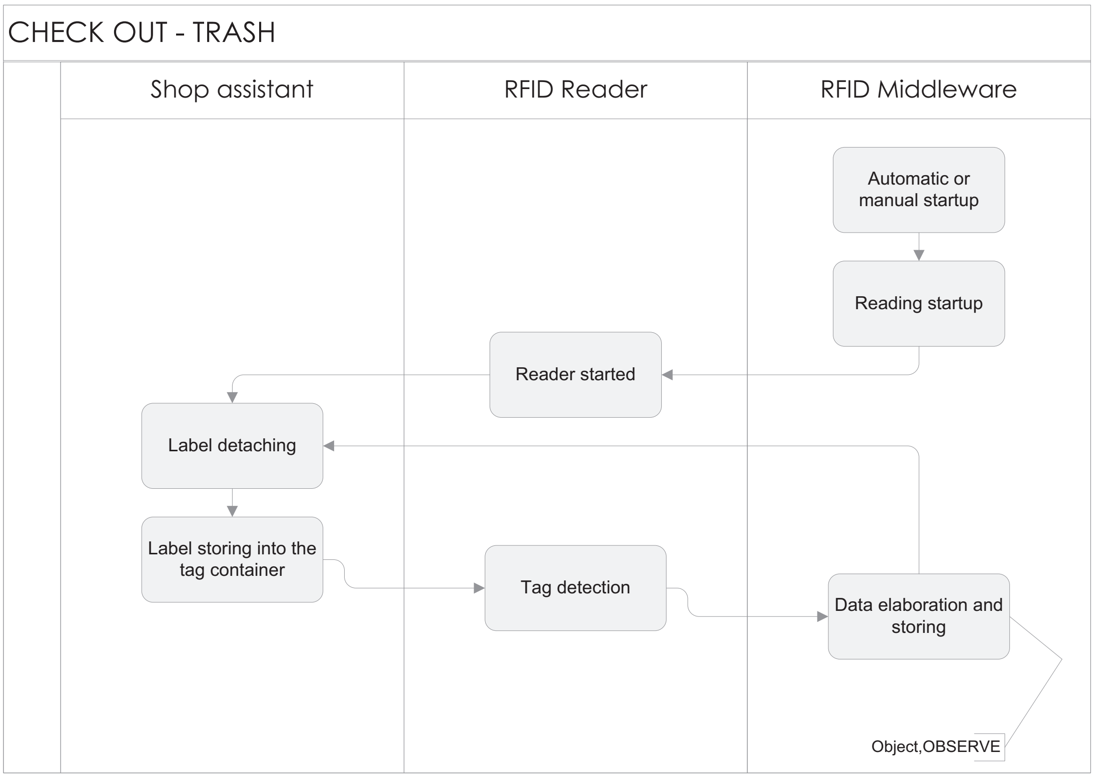


Fig. 36: Cross-functional diagram of the trash process.

Hardware devices

The equipment installed in the check-out desk is following reported (see Fig. 37):

- ✓ Fixed RFID Reader Impinj Speedway
- ✓ MTI near field antenna (MT-249568/NRH), installed into a metal container (trash container);
- ✓ MTI near field antenna (MT-249567/NCP), installed under the desk surface, used to read the garments;
- ✓ RF shield installed under the check-out antenna in order to limit the reading area only above the desk surface.
- ✓ Button, installed under the desk container, connected to the reader by GPIO port, used to startup the check-out process.

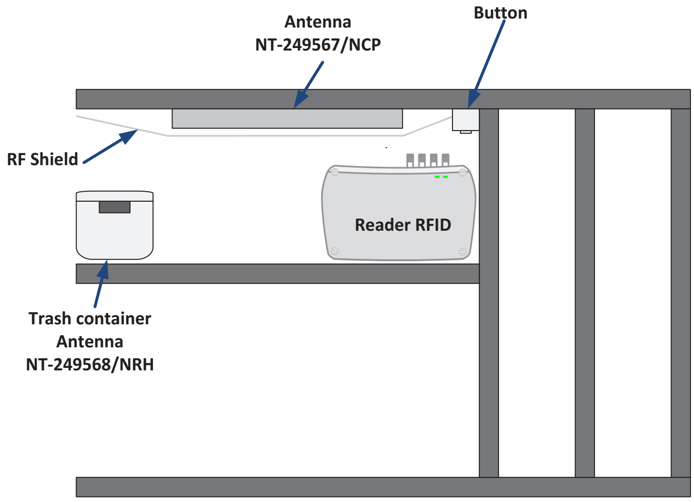


Fig. 37:Installation shema of the check-out equipment.

Data flow

Check-out readings

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = “OBSERVE”
BizStep = urn: rfidlab:bizstep:fashion:checkout
Disposition = “sold”
ReadPoint = urn:epc:id:gid:95100046.00000003.3 (portable reader)
BizLocation = urn:epc:id:sgln:95100046.225.1
BizTrans = ‘null’

Trash readings

EventTime = timestamp, timezone
RecordTime = timestamp, timezone
EPCList = SGTIN
Action = “OBSERVE”
BizStep = urn: rfidlab:bizstep:fashion:trash
Disposition = “sold”
ReadPoint = urn:epc:id:gid:95100046.00000003.3 (portable reader)
BizLocation = urn:epc:id:sgln:95100046.500.1
BizTrans = ‘null’

Barriers and solutions

A list of the most important barriers happened are reported in Tab. 14.

Barrier	Description	Issue	Solution
Minimum impact on the check-out application	Strong integration between check-out application and RFID system is not allowed	Technical issues	Keyboard emulation protocol is used to communicate with the check out application.
Minimum impact on the check-out application	Strong integration between check-out application and RFID system is not allowed	Receipt changes cannot be communicated to the RFID system.	RFID trash process is developed.
Limited read area (above the check out desk)	The read area must be only above the check-out desk. Other garments must not be read.	If another item is read, it is removed from the inventory generating inventory inaccuracy.	An RF shield is installed below the antenna, and tests are performed in order to set the read power right.
There is limited read (trash container)	The trash antenna should read only the label inside.	If another item is read, it is removed from the inventory generating inventory inaccuracy.	A metal container is provided with a thin aperture.
Labels put on the floor of the metal container cannot be read.	If the label is stored too quickly, it can be found on the bottom of the container before being read.	Inventory inaccuracy.	A polystyrene layer is posited on the bottom in order to create a distance between the metal surface and the tag. The label can be read.

Tab. 14: Barriers and solution about check-out and trash processes.

6. RFID FASHION DASHBOARD

6.1. Overview

The RFID Fashion Pilot Dashboard is a Web Accessing Application specifically developed to provide the user the ability to query the database populated by the pilot processes. This logistics dashboard is able, through the various modules that make up, to provide high value-added information, through analyzing data compliant with the EPCIS specifications.

It may, in fact, infer information about the processes that affected each item, the process performance achieved. Also RFID device performances are provided. Therefore overall the available information on the Dashboard allow to determine the benefits and potentials of the RFID system. From design point of view is to be seen as a Proof of Concept and as such is a basic idea of helping to clarify the operation of the system that it wants to provide every single actor.

6.2. The modules

The RFID Fashion Pilot Dashboard is break down in some modules, each of which focused on a certain information type. The next section describe the various modules and the information available. Each module has a button to download data in csv format file.

The application is a web application, so it is accessible with a internet browser at the following link: http://xxx.xxx.xxx.xxx:8000/Dashboard/#hme where the home page is present. The core of the web application is placed in RFID Lab server and, every about 30 minutes, the application queries the remote EPCIS (DC and PoS), and downloads data. The home page shows the companies involved in the project (see Fig. 38).

Fig. 38: Home Page Dashboard

On the top of the page the link to the other modules are placed. They are:

- "Track&Trace": provides the information about items with common characteristics. For each of them all the EPCIS events occurred are shown. It answers question "*what's that?"*.
- "Inventory": provides the real time inventory levels in DC and PoS. It answers question "*how many do you have?*".
- "Replenishment": provides information about replenishment process. It shows the products to be replaced. It answers question "*what reassert*?"
- "Fitting": it provides information about fitting process. It answers questions "*What's tried on? Where? Has it been sold?"*
- "History": It provides all the EPCIS events involved a particular EPC. It answers question "*where tag has been seen*?"

In each module two zones can be recognized: the first one, on the left of the page provides the query options, the second one, most important, provides the results of the questions.

6.2.1. Track&Trace

In Fig. 39 the "Track&Trace" page is shown.

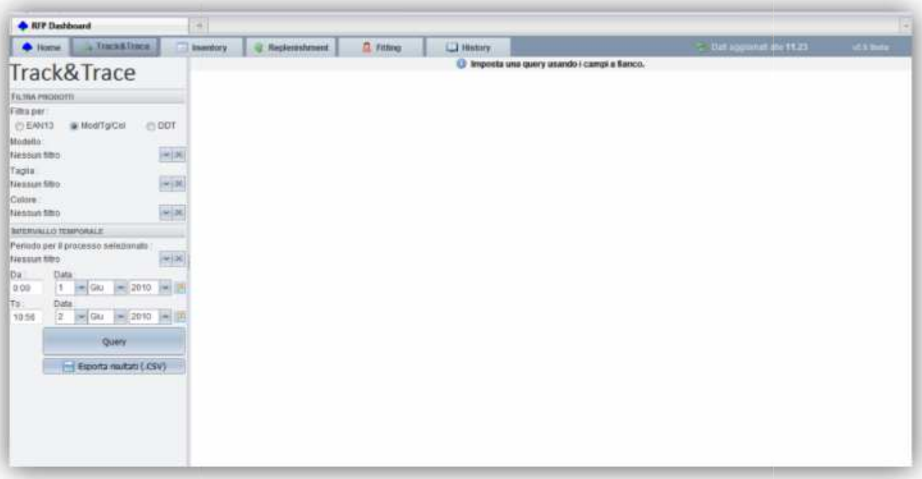


Fig. 39: Track&Trace page.

The query option section can be spitted in the following sub-sections:

- "Filtra prodotto": provides the information regarding the items to filter:
  - EAN 13: the results will show all the items of the EAN13 selected
  - Modello, Taglia, Colore: the the results will show all the items with the characteristic selected in term of model size and color;
  - DDT : the results will show all the items belonging to the selected Bill of Lading.
- " Intervallo Temporale" (time range): a time interval and one or more process can be selected. The results will show the history of all the garments involved by at least one of the selected process during the time interval chosen.

In Fig. 40 a possible result is shown. Each raw represents an items (responding the filtered options), each column represent a process. Each cells provides the last reading time involving the item made by the process. For this reason when the data are downloaded the table report only the last read time, not all the events. Clicking on any row the history page is automatically opened showing all the events involving the EPC selected.

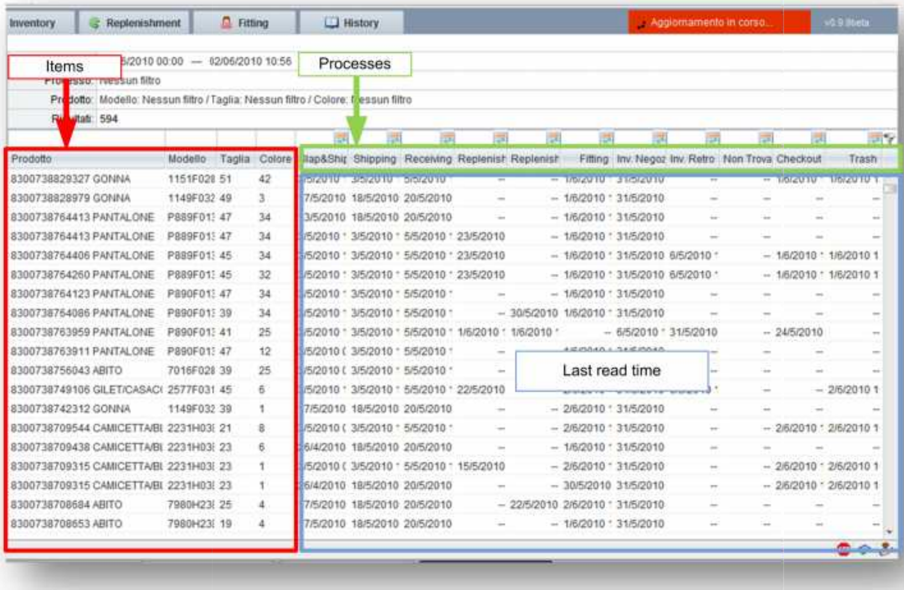


Fig. 40: Example results of a Track&Trace query. The three main elements are highlighted.

