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Applying RFID in warehouse operations of an Italian courier express company

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ABSTRACT

This paper deals with the re-engineering and design optimization of a warehouse for package storage operations occurring daily at a leading courier express company in Italy. The objective of our study is to quantify the return on investment and error reduction that can be achieved by the application of advanced tracking technologies in the package management process. In a first phase, we analyze the current process and show the speed-up of the operators with barcode readers compared to the operations handbook. In a second phase, we introduce radio frequency identification (RFID) technologies in the warehouse and perform practical experiments in order to detect configurations with error-free item scanning. An optimal configuration of the warehouse and of the RFID-based package management process is obtained by a non-linear optimization model that minimizes the overall technology and management costs. The probability of item errors is modeled by a maximum likelihood estimation procedure that determines the scanning area of each antenna with minimal scanning error. The new process with RFID technology reduces the costs of daily operations in the studied warehouse up to 25% and the workload of the operators up to 4 hours.

List of Symbols

- D : Horizontal distance shelf to antenna
- n : Total number of antennas
- N : Total Number of tag scannings
- R : Ray of the area radiated by one antenna
- H : Height of each shelf
- L : Length of the overall shelves
- J : Minimum distance from a focus to a border of the ellipsoid
- K : Length of the longest ellipsoid axis
- P_e : Probability of tag scanning error
- A_s : Total area of one shelf
- A_a : Total area radiated by one antenna
- A_{sa} : Scanned area of the shelf
- E^s : Estimated error for tag scanning
- E^m : Measured error for tag scanning
- C_a : Daily cost of the antennas
- C_r : Daily cost of the readers
- C_t : Daily cost of the passive RFID tags
- C_{o1} : Daily cost of the operators for the process management with RFID
- C_{o2} : Daily cost of the operators for the error correction with RFID
- W: Average number of packages in the warehouse

1 Introduction

RFID is a promising technology that allows automatic identification of the tags applied to items located at reading distance from an antenna. Scanning is generally faster and can be more accurate with to respect other technologies, such as bar codes, since no physical contact is require to detect items. However, the problem of quantifying the RFID value appears to be an important open issue in the related literature [3, 4, 7]. In fact, the potential of advanced tracking technologies is not yet fully known and there is a lack of scientific studies for evaluating their practical value in industry. While the cost of introducing RFID technology in the shop floor can be easily computed, estimating the Return On Investment (ROI) is a challenging task [6, 9].

This paper focuses on the development of a quantitative method in order to estimate the ROI and error reduction that can be achieved by the application of advanced tracking technologies in a courier express company in Italy. We study the daily management process of the packages that must be stored in a warehouse due to unsuccessful delivery to costumers. When packages enter the warehouse, each one receives a tag for univocal identification. A status is also assigned to each item, describing the reason of the unsuccessful delivery. At regular time intervals, items are scanned by human operators and are picked-up on the basis of their status for the next delivery trial. For a general overview of warehouse operations, we refer the reader to, e.g., [12].

A relevant problem of item scanning is the implementation of a low error system configuration. Holland et al. [5] recently proposed a test case in an empty room for scanning items with passive RFID tags. They found that several antennas are needed in order to cover the overall area of the room with 100% successfully readings, i.e., to identify exactly where the tagged items are located. In this study, we are dealing with a more difficult location problem since item scanning has to be done in a room with a number of interferences (e.g., metal rolls and human operators). Furthermore, we are not only interested in scanning of all items in the warehouse with a low error rate. Another and ever more important objective is the development of an accurate methodology in order to design a warehouse configuration that reduces the overall costs for the company.

The main contributions of this paper are:

- The current barcode item scanning by the operators is analyzed and compared with the operations handbook;
- Experiments with fixed/portable RFID readers and passive tags are performed at the warehouse to define error-free item scanning configurations;
- A maximum likelihood estimation procedure is presented to estimate the scanning area of each antenna with a minimal item location error;
- A non-linear optimization model is given in order to design the minimum cost configuration of the warehouse;
- A quantitative study is proposed to compare the current package management process with the new one based on RFID.