6.2.2. Inventory

The query section allow to filter data using the characteristic of the items (season, model, size, color) and the time interval.

The results (see Fig. 41) show the inventory level for each day of the selected time interval of each logical location: distribution centre, back store, selling area and oblivion. The fifth column reports the cumulative sums of sales.

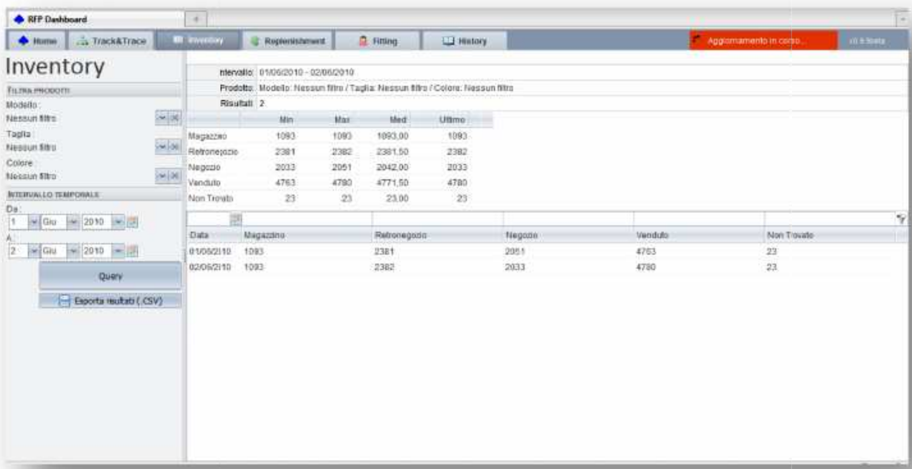


Fig. 41: Example results of a Inventory query.

6.2.3. Replenishment

The query section allow to filter data using the characteristic of the items (season, model, size, color) and the base number of days.

The results shows all the selling area stock outs: each row represent a certain Sku, the first three columns represent the stock level of distribution centre, back-store and selling area respectively. The forth column reports the number of items sold in the last x days (where x is the base number of day selected).

The results are sorted and spitted in order to highlights the most critical Sku (see Fig. 42.). They are the reference with an out of stock in selling area, but with a positive store in back-store. That means that these references could be replenished reducing the loss sale.

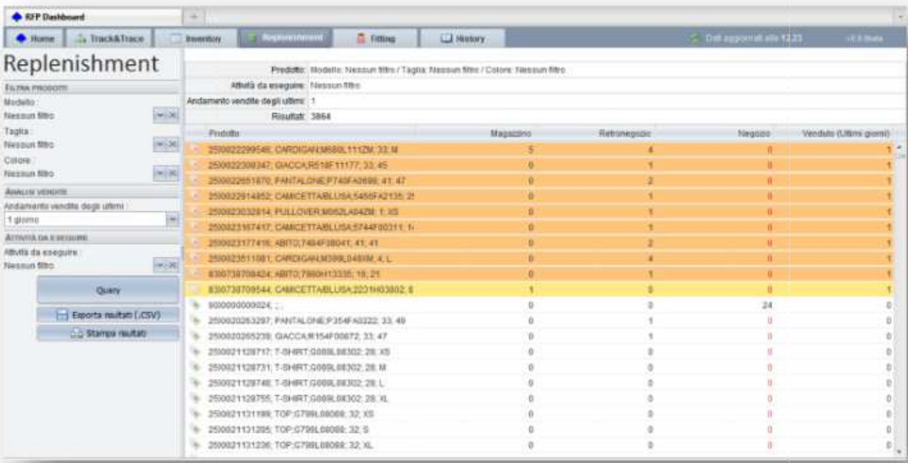


Fig. 42 Example results of a Replenishment query.

On the web page a "print botton" is provided. It used by shop assistant to print the list of items to replenish. In fact, in according with the management, the shop assistants should replenish the critical Sku every morning. Each time the page is printed a record in the DB is saved in order to compare this activity with the sale trend.

6.2.4. Fitting

The query section provides the same options of the replenishment module. The results reports the number of the fittings for each Sku (see Fig. 43)

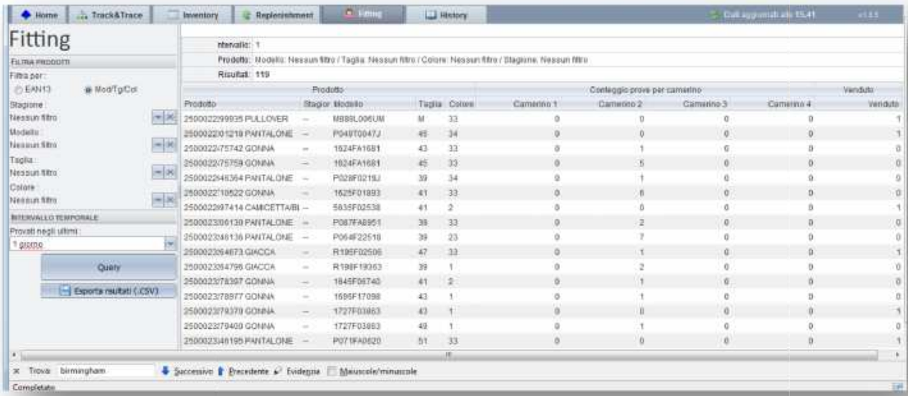


Fig. 43: Example results of a Fitting query.

6.2.5. History

Finally, the History module provides all the events involving the requested EPC (see Fig. 44).

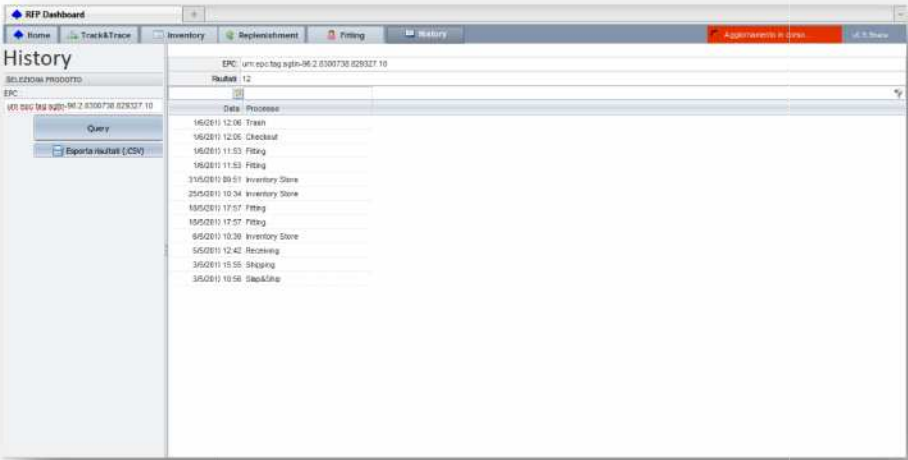


Fig. 44: Example results of a History query

7. EXPERIMENTAL CAMPAIGNS

7.1. Introduction

The reference period which is referred to starts at 2nd April 2010 and finishes at 30th August 2010. In the next sections an overview of the key performance indicators, developed during the experiments campaigns conducted, and the results are presented.

The first section reports the descriptive statistics, after that the earned values are described and finally the results are reported.

7.2. Descriptive statistics

This section shows the main features of a collection of data quantitatively. The descriptive statistics aim to summarize a data set quantitatively without employing a probabilistic formulation [40], rather than to supporting inferential statements about the population that the data are thought to represent.

The results reported were obtained from analysis of data extracted from the Track&Trace module of the RFID Fashion Dashboard.

The total volume of items treated during the experimental period amounted to (undisclosed information - confidential) garments. Of these:

- ✓ 65% are hanging items (jackets, pants, shirts, etc..);
- ✓ 35% are folded items (T-Shirts, Blouses, Scarves, Costume Jewellery, etc).

Items can be sorted by category, model, color, it is possible calculate the number of model for each category, the average number of colors for model and the average number of sizes for each model/color. The product of these values gives the total number of variants (Sku) in each category. The sum of these gives the total number of variants. On a total of (undisclosed information - confidential) models were tracked (undisclosed information - confidential) Skus. These numbers give an idea of the complexity of the supply chain monitored during the project.

During the experimental period (undisclosed information - confidential) cases have been sent for a total of (undisclosed information - confidential) items (see Fig. 45), divided among (undisclosed information - confidential) cases of hanging items (average about 80 items/case), corresponding to (undisclosed information - confidential), and (undisclosed information - confidential) cases of folded items, corresponding to (undisclosed information - confidential) items, (average about 58 items/case). For each shipment were sent an average of 12 cases divided into 7 packages of hanging items and 5 of folded items.

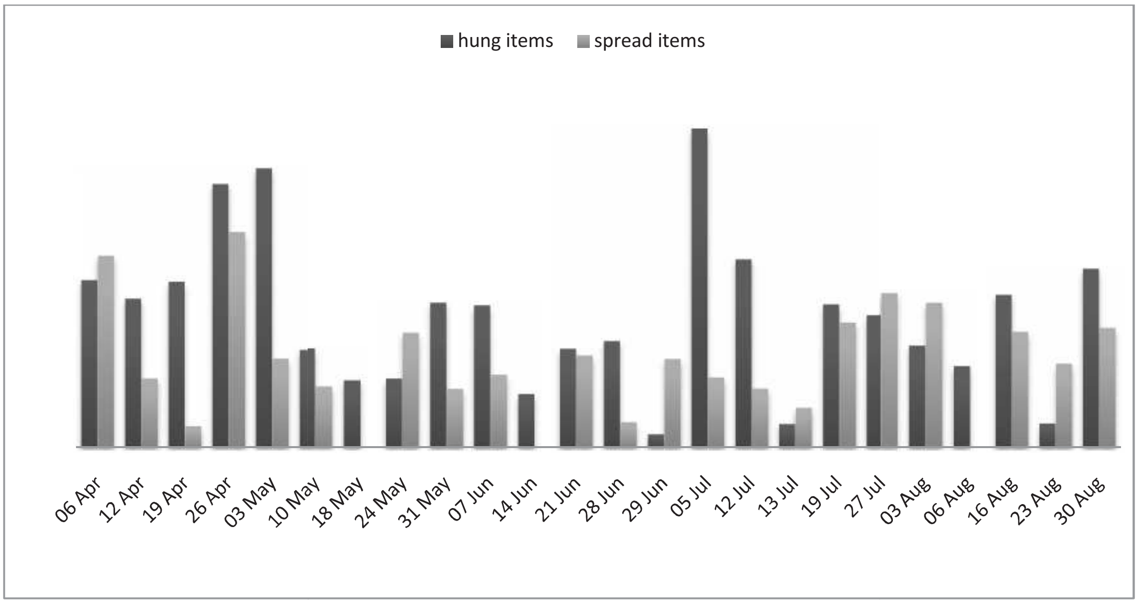


Fig. 45: Time distribution of the shipment from the DC to the store.

From the RFID Dashboard it is possible extract sale data grouped by date of sale. The investigation requires the following values:

- ✓ Product characteristics: no one;
- ✓ Time interval: from 02/04/2010 to 20/08/2010;
- ✓ Process: checkout and trash.

The results are sorted by category (see Fig. 46).and sale date (see Fig. 47) and reported in a bar chart. Fig. 47 shows clearly the typical sales trend, in fact the weekend peaks can be recognized, with a reduction of the sales during the other days of the week.

In Fig. 48 the sales are grouped by week.

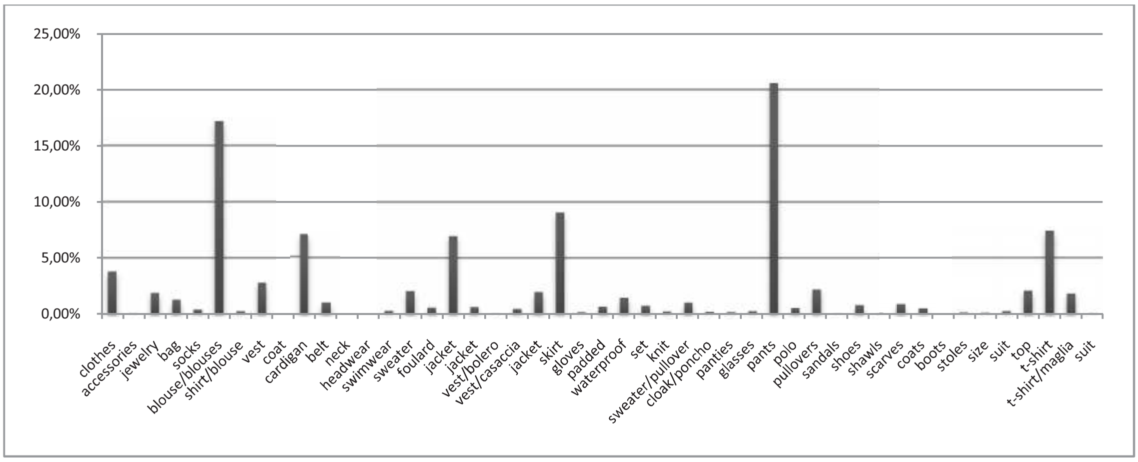


Fig. 46: Sales grouped by category.

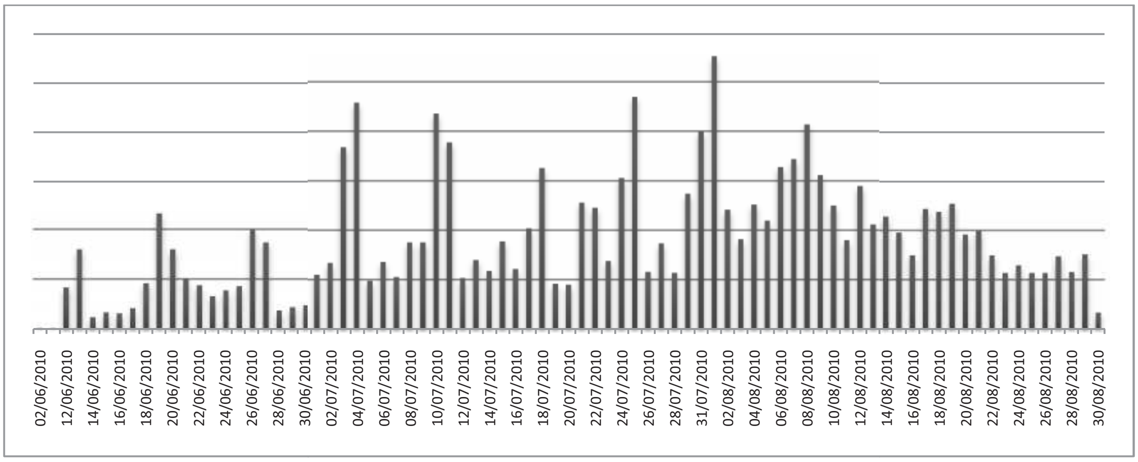


Fig. 47: Sales grouped by date.

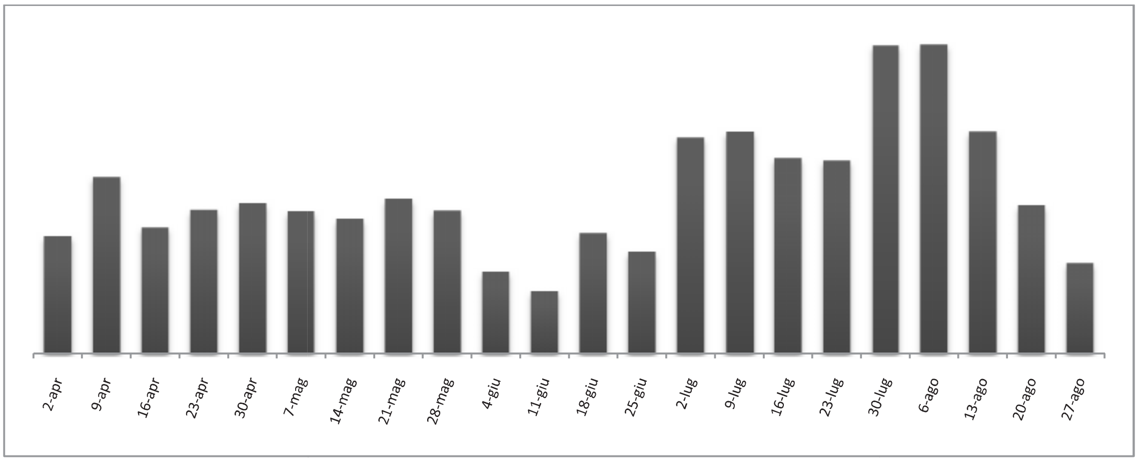


Fig. 48: Sales grouped by week.

7.3. Critical garments

In order to better understand the next sections and evaluations, it should be dedicated to explain critical items. These kinds of items showed a particular behavior with regard to the RFID technology. In fact the particular composition of their weave can reduce the RFID performance and impede the detection of the other items.

There are three type of critical items:

- ✓ Garments with metal fiber. Italian laws require specification on the label of the materials exceeding 3% or more. For this reason the label cannot be used to detect these kinds of items. In fact some critical garments were found without specification on the label;
- ✓ Garments with metallic decoration;
- ✓ Jewellery.

The metallic constituents of this items makes more difficult the communication between the tag and the reader and also can shield the other normal items reducing the RFID performances. For this reason during the experimental campaign these garments need a particular treatment.

7.4. Key performance indicators

The next sections presents a detailed description of the key performance indicators (KPI) which were proposed in order to determine the impact of the RFID technology on the experimental supply chain deployed in accordance with the procedures developed and described in the previous sections.

Key Performance Indicators (KPIs) provide a set of quantitative and objective measurements of process performances, allowing their real-time monitoring [3].

In accordance with Krauth et al. [41] the logistics KPI can be differentiated between the following four categories:

- ✓ Effectiveness –the capability of producing an intentional result.
- ✓ Efficiency – measurement for producing results from the used resources.
- ✓ Satisfaction - represents the human factor in the model..
- ✓ IT and innovation - concerning with the future performance of the organization. IT utilization are important factors for measuring long term performances.

In compliance with the aims of the projects only the second category will be developed.

7.4.1. RFID Shipping indicators

In general, benefits achievable during shipping process refer to possibility of reducing the manual checks to be performed on products received/shipped and to reduce the errors.

The most important efficiency indicator is the ‘labor utilization’, that is the variation of the time necessary to control and check the garments during the process.

In order to evaluate the Labor utilization a real timing measurement is performed using a barcode scanner before, and the RFID systems later. The aim of each trial is to check all the garments in a case. The variables are the item type (hanging or folded items), the RFID compatibility (RFID friendly, RFID unfriendly) and the device used (Barcode scanner, RFID HH, RFID cage). The results are the time needed to check all the items of a particular case. Actually the ‘As Is’ situation does not need such an accurate control of the shipment achieved thanks to the barcode scanner, but it is however calculated in order to generalize the results in all the possible situations.

Assuming a linear relationship between the number of items (independent variable) and the time (dependent variable) a linear regression is performed in order to estimate the time needed to check any quantities of garments. In this way a generalization of the impact of the RFID technology on the labor utilization can be done.

7.4.2. RFID Receiving Indicators

In regards to the evaluation of the impact of RFID technology on Receiving the items, metrics are calculated separately for item type (hanging, folded) using a two step process:

1. Firstly, the case are read and the data for the cases that reach 100% accuracy is selected and average read time and item per case calculated.
2. Secondary, the cases that have not been read with 100% accuracy during the first attempt, are selected and that data is used to calculate the average of inaccuracies, read time and item per case.

The results are shown by a pie chart.

A comparison between Bill of Lading data and the real shipment provided by RFID technology is performed in order to calculate the shipment errors. In fact the quantities reported on the BoL is used to update the store informative stock. The discrepancy between BoL and real product flow frequently stems from media breaks and the missing real-time or near real-time alignment of both data and the physical flow of goods. The result is inaccurate inventory information. Fleisch et al. argue that '*an elimination of inventory inaccuracy can reduce supply chain cost and decrease the out-of-stock'* [42].

The evaluation of the shipping accuracy is done following the next procedure:

1. Each BoL is collected and reported in a spreadsheet in order to be easily elaborated;
2. The real shipment is obtained by the RFID Fashion Dashboard using the Track&Trace module. Input data is the BoL id, reported on the itself document.
3. Results are collected and elaborated in order to have the same structure of the BoL.
4. Each row is compared, if a gap is recognized the row is considered incorrect and the difference is determined.
5. The results are used to calculate statistics such as: incorrect BoL rate, incorrect row rate, total and average deviation between the document quantity and the real one.

7.4.3. RFID Inventory indicators

In regards to the evaluation of the RFID impact on inventory activities, the following step process is used:

1. The expected items for each location are extracted from DB (Esa_i, Ebs_i are the number of expected items in selling area and back store respectively of the *i-th* trial);
2. The inventory activity is performed in the two locations fixing a time limit of 5 minute;
3. The read items for each location are extracted from DB;
4. The expected and read items lists are compared in order to calculate the process accuracy (Rsa_i and Rbs_i are the number of expected items actually read in selling area and back-store respectively of the *i-th* trial).
5. Periodically, the list of unread expected items of each trial is compared during all the experimental campaign in order to verify if unread items had never been seen after each trial (never-seen-after items). NSA_i is the number of never-seen-after items of the *i-th* trial.
6. The accuracy (acc_i) and the shrinkage (srg_i) are calculated:

$$acc_i = \frac{(Rsa_i + Rbs_i)}{(Esa_i + Ebs_i) - NSA_i} \quad (1)$$

$$srg_i = \frac{(Esa_i + Ebs_i) - NSA_i}{(Esa_i + Ebs_i)} \quad (2)$$

For instance, assuming the existence of a list of 100 expected items. After the trial just 80 items are read. The other 20 are not read because or they are lost (shrinkage) or the RFID technology has failed. Comparing the list of unread items during the experimental campaign, 15 items were never seen, while 5 are seen by other processes. In this example, using equation (1), the process accuracy will be 80/(100-15)=94%, because the 15 never-seen-after items probably were missing during the trial, so the number actually present was 100-15=95.

7.4.4. RFID Fitting indicators

The fitting readers started the detection every morning and stopped in the evening. That means that there are no events that start the read but every time an item is entered into the reading area of a fitting room, a new EPCIS event is stored. After that, the same item is ignored for a certain time (filter time), so if the garments is still in the reading area after the filter time, a new EPCIS event will be stored.

The filter time parameter is very important, in fact if it is too short more EPCIS are stored during the same fitting session, or, if it is too long the detection of two different fitting session cannot be recognized. For instant, a customer, called *A*, fits the garment *x* and the following EPCIS event times are stored: 13:40, 13:45, 13:50. A different customer, called *B*; fits the same garment, *x*, and the following event times are stored: 14:10, 14:15 and 14:20.

The events can be summarized in the following table:

Item	Time	Customer (unknown)
X	13:40	A
X	13:45	A
X	13:50	A
X	14:10	B
X	14:15	B
X	14:20	B

In order to estimate the actual number of trials the filter time is changed.

In the following table an estimation of the number of trials is performed changing the filter time value.

Filter time = 3 min

Item	Trial id	Time
X	1	13:40
X	2	13:45
X	3	13:50
X	4	14:10
X	5	14:15
X	6	14:20

Total Trials = 6

Filter time = 60 min

Item	Trial id	Time
X	1	13:40

Total Trials = 1

Filter time = 10 min

Item	Trial id	Time
X	1	13:40
X	2	14:10

Total Trials = 2

From the table is it clear that filter time is very important in order to estimate a realistic number of trial to compare with sales. But the problem is that the real distribution of the trials is unknown and it cannot be compared with the results in order to estimate the best filter value.

Therefore, to do it a different approach has been followed. The filter time is changed from 3 minute to 120 and the total number of trials is calculate using the following procedure:

1. All the EPCIS event are reported and sorted by (in sequence) fitting room, item code (epc), date, time.
2. Scrolling the data from the top to bottom, the number of trial is incremented one by one every time one of the following event occurs:
   - ✓ The fitting room changes;
   - ✓ The item code (epc) changes;
   - ✓ Date changes;
   - ✓ Difference between the reading and the previously is more than the filter time.

The results are reported in a chart which shows a particular behavior. In fact at the beginning the number of trials decreases until a particular value after that it tends to an asymptote. This value can be chosen to set the filter time.