The paper is organized as follows. Section 2 reviews current applications of RFID to manage postal service problems. Section 3 describes the package management process studied in this paper, both pre and post RFID application. Section 4 introduces the practical test case at the warehouse of the courier express company. Section 5 uses the data from the practical measurements and a maximum likelihood estimation procedure in order to estimate the probability of tag scanning error. Section 6 gives the cost optimization model, presents the optimal warehouse configuration and discusses the improvements compared to the practical operations before RFID implementation. Section 7 concludes the paper with a discussion of the potential benefits of RFID technology and with an outline of new research directions.

2 RFID in postal services

This section gives an overview of world-wide RFID applications for the management of postal services. We limit our analysis to recent case studies on item scanning while other RFID applications are discussed in the survey paper of Zhang et al. [13].

In 2005, the Swedish postal service tested a first version of secure packaging by using tags with an embedded RFID circuit [11]. Their objective is to offer a secure service for delivering valuable items and to improve the investigations on damaged packages.

During the same period, a different monitoring approach is proposed by the Australian post [2] that are interested in understanding more about the delivery process of their envelops. Since this monitoring process involves a large number of items, their approach is limited to a small number of envelops and to the domestic mail service. Their results allow a better understanding of the process but do not offer accurate and complete information.

A German logistic company has recently proposed an efficient tracking system in order to reduce the risk of damaged packages or incomplete shipment [10]. The system integrates bar codes, video surveillance and RFID in order to locate automatically a package and to document its movement inside the warehouse.

The Spanish post is also interested in tracking packages and envelops in their warehouses [8]. They apply passive tags on each item passing each sorting center in order to understand the process bottlenecks and delays. Since the use a large number of tags, readers are both fixed antennas and portable readers.

In this paper, we focus on the tracking process of packages located inside a single warehouse. Our interest is focused in scanning of all items with high probability that the information flow coincides with the item flow more than in other issues like security tracking of packages. A major contribution is the development of a mathematical model in order to design a warehouse configuration with accurate tracking of the packages and to analyze the ROI from the RFID implementation.

3 Package management process

This section describes the warehouse operations related to the management of undelivered packages. We first summarize the package management process reported in the company operations handbook and compare its cost with that of the procedure actually implemented by the operators (named "as is"). In both cases the item scanning is performed by the operators using barcode technology. We then report on the main modifications of the process required by the introduction of RFID technology.

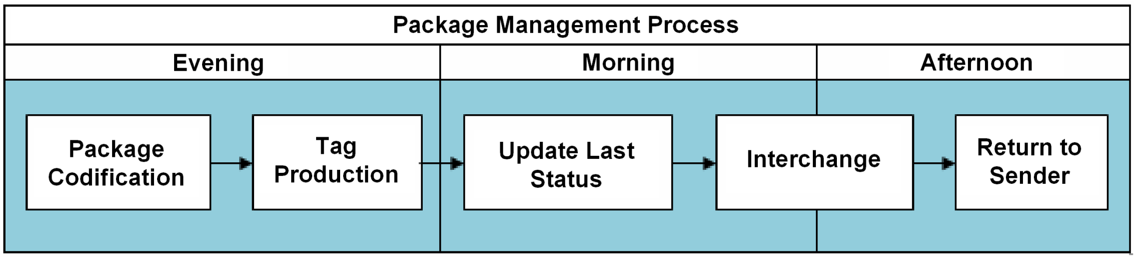


Figure 1: Layout of the daily activities of the package management process

3.1 Barcode-based operations

Figure 1 gives an overview of the package management process at the courier express company. According to the operations handbook, the process is organized in three time periods and several elementary daily activities:

1. Evening: The rolls with undelivered packages are returned from vans to the warehouse. A *package loading* activity follows that is divided into two sub-activities: (i) the *package codification* activity, in which undelivered packages are moved from the rolls to the warehouse room, and (ii) the *tag production*, in which a barcode tag is applied on each new undelivered package and the packages are then positioned in dedicated shelves;

2. Morning: The first activity is *update last status* that consists in a time-consuming scanning of all items in the warehouse by the barcode reader and in loading the new status of each package into the database. Any error in the scanning activity produces a missed package that has to be searched manually, so that reading errors are quite costly. The second activity is the *interchange* at the warehouse that consists of producing the list of packages that can be delivered in the next hours to their final destination.