Fitting data can be now compared with check-out data, in order to discover particular behaviors. The following analyses are performed:

1. The trials are grouped by weekday and hour in order to find demand peaks. This is useful in order to understand when the max customer support is required.
2. The chart of the time between a trial and a sale of the same garment:

i. The fitting data are extracted from DB;
ii. The data are elaborated fixing the filter time calculated above;
iii. The sales are extracted from dashboard;
iv. A sale is searched for each fitting items, if it happens in the same day it is kept, if it happens in another day it is ignored, assuming that there is no link if a garment is fitted on a day and sold on another one.
v. The time difference between trial and sale is calculated and reports in a chart.

3. Relationship between trials and sales:
   i. The total number of trials is counted for each model;
   ii. The total number of sales is counted for each model;
   iii. The ratio between trails and sales is calculated and reported in a bar chart.
   iv. Anomalous behaviors are highlighted.
4. Relationship between sales and trials:
   i. The total number of trials is counted for each model;
   ii. The total number of sales is counted for each model;
   iii. The ratio between sales and trials is calculated and reported in a bar chart.
   iv. Anomalous behaviors are highlighted.

7.4.5. Sales impact indicators

One of most important benefits of the RFID technology on a fashion store is the its impact on sales. In fact, previously studies conducted by RFID Lab of Parma prove that sales impact is one of the most important factors in decide about the adoption of RFID.

In order to evaluate the impact of RFID technology two instruments are developed:

- ✓ Shop assistant support application;
- ✓ Replenishment support.

Shop assistant support application

This software provides information about the stock level of a particular model more quickly than the ‘As Is’ procedures (for more detailed explanation see section 5.7.4, pp. 65). Using the replenishment gate the shop assistant can read an item and, quickly, determinate the stock level of the model in the selling area and in the back-store categorized by size and color. This help her to reply to a customer request about the availability of a certain size or color of the requested garment. If the item requested is in stock, the shop assistant can know where it is and provide it to the customer, if it is not in stock, she can suggest something else in order to prevent a loss sale. For these reason this kind of application is able to increase sales because it provides support during the selling process.

Moon et al. argue '*RFID could enhance ability to serve customers better at shop floor level, particularly those who are tourists requiring immediate availability of selected merchandise*' [9].

In order to evaluate the impact of this application on the sales, every time the shop assistant use the application, a record is stored saving read epc and event time. Comparing these data with the following sales the time gap can be calculated and a cumulative graph can be drawn.

Replenishment support

The RFID Fashion Dashboard provides the replenishment tool. This can be used to know if garments are stocked out in selling area and replenish them. Every morning, before the opening time, or when it is possible, the shop assistant prints the list of garments to replenish, starting with the operation.

These operations reduce the stock-out rate in the selling area and any reduction in out-of-stocks provides benefit for the retailer, the supplier, and the consumer [43].

Every time the shop assistant print the replenishment list, records are stored saving model and event time. Comparing the time gap between printing and sales the impact can be evaluated.

7.5. Experimental results

In the next sections results for each process are reported.

7.5.1. RFID Shipping results

The experimental sample is reported in Tab. 15.

CASE ID	GARMENT TYPE	RFID FRIENDLY	AMOUNT OF ITEM
234	HANGING ITEMS	RFID FRIENDLY	48
235	HANGING ITEMS	MIXED	62
236	FOLDED ITEMS	RFID FRIENDLY	18
237	FOLDED ITEMS	RFID FRIENDLY	32
238	FOLDED ITEMS	RFID FRIENDLY	14
239	FOLDED ITEMS	RFID FRIENDLY	53
240	FOLDED ITEMS	RFID FRIENDLY	27
242	HANGING ITEMS	RFID FRIENDLY	19
243	HANGING ITEMS	RFID FRIENDLY	25
244	HANGING ITEMS	RFID FRIENDLY	155
245	HANGING ITEMS	MIXED	36
246	HANGING ITEMS	MIXED	114

Tab. 15: Experimental sample and characteristic.

As described in section 7.4.1, the measurements are done with different devices: barcode scanner, RFID handheld device and RFID cage.

The procedures used are:

- ✓ Barcode scanner:
  - i. Operator recognizes the package;
  - ii. Operator opens the package;
  - iii. Operator scans all the items into the package;
  - iv. Operator verifies the scan;
  - v. Operator closes the package.
- ✓ RFID Handheld device:
  - i. Operator recognizes the package;

ii. Operator inserts the information on the application;
iii. Operator reads all the garments into the package without open it;
iv. Operator finishes to read when the 100% accuracy is achieved;
v. Operator save data.

- ✓ RFID cage
  i. Operator opens the cage and put the package into it;
  ii. Operator inserts the information on the application;
  iii. Starts the reading;
  iv. The application will stop when the 100% accuracy is achieved;
  v. Operator bring out the package from the cage.

In accordance with the linear regression assumption (see Appendix A) x and y are quantitative variable. x is the independent variable or explanatory variables, and in this case it is the number of item to detect, while y is the dependent variable and it is the measured time.

The linear regression model is

$$y' = \beta x, \qquad where\, y' = \; y - a$$

Where:

- ✓ a is the set time (the fixed time);
- ✓ β is the regression coefficient.

Data reported in Tab. 16 are the time needed to read all the hung RFID friendly items.

CASE ID	# OF ITEMS	BARCODE SCANNING TIME [s]	RFID HH DEVICE READ TIME [s]	RFID CAGE READ TIME [s]
234	48	148	21	35
242	19	59	6	22
243	25	77	7	31
244	155	478	62	30

Tab. 16: Read time for hung RFID friendly items.

The linear regression analysis is reported in Fig. 49.

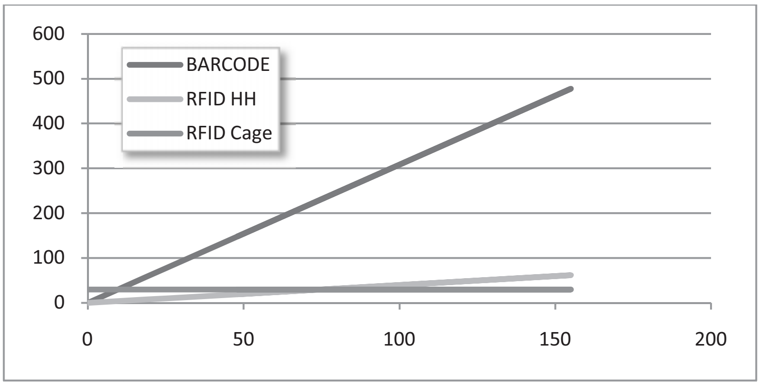


Fig. 49: Linear regression analysis for hung RFID friendly items.

The detailed results of linear regression analysis are reported in APPENDIX A.

From the graph of Fig. 49 the time trend can be observed. It is clear that the read time using the RFID cage is independent of the number of items (under 150 units). In fact the conditions are perfect the RFID detection (the items are hung and there are no critical garments) and reading time is dependent just on the set-up activities. The time needed to detect the garments is so low as to be insignificant.

Comparing the other two technologies, it is clear that the barcode scanning time is considerably longer than the other two devices. In fact in order to check more than 150 items using the RFID devices, about one minutes is necessary against more than one hour using bar code.

In the next table (Tab. 17) the time data are reported for hanging items with critical garments, while in Fig. 50 the linear regression analysis is reported.

CASE ID	# OF ITEMS	BARCODE SCANNING TIME [s]	RFID HH DEVICE READ TIME [s]	RFID CAGE READ TIME [s]
235	62	191	31	39
245	36	111	18	23
246	114	352	62	72

Tab. 17: Read time for hanging items with some critical garments.

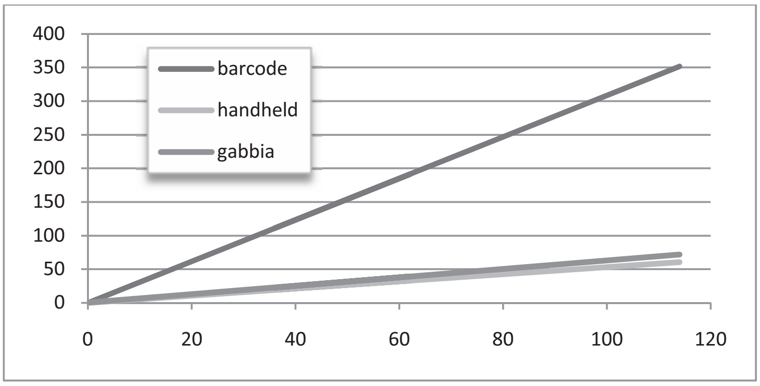


Fig. 50: Linear regression analysis for hanging items with some critical garments.

In regard to the new experimental sample, the time needed to read all the garments is higher than in the previous sample. In particular, regarding the RFID cage, the time became dependent on the number of items. This can be explained with the following considerations:

- ✓ The read accuracy depends on the space density of the garments. More items are in the same space, the probability to have unread tags is more;
- ✓ More items are on the same z-rack, the shielding effect of the critical garments is higher;
- ✓ The time depend on the loss readings, because an additional time to correct the set up is necessary.

For these reasons the time needed can be considered dependent on the number of items.

In addition, a similar behavior between the RFID handheld device and the RFID cage, can be observe. But an bigger experimental sample is needed.

In the next table (Tab. 18) the time data is reported for hanging items with critical garments, while in Fig. 51 the linear regression analysis is reported.

CASE ID	# OF ITEMS	BARCODE SCANNING TIME [s]	RFID HH DEVICE READ TIME [s]	RFID CAGE READ TIME [s]
236	18	135	6	10
237	32	240	17	14
238	14	105	3	11
239	53	398	15	32
240	27	203	12	25

Tab. 18: Read time for spread RFID friendly items.

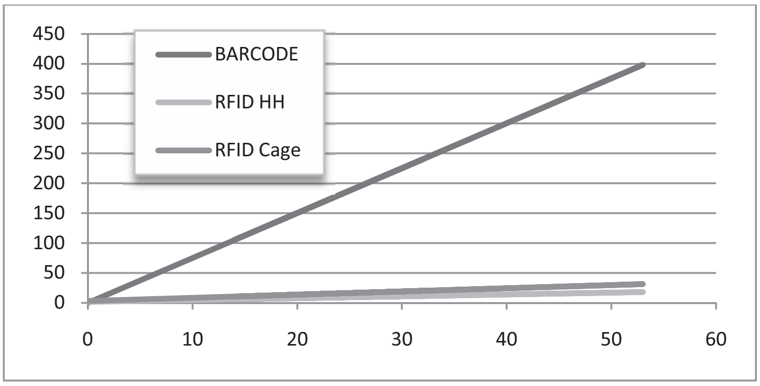


Fig. 51: Linear regression analysis for spread RFID friendly items.

A similar behavior can be observed: the read time using RFID devices, handheld device or cage, is significantly less than the one using the barcode scanner.

Overall the productivity achieved was 160 items/min by handheld device and 117 pieces/min by the RFID cage in the case of hanging items, while 184 items/min with handheld device and 97 items/min with the RFID Cage in the case of folded items. Generalizing the results of the monitoring of this shipment to all packages sent and received, it is estimated that:

- ✓ The total time required to ship terminal with barcode was equal to 6 hours;
- ✓ The total time required to ship by RFID HH device was equal to 28 minutes;
- ✓ The total time required to ship by RFID cage was equal to 36 minutes

This means that a reduction of more 90% of labor time can be achieved using the RFID technology to check the shipments.

7.5.2. RFID Receiving Results

Labor utilization

In regards to the receiving operations, the time needed to read and check all the received items and the accuracy achieved are measured and reported in the following charts in Fig. 52 and Fig. 53 (all the data is available in APPENDIX B).

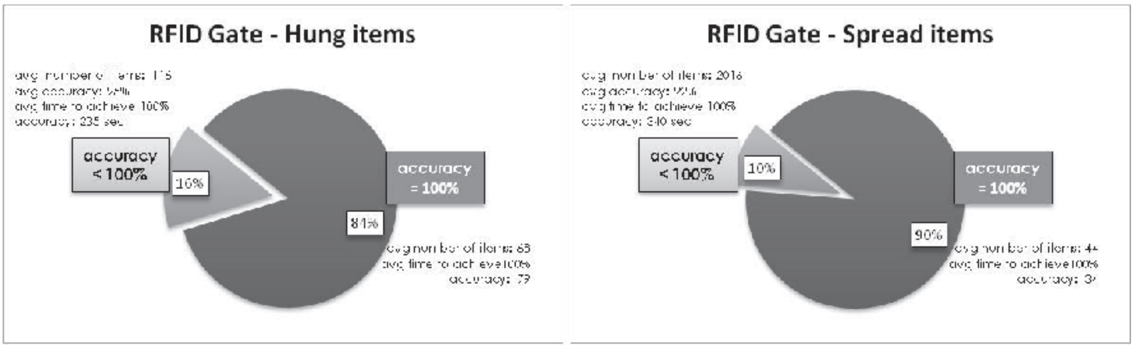


Fig. 52: Results receiving experimental campaign using HH device.