3. Afternoon: The *interchange* activity is first completed, i.e., deliverable packages are prepared to leave the warehouse. The second activity is the *return to sender* in which undeliverable packages are returned to the senders.

Figure 2 compares, in terms of daily working hours, the operations described in the handbook with those actually executed by the operators ("as is"). The results are obtained by the analysis of 729000 elementary activities at the warehouse during the period 1 September 2009 - 28 November 2009.

The main differences are the interchange activities and the activity of return to the sender. The operators perform their work faster compared to the handbook for the following reasons. The item scanning is organized in four blocks on the basis of the arrival day of the week and of the type (national, international, other) of each stock stored in the warehouse. The operators speed up these activities by using a worksheet with all the information regarding the update last status activity (scanned packages, time of the day, barcode identifier). This worksheet helps them to search physically the package in the warehouse or, in special cases, even outside the warehouse.

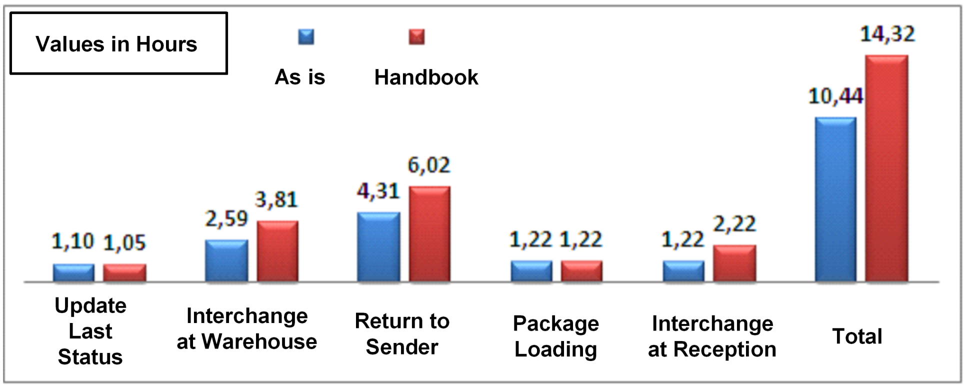


Figure 2: “As is” versus handbook

3.2 RFID-based operations

The warehouse operations have to be re-organized when dealing with RFID technology. The main differences for the elementary activities can be summarized as follows:

- The package insertion activity requires to apply an RFID tag (and a barcode tag, if not present) on each stored package and to save this information in the database.
- The update last status activity can be done automatically by the antennas of a fixed reader, except for possible reading errors that must be corrected manually. The operators perform manual scanning by RFID portable readers specially for envelopes and big packages placed in the rolls, since the reading error by automated scanning of these items is higher than the one by manual scanning. The combined scanning with fixed and portable RFID readers is thus the most cost-competitive.
- The interchange and return to sender activities are performed by portable readers that also show the current status of each scanned package. When the packages leave the warehouse, there is (possibly) an additional activity of tag recovery if multi-use RFID tags are used.

These process modifications have the objective to reduce the workload of operators by a faster item scanning, a better information updating and a more informed physical search of the packages stored in the warehouse.

4 Test case description

The warehouse under study is a rectangular room of 40 m^2 (5 meters x 8 meters). The entry door is located on the left-side of the room. As shown in Figure 3, there are 11 shelves that are located around the wall. Each shelf is rectangular and has the following size: height 1.48 m, width 1.58 m and depth 0.69 m. There are two locations for the packages on the shelf: one at 0.2 m from the ground and another one at 1.28 m from the ground. The colored shelves are for the small-size packages (ordered from Monday to Saturday, plus a shelf for the international packages and a roll for special services), while the envelops are located on the additional shelves. The large-size packages are placed on up to 5 rolls that are placed in the middle of the room. Each roll is rectangular and has the following size: height 1.6 m, width 0.68 m and depth 0.78 m. The packages are placed at 0.16 m from the ground on the only open side of each roll. We observe that shelves and rolls are made with metal and may cause interference when using RFID item scanning.

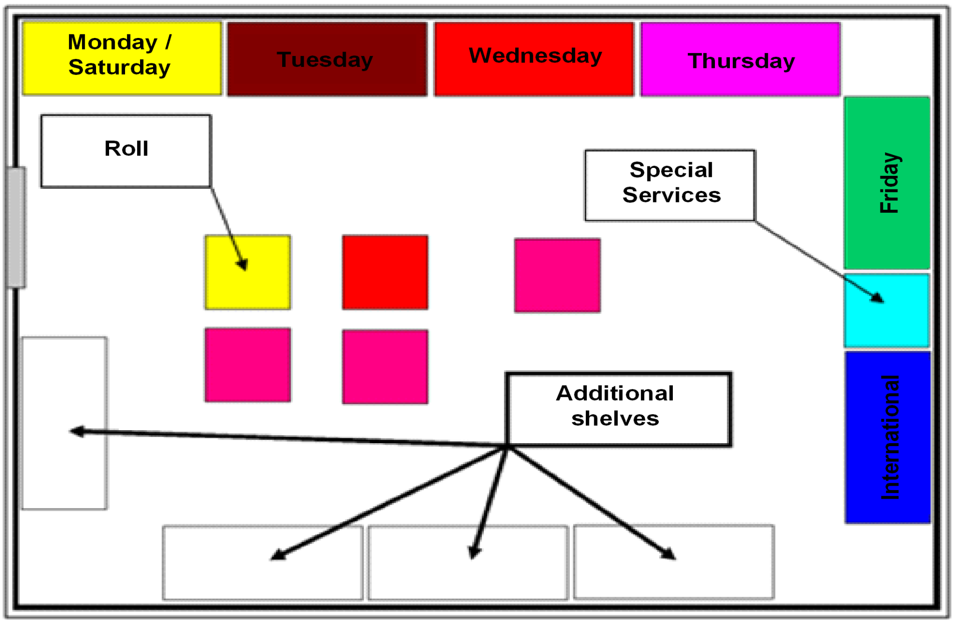


Figure 3: Warehouse configuration

A number of experiments have been performed in order to select the RFID technology configuration (antennas, readers and tags) with lowest item scanning errors in each point of the room. According to the experiments, the main parameters that influenced the scanning system performance are: the power and running time of the reader, the gradient and distance between the antenna and the shelf, the type and location of tags and the frequency of signal emission. The best RFID configuration is discussed in the next sections.

5 Maximum likelihood estimation

A first experimental phase is dedicated to determine the type of antennas, readers and tags. The objective of this phase is the definition of a mathematical model for the reading error as a function of the distance D between antennas and shelves and of the area $A_s(D)$ covered by each antenna. We consider the maximum power radiated by the reader equal to 30 dbm. Passive UHF tags have been applied to the frontal face of each package placed on the shelf.

Figure 4 shows the result of a typical item scanning for which the error was located on the left-top and right-top sides of the scanned area. From a set of 72 measures on the field for different values of D, we achieved an average error over 180 tags equal to around 0,08 with a minimum of 0,04. Since the item scanning of an antenna is not error-free, our approach takes into account the cost of manually correcting scanning errors. To this aim, we need a mathematical model for the error probability of an antenna.

From the results of the experimental phase, we observe that the scanning area of each antenna can be described by a rotational ellipsoid, or prolate spheroid, with the