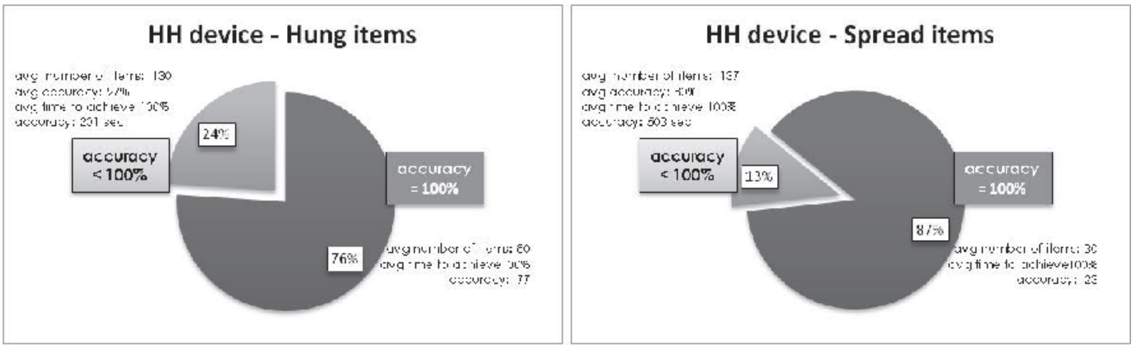


Fig. 53: Results receiving experimental campaign using RFID gate.

The same results are summarized in Tab. 19.

		RFID HH device		RFID gate	
		Acc. = 100%	Acc. < 100%	Acc. = 100%	Acc. < 100%
Hanging items	Avg nbr of items	80	130	68	116
	Avg accuracy	100%	97%	100%	95%
	Avg time [sec]	77	123	79	128
	Avg $time_{100\%}$[sec]		201		235
Folded items	Avg nbr of items	30	137	44	120
	Avg accuracy	100%	80%	100%	92%
	Avg time [sec]	23	184	34	131
	Avg $time_{100\%}$[sec]		503		341

Tab. 19: Results of receiving experimental campaign.

Results show that cases containing hung and RFID friendly items require more time to check all of the contents using both the RFID HH device and the RFID replenishment gate compare with the folded items. But the results is opposite if RFID unfriendly items are considered. In fact, in the instance of loss readings in closed package (folded items), the ultimate check requires more time because the box must be opened and the items inside are not tidy. Whereas the ultimate z-rack check (hung item) requires less time because the items are tidy and the critical items are more easily recognized. The hanging items average accuracy is higher than the folded items, because the neater arrangement of the garments on the z-rack facilities the reading operations. With regards to the timing, the two devices are similar, but the shop assistant has preferred the RFID replenishment gate because it is more reliable.

In Fig. 54 the time distribution is reported. In particular it is possible to estimate that the 50% of the cases can be completely checked in less than one minute and about the 87% of them in about 7 minutes and half. On the whole the RFID technology can reduce the labor time about 74% compared to the barcode operations.

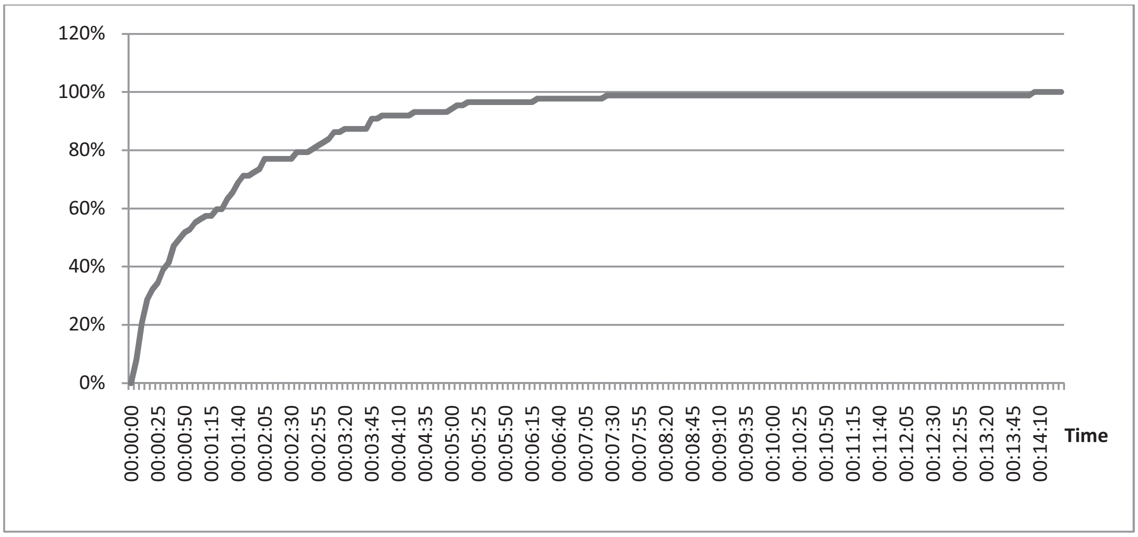


Fig. 54: Cumulative distribution function of the time needed for completely check of the cases.

Shipping/Receiving accuracy

From the comparison between the BoLs and the real product flow the following metrics are calculated:

- ✓ Total number of BoLs: (undisclosed information - confidential)
- ✓ Total number of BoL rows: (undisclosed information - confidential)
- ✓ Average number of rows per BoL: (undisclosed information - confidential)
- ✓ Average amount of items per row: (undisclosed information - confidential)
- ✓ Incorrect BoLs: (undisclosed information - confidential)

- ✓ Total incorrect BoL rows: (undisclosed information - confidential)
- ✓ Average BoL inaccuracy: (undisclosed information - confidential)
- ✓ Average deviation between BoL data and real amount: (undisclosed information - confidential) items per row
- ✓ Total deviation: (undisclosed information - confidential) items

The results reported above, provide the following scenario: (undisclosed information - confidential) BoLs, for a total of (undisclosed information - confidential) rows were checked. (undisclosed information - confidential) of these BoLs were incorrect. These contained a total of (undisclosed information - confidential) incorrect rows with an average of (undisclosed information - confidential) of rows for incorrect BoL. Each row shows a mean difference of (undisclosed information - confidential) units for a total of about (undisclosed information - confidential) pieces in total.

The chart of Fig. 55 reported the deviation distribution of the differences between the BoL data and the real quantity received.

From the chart it is clear that the (undisclosed information - confidential) of the row is correct, that means the amount of the (undisclosed information - confidential) of the reference received is equal to the data reported on the document. But the other (undisclosed information - confidential) is incorrect, that means that the store receives a different amount of items and its informative stock is update with a incorrect data. This generates inventory inaccuracy. Thank to the RFID tracking it is possible detect these errors and update the informative stock with real and correct data.

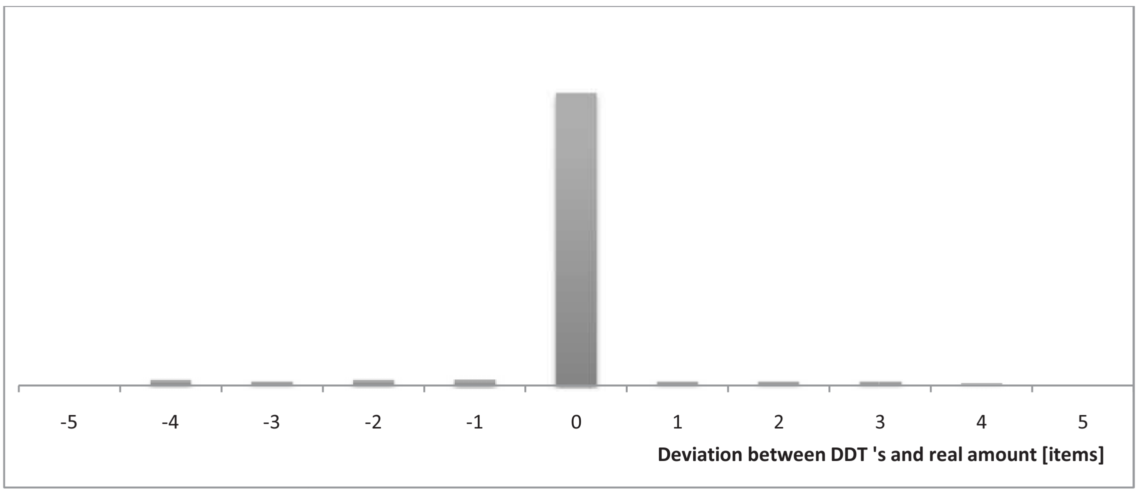
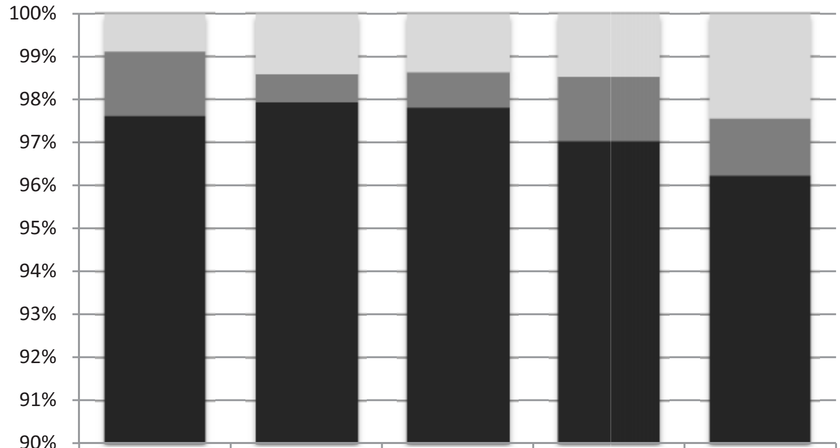


Fig. 55: Deviation between DDT quantity and real quantity distribution.

7.5.3. RFID Inventory results.

During the experimental campaign five tests have been performed. The results are showed in Fig. 56.



	05/05/2010	25/05/2010	31/05/2010	07/06/2010	15/06/2010
Unread never-seen-after items	0,9%	1,4%	1,4%	1,5%	2,4%
Unread items, but seen after	1,5%	0,7%	0,8%	1,5%	1,3%
Read items	97,6%	97,9%	97,8%	97,0%	96,2%

Fig. 56: Inventory accuracy analysis.

The process accuracy, calculated with the formula, varies between a maximum of 99.3% and a minimum of 98.5%, with an average of 98.8%. The never-seen-after items are about 1.5% of the total. This means that the informative stock has an 1.5% inventory inaccuracy or 70 items are missing. Is it clear that the never-seen-after items not read in the first test are missing also in the subsequent tests. So it is possible to infer they have not been read because they are actually missed.

The time needed to perform a trial is 5 minutes, that means that in 5 minutes more than 98% of the garments can be successfully read. Three reasons can be detected to explain the read accuracy:

1. Critical items: critical items can be unread because their composition blocks the communication between the tag and the reader;
2. Metal shelves: items with the label direct contact with the metal surface of the shelves cannot be read. To reduce this issue the folded items on the shelves are lift in order to move the labels and increase the read probability;

3. High volumetric density: in the back-store the number of the items is very high compared to the available space, that means some interferences among the tags can occur.

7.5.4. RFID Fitting results.

The procedure described in section 7.4.3, pp. 102, is used to estimate the best filter time. The results of the procedure is the chart are reported in Fig. 57. With the agreement of the Board of Advisors the filter time is fixed and it is 35 minutes.