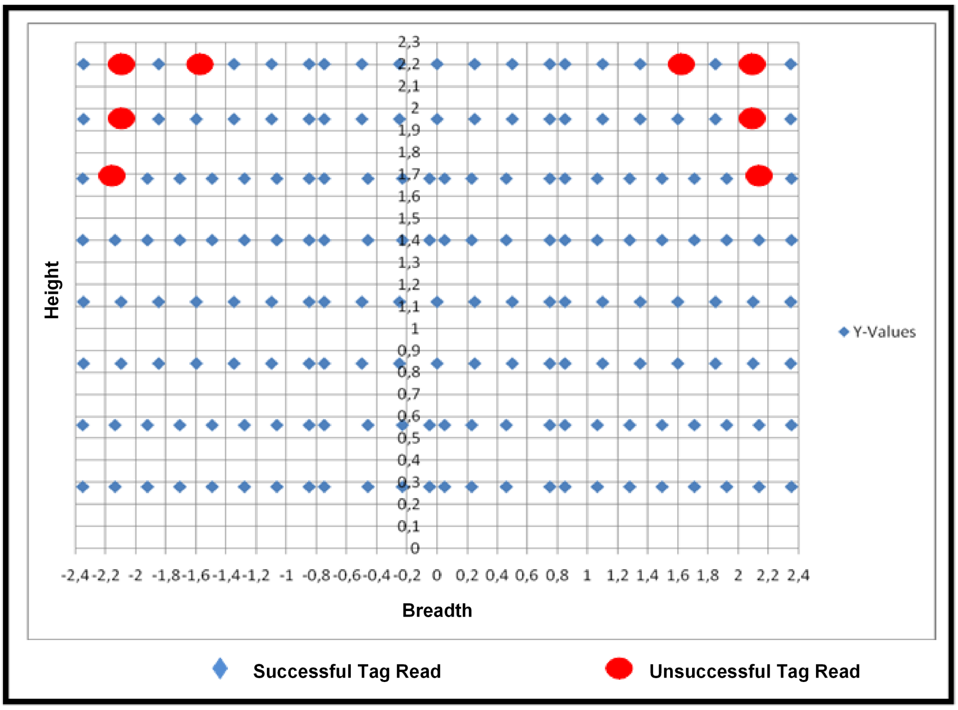


Figure 4: Results from a typical item scanning

antenna placed at one extremity, as in Figure 5. Therefore, the scanned area is completely described by two parameters, e.g., the major axis length K and distance J between a focus and the closest extremity of the ellipsoid (see Figure 5).

We assume that the power received by the tag exceeds the minimum read threshold if and only if the tag is inside the ellipsoid.

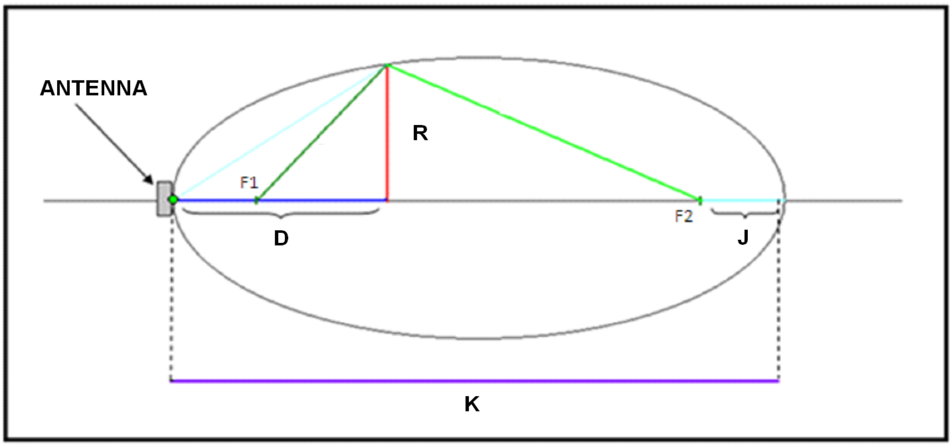


Figure 5: Ellipsoidal scanning area of the antenna

With this assumption, the scanned area of a shelf by an antenna is described by a circle, as shown in Figure 6.

Let $A_s(n) = HL/n$ be the total area of the shelf controlled by an antenna, where H is the shelf height, n is the total number of antennas and L is the total length of the shelves in the warehouse (see Figure 6). Let $A_a(D, K, J) = \pi R^2$ be the total area radiated by the

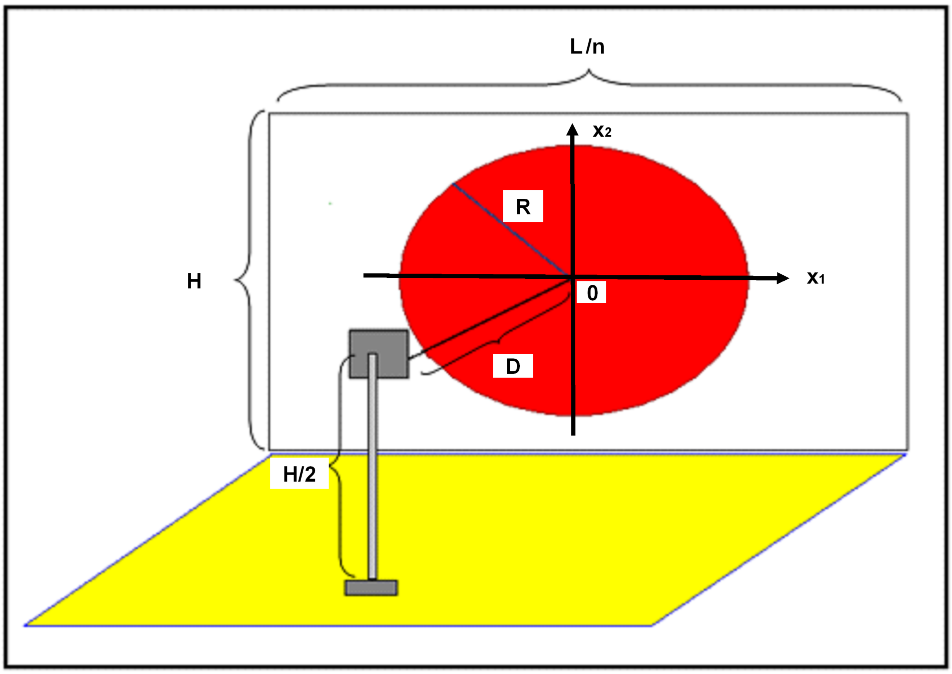


Figure 6: Circular scanned area of the shelf

antenna, where the radius R of the area radiated can be computed by triangulations on the ellipsoid of Figure 5:

$$R^2 = \left[\frac{K^2 + (D-J)^2 - (K-J-D)^2}{2K}\right]^2 - (D-J)^2.$$

The area of the shelf scanned by the antenna is $A_{sa}(D, n, K, J) = A_s \cap A_a$. Assuming that the packages are uniformly distributed in the shelf, the probability of tag scanning error is:

$$P_e(D, n, K, J) = 1 - A_{sa}/A_s.$$

The *estimated tag scanning error* in a warehouse with W packages is therefore $E^s(W, D, n, K, J) = WP_e(D, n, K, J)$. We denote *measured error* $E^m(W, D, n)$ the number of missed tags obtained from a measure on the field for n antennas positioned at distance D from the shelves.

In order to set the ellipsoid parameters J and K that best describe the scanning area of each antenna, we adopt a maximum likelihood estimation based on N measures on the field. Let J^* and K^* be the optimal solution to the problem:

$$\min_{K,J}\Big\{\sum_{i=1}^{N}\Big[E^s(W_i, D_i, n_i, K, J) - E^m(W_i, D_i, n_i)\Big]^2\Big\}.$$

In our experiments at the warehouse room, the value for the objective function results to be equal to 0,0074 for $N = 72$. This value confirms the validity of the ellipsoid model, since the difference between E^s and E^m is very low compared to N. In the next section, we denote with $P_e^*(D, n)$ the probability of tag scanning error having parameters J^* and K^*, i.e., $P_e(D, n, K^*, J^*)$.

6 RFID value

This section describes the mathematical methodology we propose to estimate the operational costs of the RFID-based package management process (subsection 6.1). We then illustrate the optimal warehouse configuration computed with this methodology (subsection 6.2). A comparison between the actual and the new warehouse configurations, using two alternative types of tags, is finally given in terms of various cost and workload indicators for the warehouse operations (subsection 6.3).

6.1 Cost minimization model

Operational costs of the new warehouse management process include the cost of the new hardware and software components and the cost related to the manpower for management and error correction. We consider an amortization period of seven years for one-time costs and 252 working days per year for iterated costs. In what follows, both types of costs are expressed in daily costs.