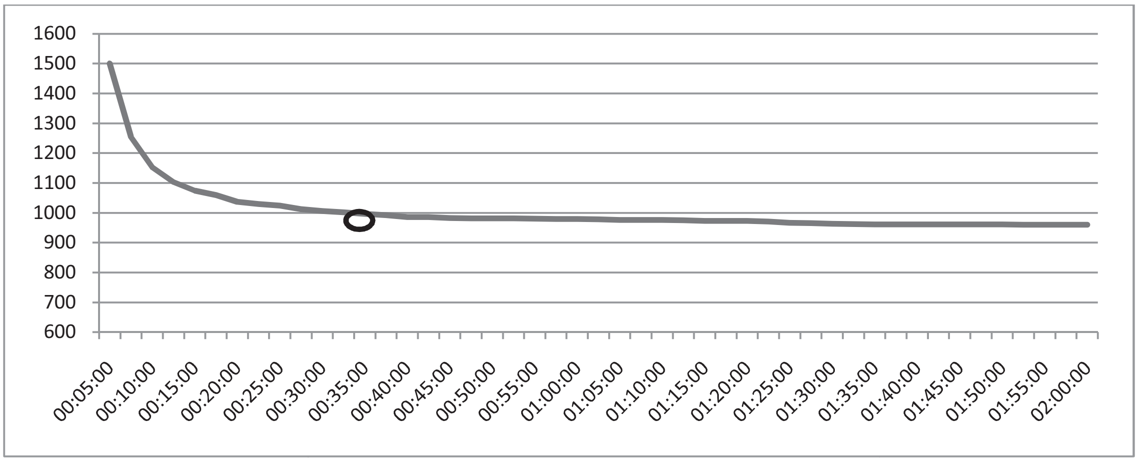


Fig. 57: Filter time distribution.

Setting filter time equals 35 minutes, the relative number of fittings is calculated and reported in Fig. 58. The categories mostly fitted are trousers and shirts. The least fitted are the sport suits.

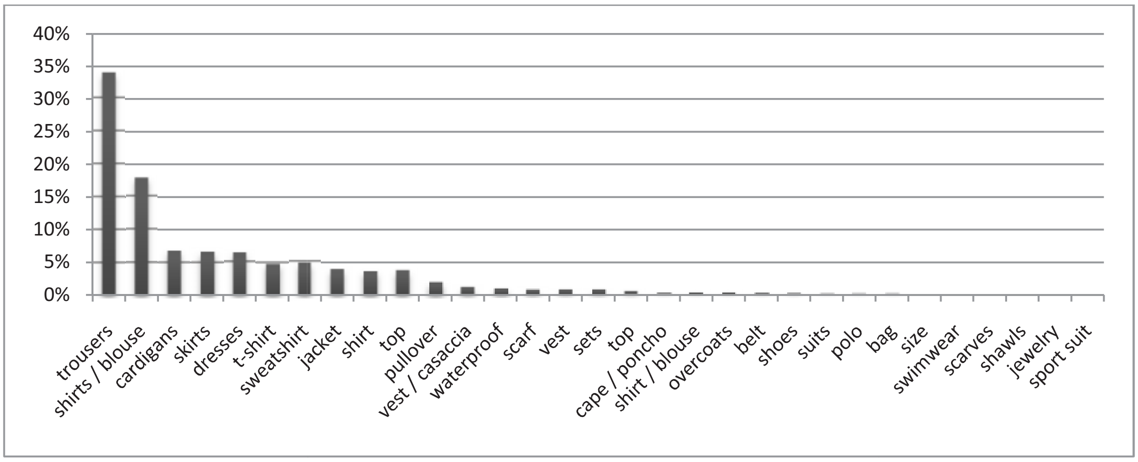


Fig. 58: Number of fittings per garments category.

In Fig. 59 the time gap between the fitting of a certain garment and its sale is reported. The graph shows that just about 10% garments are sold after a trial and in a time less than 30 minutes. 14% garments are sold in less than 3:30 hours. The curve rises rapidly, indicating a relationship between the fitting and the sale of the same item, in fact it is not possible determine a relationship between the fitting and the sale, because these data are not available, but by reducing the time gap the probable relationship increases.

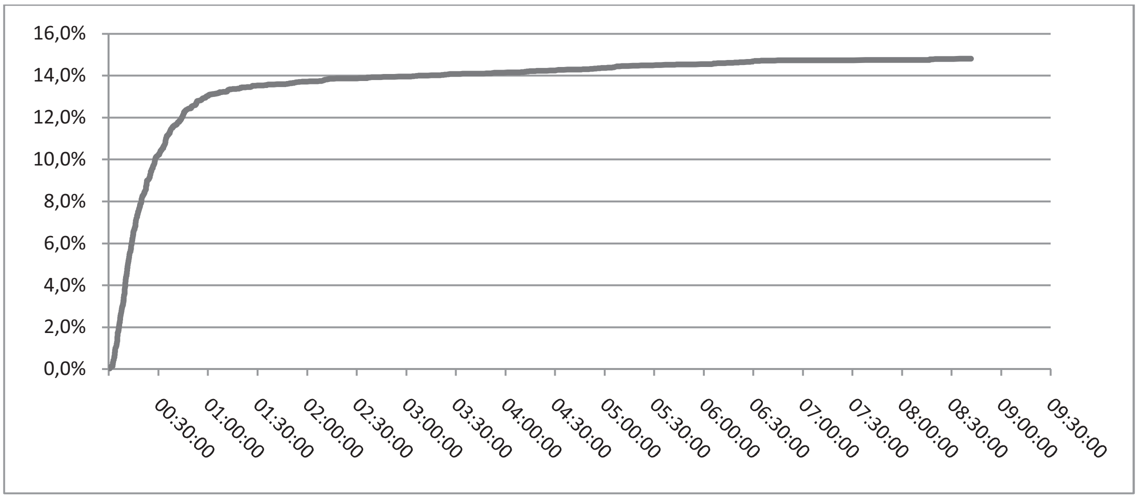


Fig. 59: Time gap between fitting and sale distribution.

In Fig. 60 and Fig. 61 the relationships between fittings and time are shown. In particular in Fig. 60 fittings per weekday distribution is reported. The trend pick up during the weekend. Indeed, most sales occur on Saturday and Sunday when customers have more time to leave to shopping. But these kinds of data and results confirm the trend obtained with normal systems (cash counting and sales analysis). The second graph is not available with the previous technologies, in fact the number of fittings per daytime-hour is not deducted from the sales data. Fig. 61 shows the fitting distribution per hour, and a particular trend can be recognized. The number of fittings is high in the first hours, but it decreases about midday probably because customers have a break for lunch. In fact, after 3 pm, the number increase again with a peak between 4 pm and 6 pm, after that it starts to reduce again.

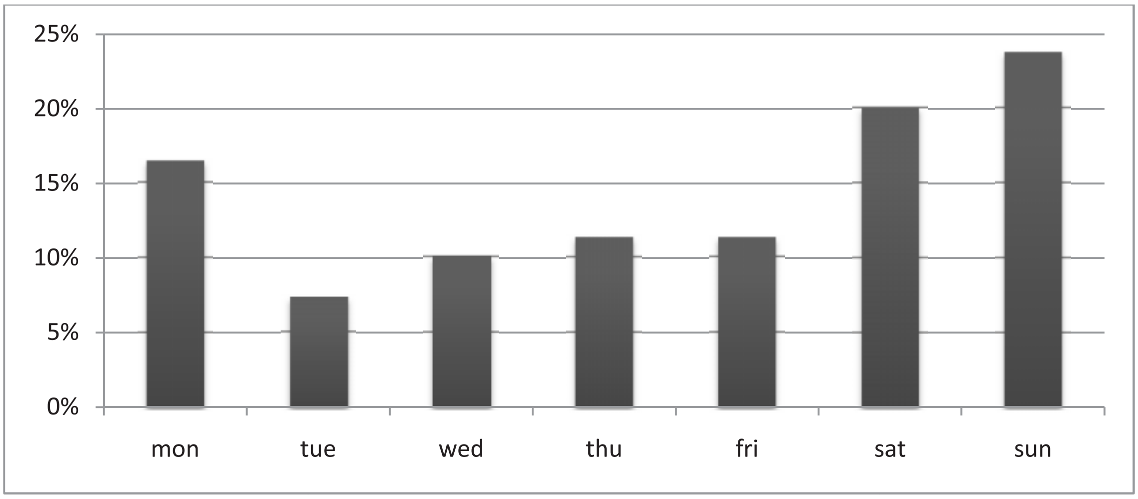


Fig. 60: Fitting per weekday distribution.

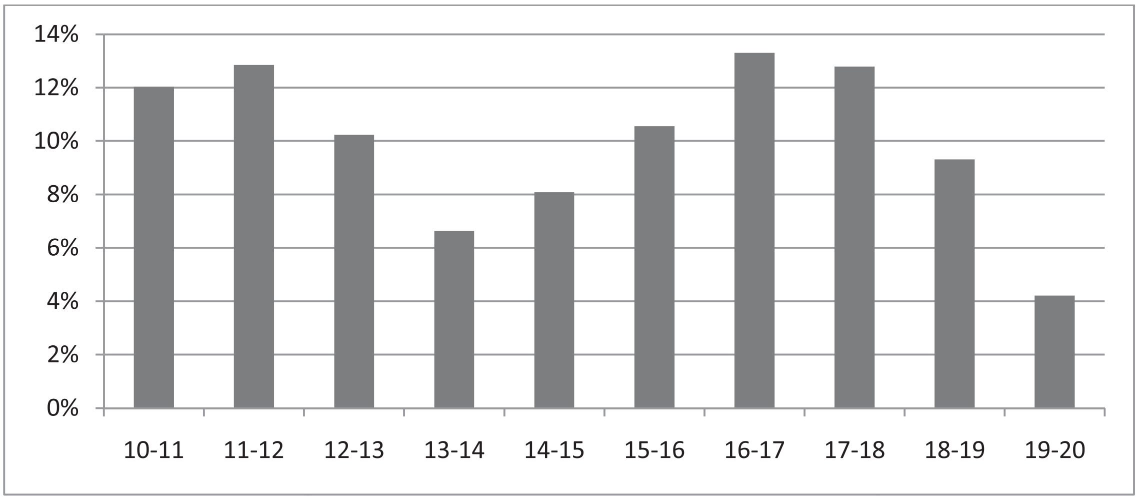


Fig. 61: Fittings per day hour distribution.

Fig. 62 shows the comparison between fitting and sales. In particular the rate between the number of fittings and the sales is reported.

Four categories can be recognized:

- ✓ A: models with the number of fittings equaling zero. This category is apparently the best because it provides profit with the minimum human activity (the human assistance is not needed). But, after an accurate analysis, it is clear that these models are products which do not need fitting room (see Fig. 63). In fact they are shoes, sandals, sunglasses, socks and some kind of jewellery. The identification of these kinds of products is very important in order to optimize the store layout. In fact these products can be placed in location at a distance from the fitting rooms.

- ✓ B: models with a number of sales greater than fittings. This category represent the models for which the fitting room is not generally required, but may sometimes occur. For instance a jacket can be fitted out of the fitting room without being detected. Or some of them can be sometimes impulse-buy products. For instance belts, scarves, t-shirts can be bought without a real fitting but just under a discount impulse.
- ✓ C: models with a number of sales lower than the fittings. This category represent the models which need the fitting room. Shirts, skirts, trousers etc, need to be fitted in the fitting room. In a normal purchase process some of them can be bought or not and this explain the lower ratio.
- ✓ D: models fitted but never sold. These categories represent the critical and important group of models. They were fitted but not sold, that means the product has a particular appeal, but after the fitting it is not appreciated. Understanding the reason for this change of mind can help the marketing or styling department to improve the models and increase the sales.

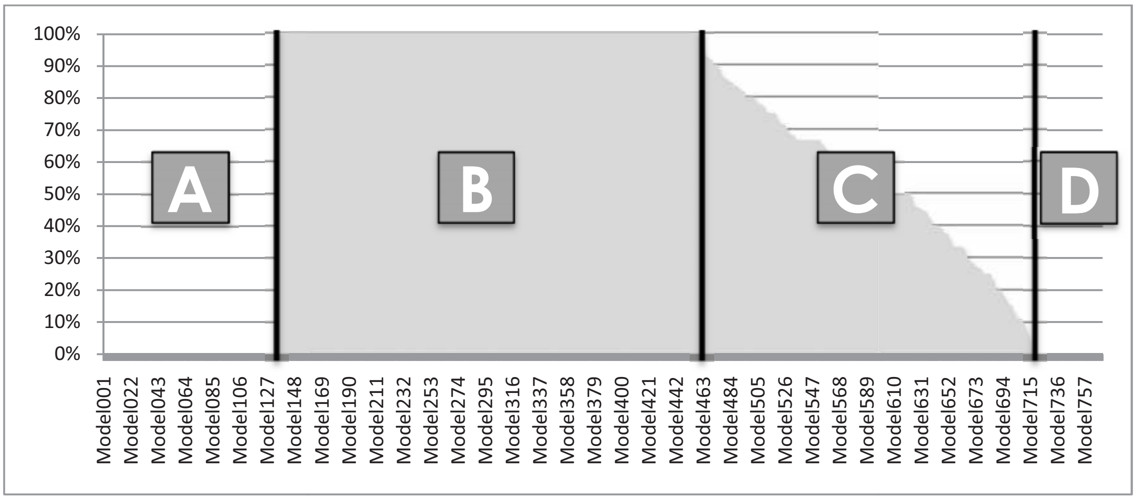


Fig. 62: Rate between fittings and sales per model.