We next describe the cost minimization model for optimal warehouse configuration based on RFID technology. The model parameters are the daily costs C_a, C_r, C_t, C_{o1} and C_{o2}, where C_a refers to the antennas, C_r to the readers (each reader supports up to four antennas), C_t to the RFID tags (we analyze mono-use or multi-use tags), C_{o1} is the manpower cost for the process management with RFID, C_{o2} is the manpower cost for the manual correction of a reading error. Finally, we denote with W the average number of packages in the warehouse when the *update last status* activity is performed. We address the following cost minimization problem:

$$\min\{nC_a + \lceil n/4 \rceil C_r + C_t + C_{o1} + C_{o2} W P_e^*(D, n)\}.$$

Note that we assume that the antennas are equidistant, that the area $A_s(D)$ covered by each antenna is centered at height $H/2$ and that a reader can pilot up to 4 antennas.

6.2 Optimal warehouse configuration

The optimal solution of the cost minimization problem for the warehouse room of Figure 3 is shown in Figure 7. The optimal configuration has the following UHF RFID components:

- 1 reader with a maximum power of 30 dbm and a running time of 30s;
- 3 antennas ($n = 3$) with circular polarization that are used for scanning the items at a distance $D = 1.8$ m on the Monday-Saturday shelves, the international shelf and the special services shelf;
- 3 portable readers that are mainly used for scanning the items on the additional shelves and on the rolls;
- A number of tags, depending on their type (i.e., multi-use or mono-use). This issue will be discussed in Section 6.3.

The estimated probability of error for this configuration is null ($P_e^*(D, n) = 0$ for $n = 3$ and $D = 1.8$ m).

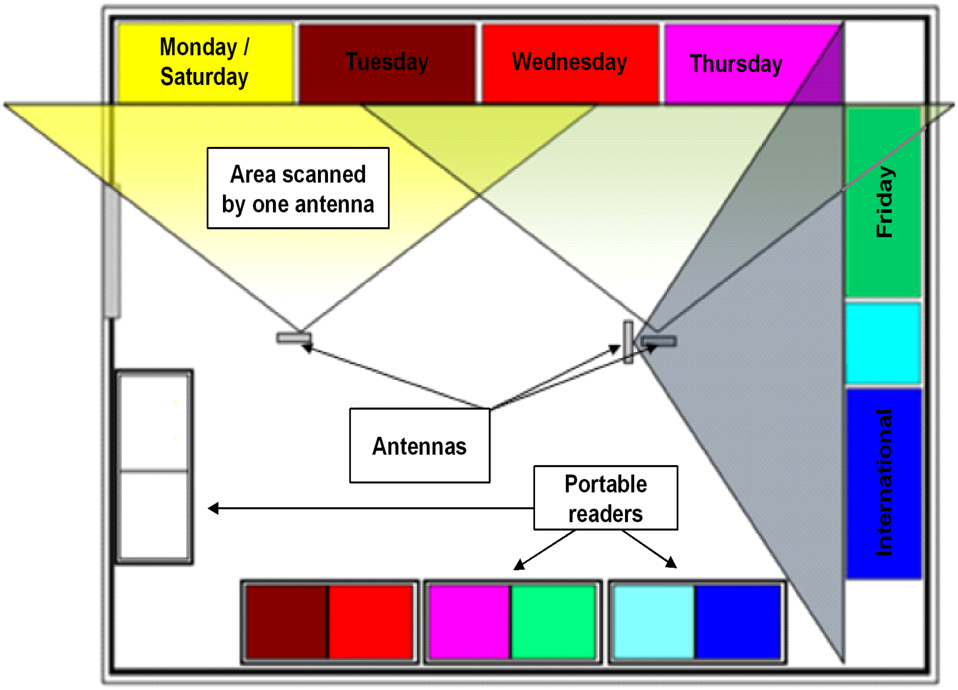


Figure 7: RFID-based warehouse configuration

6.3 Comparison between configurations

This subsection presents two optimal warehouse configurations, obtained by using mono-use or multi-use RFID tags A preliminary analysis of the package management process over two months (September and October 2009) has revealed a daily flow of around 200 in-bound packages in the warehouse. On average, less than 800 packages are stored at the same time.

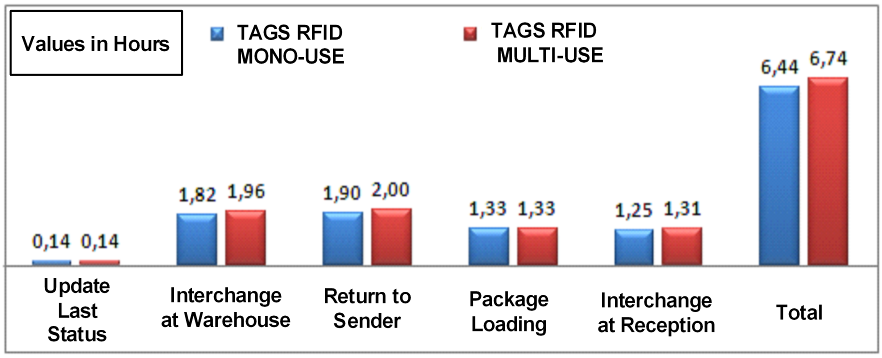
Table 1 shows the costs per type and volume of the passive UHF RFID tags used in the optimal warehouse configurations:

- Mono-use tags can only be used one time and for one package;
- Multi-use tags are plastified and can be used several times, we consider a plastification cost of 0.25 euro per tag.

TAG	Multi-use	Mono-use
Volume per year	1000	50000
Single tag cost (euro)	0.50	0.25
Total daily cost (euro)	1.98	50
Total annual cost (euro)	500	12600

Table 1: Multi-use and mono-use tags

Figure 8 shows the results achievable by the two optimal warehouse configurations for the given costs of the two types of tags. The two configurations are compared in terms of daily working hours for the elementary activities at the warehouse. Figure 8 also presents a comparison between the two optimal configurations and the actual daily warehouse operations of Figure 2, in terms of the cost of daily operations and of the operators workload.



DAILY WAREHOUSE OPERATIONS: RFID-BASED PROCESS versus AS IS		
COMPARISON	COST	TIME
TAGS RFID MONO-USE versus AS IS	- 7 %	- 4 HOURS
TAGS RFID MULTI-USE versus AS IS	- 25 %	- 3 HOURS AND 42 MINUTES

Figure 8: RFID benefits at the warehouse

From the results on the new warehouse configurations, we conclude that the RFID technology implementation deserves a high potential in reducing the daily costs of the warehouse operations. Regarding the choice of one optimal configuration, there is a trade-off between the two configurations based on RFID tags: the one based on mono-use tags is the best in terms of reducing the operators workload, while the other one is the best in terms of reducing the cost of daily operations.

7 Conclusions

This paper presents a new methodology to quantify the costs of implementing RFID technology in a warehouse room of an Italian courier express company. We introduce a new cost minimization model that takes into account the following factors related to the RFID technology: the re-engineering of the package management process, the re-configuration of the warehouse room, the one-time and iterated investment on the various technological elements and the performance of the new item scanning system.

The results obtained from the experimental phase and from the application of the cost minimization model demonstrate the remarkable value of the RFID technology to reduce operational costs. However, the overall benefits for the company can be higher. Table 2 shows the potential saving achievable by implementing the RFID technology on 40 warehouses. In this case the cost of the tag can be smaller, due to the higher number of tags purchased, so that the potential saving with respect to barcode technology can sum up to 34 % of the operational cost.

On-going research at the courier express company is dedicated to the application of the proposed methodology to other warehouses and to the integration of new database

Results on 40 warehouses	Multi-use	Mono-use
number of tags per year	40000	2000000
Single tag cost (euro)	0.34	0.17
Rfid vs Barcode cost	-34%	-20%

Table 2: Potential benefits over 40 warehouses

models and architectures for storing and processing the RFID information. The latter topic has been investigated extensively in the recent literature (see, e.g., [1]).

General conclusions of our study at the courier express company are that the RFID technology can be used to support several other tasks of the logistic supply chain, such as the management of the overall flow of packages from the warehouse to each specific customer. In fact, the RFID systems provide more accurate, frequent and fast information on each tagged item compared to the actual tracking systems. However, an important element to take into account is the cost of implementation and management of the new tracking system compared to those of alternative systems, specially when dealing with high volume of operations.

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