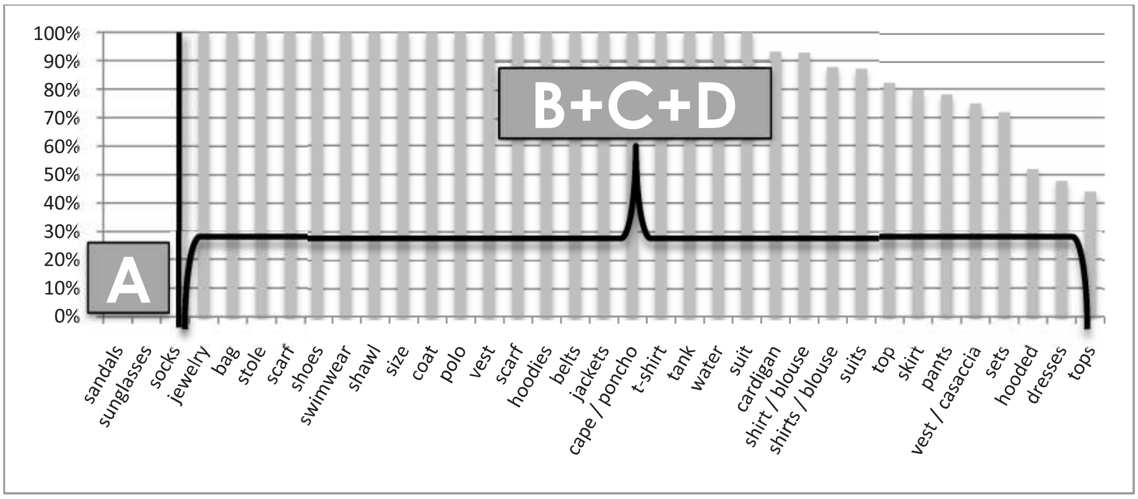


Fig. 63: Rate between fittings and sales grouped by category.

7.5.5. Sales impact results

Shop assistant support application

During the utilization of the application, (undisclosed information - confidential) items were sold, (undisclosed information - confidential) (2.68% sales) were searched by the application provided. Of which (undisclosed information - confidential) items were searched and also sold. That means, the total sales increase is 0,37%.

The time gap between the searching and the sale is reported in Fig. 64. The graph shows that 90% of the searched items are sold in about 2 hours.

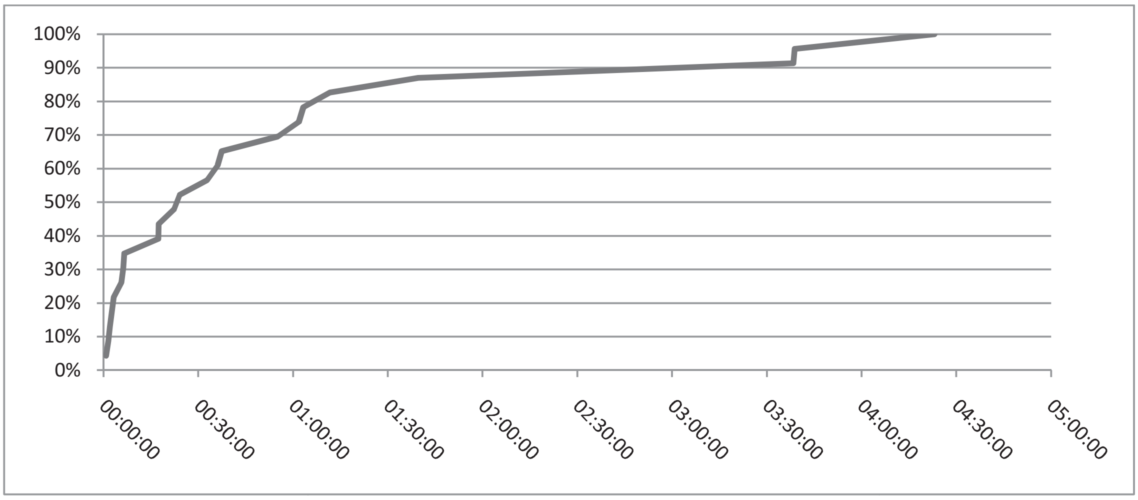


Fig. 64: Shop assistant support application usage.

Replenishment support

The replenishment activity is performed 18 days from 12th June to 31st August, that is equal to 22% of the available days. During these 18 days (undisclosed information - confidential) items were sold, while (undisclosed information - confidential) items were replenished (10,8% of the sales), (undisclosed information - confidential) of them were also sold (88,6% of the replenished items). That means that, during the days in which the replenishment activity was performed, the store increased its sales by 8%.

The Fig. 65 shows the distribution of the sales per number of days between replenishment and sale. It shows that the most of them take place in the first days and the trend is decreasing. That means that a relationship between the replenishment activity and the sales exists.

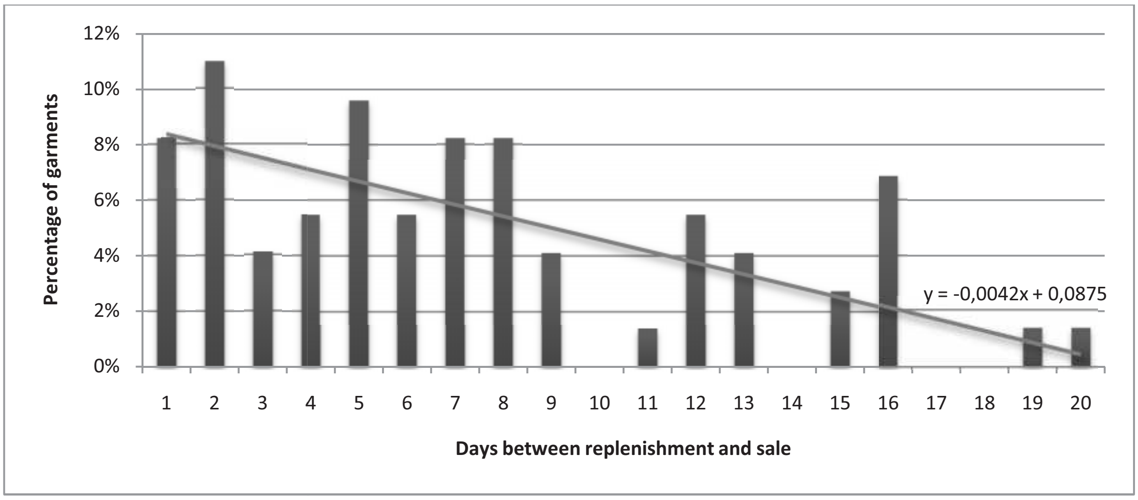


Fig. 65: Percentage of garments sold per number of days between replenishment and sale.

7.6. Results at a glance

The results are summarized in the following schema:

RFID Shipping and process:

- ✓ Labor efficiency increased by 80% (from 8 items/min to 100 items/min)
- ✓ Accuracy increased by 8.6%

RFID Inventory

- ✓ Labor time compatible reduction. An inventory per day is possible
- ✓ More than 97% accuracy

RFID Fitting

- ✓ Data availability
- ✓ Purchase assistance can be adapted to the needs
- ✓ New marketing information

Inpact on the sales

- ✓ More information are available to the shop assistant (+ 0.37%)
- ✓ Replenishment support: + 8%

8. CONCLUSIONS

The results of the project show that passive UHF RFID technology can improve data accuracy and labor efficiency and can increase sales in the apparel industry.

The companies involved on the pilot project, together with the RFID Lab, were Branded Apparel, Dolce&Gabbana Industria (with its logistics partners TNT and DHL), Imax (MaxMara Fashion Group), Miroglio Fashion, Trussardi and Norbert Dentressangle.

The pilot's aims were to evaluate the technical feasibility of the RFID technology in the fashion industry supply chain, including in retail points of sale and assess the business benefits of RFID, with a particular focus on store processes. A key goal was to quantify the RFID's impact on store sales.

The pilot supply chain involved two players: (i) the distribution center (DC) of Miroglio Fashion located in Pollenzo (CN) and (ii) the point of sale (PoS) "Elena Mirò" located at the outlet district "Fidenza Village" (PR).

The pilot ran from April 2, 2010 to August 30th, 2010, and collected data about (undisclosed information - confidential) items in Miroglio Fashion's spring/summer 2010 collection.

Garments and accessories were tagged at the Miroglio Fashion DC located in Pollenzo. The researchers tagged (undisclosed information - confidential) types of garments that were displayed on hangars within the store, (undisclosed information - confidential) types that were folded and displayed on store shelves, (undisclosed information - confidential). Each tag was identified with a unique ID number associated with the product information of the particular item to which the tag was applied, including price, model, size, and color.

At Miroglio Fashion's DC, the garments were placed in cases or hung on racks, and were then shipped to the Elena Mirò store located in the “Fidenza Village” Outlet. Using either the replenishment gate, or the handheld RFID device, employees identified the items, in order to check whether they precisely matched the Bill of Lading—Productivity in receiving processes improved by 80% with RFID and shipping accuracy increased more than 8.6%.

The shop assistants usually perform a physical inventory count within its stores once a season. The company updates the informative inventory using the data reported in the Bills of Landing, without checking the quantity of each item. During the experimental campaign, each garments received at the store's warehouse was read using the replenishment gate, checking the tag reads against what was shipped, and the inventory store was updated accordingly. Each time a product was replenished, its tag was detected as it passed through the replenishment gate and its location determined from the historic data. The experience indicates that a five-minute daily inventory count can be performed in the store using a portable fixed reader (the handheld processing power was too slow when reading thousands of tags). Tagged items were also detected in four fitting rooms equipped with RFID reading system in order to capture data regarding the product that were tried on with marketing objectives. A further fixed RFID reader was installed at check out desks. Tags were read during check out, updating the store's inventory once the purchase was completed.

The quick inventory counts of the entire store could be performed with the portable fixed reader in about five minutes with a 97% accuracy.

An EPCIS-based web dashboard was also developed. Employees could, for instance, check which garments were in the store's warehouse at any time, as well as which ones were on the sales floor.

Two applications to improve on-shelf availability were developed. The first one is used when a shopper requests a particular model in a different size or color. The application shows whether different sizes and colors for that same model were available in the store, as well as in the back room. The cross-checks between the model requested and checkout data reveal that such application was used several times over the experimental period, providing about a 0.4% increase in total sales for the store.

The second application was used to maintain an assortment of the best-seller models, colors and sizes on the selling area. The software provides employees with a dashboard showing which items need to be replenished when some of them are stored in the back room but no items are available on the shop floor. Shop assistants were trained to check and print the list of items to be replenished using the RFID Fashion Dashboard each morning. The system then stored when it was printed, along with the time that those garments were moved from the back room to the sale floor.

The comparison between replenishment data and reads at the checkout counter was used in order to determine how many of the replenished items were sold, resulting that an additional 8% sales can be performed thank to this application. It was thus demonstrated that the more accurate and real time data provided by the RFID technology can help the shop operators to increase the sales of the store.

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APPENDIX A – LINEAR REGRESSION[4]

In statistics, linear regression is any approach to modeling the relationship between a scalar variable *y* and one or more variables denoted *X*. Starting from a data set, the unknown parameters of a model can be estimated using different functions. Models which use liner functions are called “linear models.”

Linear regression has two most important uses:

- ✓ Prediction: linear regression can be used in order to forecast a particular behavior. It can be used to “teach” a predictive linear model to predict a value of *y* if a value of *X* is given, calibrating it using an observed data set of *y* and *X* values.
- ✓ Evaluation of relationship between more phonemes: linear regression analysis can be applied in order to verify if a relationship between *y* and a general data set X_j exists and, if it does, to quantify the entity of the relationship.

Definition of linear regression

Given a data set of *n* statistical units, a linear regression model assumes that the relationship between the dependent variable y_i and the *p*-vector of regressors x_i is approximately linear. This approximate relationship is modeled through a so-called “disturbance term” ε_i — an unobserved random variable that adds error to the relationship between *y* and *X*. Often these *n* equations can be written in vector form as

$$y = X\beta + \varepsilon$$

where

$$y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, X = \begin{pmatrix} x'_1 \\ x'_2 \\ \vdots \\ x'_n \end{pmatrix} = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix}, \beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \gamma_n \end{pmatrix}, \varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{pmatrix}$$

Terminology:

[4] Adapted from http://en.wikipedia.org/wiki/Linear_regression.

- ✓ y_i is called dependent variable. The choice of the dependent variable and of the independent variables may be based on a presumption that the value of first one is caused by, or directly influenced by the second ones. In the project, the total time needed to ship a case depend on the number of items to be read, so it is reasonable the define the time as the dependent variable.
- ✓ x_i are called independent variables (not to be confused with independent random variables). Sometime a constant is included in the model. For example we can take $x_{i1} = 1$ for any i. In this case the value of β is called “intercept”. Many statistical procedures for linear models require an intercept to be present, so it is often included even if theoretical considerations suggest that its value should be zero.
- ✓ β is a *p*-dimensional parameter vector. Its elements can be called effects, or regression coefficients. The linear regression aims to estimate β.
- ✓ ε_i is called the error term, disturbance term, or noise. This variable includes all other factors which can influence the dependent variable y_i other than x_i.

Analysis results

The following tables report the results of the regression analysis applied to the time necessary to detect all the garments in a case. The models was applied considering the “time” as the dependent variable and the “number of item” as the unique independent variable.

Other independent terms, such as the type of garments (hanging or folded), the RFID friendship (yes or no) and the detecting device (Barcode, RFID HH and RFID cage) were not considered in the regression models because not numerable variable. Thus, for each combination of those terms, a different regression models were determined. In this way it is possible verify which kind of RFID device is faster on equals other terms (garments type, RFID friendship and number of items).

The regression parameters resulted are reported in the following tables.

Hanging items - RFID Friendly

Regression Statistics	*Barcode*	*RFID HH device*	*RFID Cage*
Multiple R	0,999999389	0,998306715	0,228251152
R square	0,999998778	0,996616297	0,052098588
Adjusted R Square	0,999998167	0,663282963	-0,421852117
Standard Error	0,264631133	2,220118902	6,494737317
Observations	4	4	4
Significance F	6,11E-07	1,13E-03	7,72E-03

Hanging items - Critical garments

Regression Statistics	*Barcode*	*RFID HH device*	*RFID Cage*
Multiple R	0,999999543	0,999309046	0,999971398
R square	0,999999087	0,99861857	0,999942796
Adjusted R Square	0,499999087	0,49861857	0,999885592
Standard Error	0,280800105	1,882200188	0,267261242
Observations	3	3	3
Significance F	4,30E-04	1,67E-02	4,82E-03

Folded items - Critical garments

Regression Statistics	*Barcode*	*RFID HH device*	*RFID Cage*
Multiple R	0,999999677	0,788859184	0,852281461
R square	0,999999354	0,622298812	0,726383689
Adjusted R Square	0,749999354	0,496398416	0,635178252
Standard Error	0,215153039	4,216294099	5,834198237
Observations	5	5	5
Significance F	1,43E-10	1,13E-02	6,66E-02

APPENDIX B – DATASHEETS

Fixed reader - Impinj® Speedway[5]

Air Interface	Protocol EPCglobal UHF Class 1 Gen 2 / ISO 18000-6C
Antennas	4 monostatic antenna ports with reverse gender TNC
Connectivity	10/100 Base T Ethernet RS-232
Dimensions	22.7 cm x 32.4 cm x 5.7 cm (8.95 in x 12.75 in x 2.25 in)
GPIO	4 input and 8 output
Network Services	DHCP, LLA, NTP, HTTP, Telnet, SSH, SNMP, mDNS, and DNS-SD
Operating Frequencies	865–956 MHz
Operating Temperature	-20 ºC to 55 ºC
Protocols	EPCglobal Low Level Reader Protocol (LLRP) v 1.0.1 Impinj Mach1™ API
RF Power	+30 dBm / +32.5 dBm with extended length cables
Sensitivity	-80 dBm
Supported Regions	US, Canada, and other regions following US FCC Part 15 regulations
	Europe and other regions following ETSI EN 302 208 with and without LBT regulations
	China
	Japan
	Korea (through OEM partner)
	Malaysia (through OEM partner)
	Supported Regions
	Taiwan
	Weight 2.7 kg (6 lbs)

[5] http://www.impinj.com/

Fixed reader - Impinj® Speedway Revolution[6]

Air Interface	EPCglobal UHF Class 1 Gen 2 / ISO 18000-6C
Antennas	4 high performance, monostatic antenna ports optimized for Impinj reader antennas (RP TNC)
Connectivity	10/100BASE-T auto-negotiate (full/half) with auto-sensing MDI/MDX for auto-crossover (RJ-45)
Dimensions	7.5 x 6.9 x 1.2 in (19 x 17.5 x 3 cm)
GPIO	4 inputs, 4 outputs
Network Services	DHCP, Static, or Link local Addressing (LLA) with Multicast DNS (mDNS)
Operating Frequencies	865–956 MHz
Operating Temperature	-20 ºC to +50 ºC
Protocols	EPCglobal Low Level Reader Protocol (LLRP) v 1.0.1 Impinj Mach1™ API
RF Power	+30 dBm / +32.5 dBm with extended length cables
Sensitivity	-82 dBm
Supported Regions	US, Canada, and other regions following US FCC Part 15 regulations
	Europe and other regions following ETSI EN 302 208 v1.2.1 without LBT regulations
	Brazil, Uruguay
	Pending regulatory approval—Australia, China, Hong Kong, India, Malaysia, Singapore, Taiwan, Thailand, and Vietnam

[6] http://www.impinj.com/

Near field antenna - MT-249567/NCP[7]

ELECTRICAL

Type of antenna	Magnetic Field Antenna consists of 4 switched antenna element.
Frequency Range	865-870 MHz
Tag orientation	Any
VSWR	2.0 :1 (max)
Polarization	CP
Input impedance	50 Ω
Max Power	2W

MECHANICAL

Dimensions	(L x W x H) 435x 289 x 25 mm (max)
Weigh	1.5 kg (max)
Connector	N-Type Female
Radome	Polycarbinat UV Resistant per ETSI 300
Base plate	Aluminum with chemical conversion coating
Mounting	NONE

[7] http://www.mtiwe.com/

Far field antenna – S8658WPC[8]

Band	Wideband UHF
Frequency	865 to 956 MHz
Max. Gain	6 dBi
3dB Beamwidth	65 x 65 º
Polarization	RHCP
Weight	2.5 lbs
VSWR	1:5.1
Mounting Style	Mast Wall Mount
Dimensions	10.2 x 10.2 x 1.5 in
Pigtail	12 in
Enclosure Material	Acrylic
	PVC
Max Power	2 watts
RF Connector	N (Female)

[8] http://www.lairdtech.com/

Handheld device – Skeye[9]

Technical data

System	Marvell PXA270 CPU, 624 MHz 128 MB SD-RAM, 256 MB Flash, up to 512 MB Flash on request 3,5" QVGA TFT, 240 x 320, touch screen Windows CE 5.0 Pistol grip with trigger
Communication options	WLAN IEEE802.11b/g Bluetooth, Class 2 GPRS
Interfaces	**I** USB Host, USB Device RS232 Internal SD card slot
Auto ID options	Integrated laser scanner RFID UHF reader
Environment	Rugged case, protection level IP54 Operating temp.: –10 °C up to +50 °C
Dimensions	PDA: 210 x 95 x 40 *(L x W x H)*
(in mm)	Antenna: 200 x 260 *(L x W)*
Battery	3400 mAh
Accessories	Desktop cradle USB/RS232 Modem, ISDN TA, Ethernet *(opt.)*

UHF-Reader

Reader Modules	High performance reader module Read range up to 5 m *(depends on tag quality and ambient conditions)* Circular polarisation
Implemented transponder protocols	EPC Class 1 Gen2, Atmel Tagidu Transponder types can be selected in the configuration Additional transponder protocols on request by firmware update
Reader firmware	Update capability in the mobile unit
Anti-collision	Fast detection of many transponders in the designated area Anti-collision mode configurable e. g.: Anti-collision on/off, Read Cycles, Tag Timeouts, Inventory Flags S0–S3
UHF performance features	Max. 500mW ERP 865–870MHz *(opt. 902–928 MHz)* Approvals: ETSI EN 302 208 ETSI EN 300 220 Channel steps 200 kHz Output power adjustable by software *(for modifying the reading distance)*

[9] http://www.hoeft-wessel.com/de/skeye/home.htm

Handheld device – Psione Workabout Pro 2[10]

Model Variants	WORKABOUT PRO C – Model 7527C-G2
Platform	PXA270 520 MHz, 32 bit RISC CPU
	256 MB Flash ROM
	128 MB RAM
Operating System	Windows Mobile® 6 Classic, Professional
Wireless Communications	802.11b/g Compact Flash Radio available on all models
Barcode Applications	1D linear imager
RFID Module	UHF module
Frequency	868 MHz or 915 MHz
Tag supported	EPC Class 1 Gen 2, other protocols depending on regions
Read range up to	98.425 in (250 cm)
Dimension	(7.87” x 2.95”/3.94” x 1.22”/1.65”
	(200 mm x 75/100 mm x 31/42 mm)

Printer – Zebra RZ400

- ✓ Integrated RFID UHF reader/encoder
- ✓ Delivers high-performance UHF smart labels
- ✓ Ability to print/encode short-pitch smart labels (with 25mm spacing)
- ✓ Thermal transfer and direct thermal operating modes (can only use one mode at a time)
- ✓ Die-cast aluminum base, frame, and printhead mechanism
- ✓ Metal media cover with large clear window
- ✓ 16 MB DRAM, 8MB Flash
- ✓ RS-232C Serial Interface
- ✓ High Speed, IEEE 1284, Bi-Directional Parallel Interface
- ✓ USB 2.0

[10] http://www.psionteklogix.com/

- ✓ Transmissive and reflective media sensors
- ✓ Multi-lingual backlit 240x128 pixel graphic display
- ✓ Color-coded operator cues
- ✓ 32-bit processor
- ✓ Unicode™ - Compliant
- ✓ ZPL® or ZPLII® (Zebra Programming Language®)

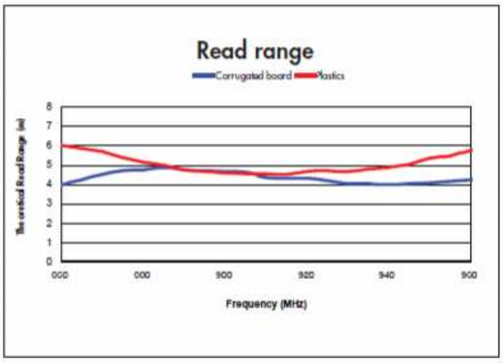
Tag – UPM Web[11]

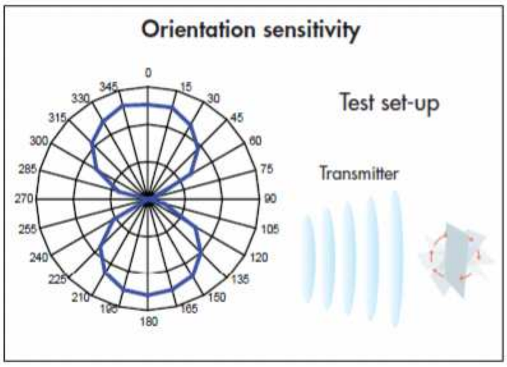
Antenna dimensions

- ✓ Antenna size 30 x 50 mm / 1.12 x 1.97”
- ✓ Die-cut size 34 x 54 mm / 1.34 x 2.13”
- ✓ Web width 40 mm / 1.57”

Electrical specifications

- ✓ IC NXP U-Code G2XL/G2XM
- ✓ EPC memory up to 240 bit
- ✓ User memory up to 512 bit
- ✓ Operating frequency 860–960 MHz





[11] http://www.upmrfid.com/rfid/rfid.nsf/sp?Open&cid=upm-rfid