Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management
Kuala Lumpur, Malaysia, January 22 – 24, 2011

Optimal location of RFID antennas in a courier express warehouse

Dario Pacciarelli, Andrea D'Ariano and Michele Scotto
Dipartimento di Informatica e Automazione
Università degli Studi Roma Tre,
via della vasca navale, 79 - 00146 Roma, Italy
pacciarelli@dia.uniroma3.it ; a.dariano@dia.uniroma3.it

Abstract

This paper deals with the re-engineering and design optimization of a warehouse for daily package storage operations at an Italian courier express company. Our study quantifies the ROI and error reduction that can be achieved by the application of advanced tracking technologies in the package management process. The probability of item errors is modelled by a maximum likelihood estimation procedure. An optimal warehouse configuration is obtained by a non-linear optimization model that minimizes the overall technology and management costs. The RFID-based process reduces the costs of daily operations up to 25% and the operators workload up to 4 hours.

Keywords
RFID, Logistics Optimization, Location System, Business Process Reengineering, Maximum Likelihood.

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 [2, 3, 6]. 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 [5, 7].

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 and courier service operations, we refer the reader to, e.g., [1, 8, 9].

A relevant item scanning problem is the implementation of a low error system configuration [10]. Holland et al. [4] 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). 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 paper is organized as follows. Section 2 describes the package management process studied in this paper, both pre and post RFID application. Section 3 uses the data from the practical measurements and a maximum likelihood estimation procedure in order to estimate the probability of tag scanning error. Section 4 gives a non-linear cost optimization model, presents the optimal warehouse configuration and discusses the quantitative improvements of the package management process compared to the one before RFID implementation. Section 5 concludes the paper with a discussion of the potential benefits of RFID technology and with an outline of new research directions.

2. 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.

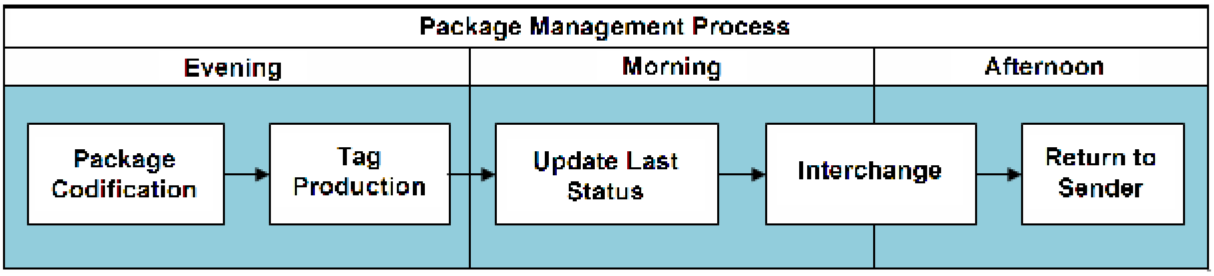

Figure 1: Layout of the daily activities of the package management process

Figure 1 describes 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 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 *return to sender* activity is then performed to hand over undeliverable packages to the senders.

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 with barcode (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 generate a reduced workload of operators for item scanning, a better information updating and a more informed physical search of the packages stored in the warehouse.

3. Maximum likelihood estimation

The warehouse under study is a rectangular room of 40 m^2 (5 meters x 8 meters). The warehouse has been re-organized with 11 shelves 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.

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. 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.

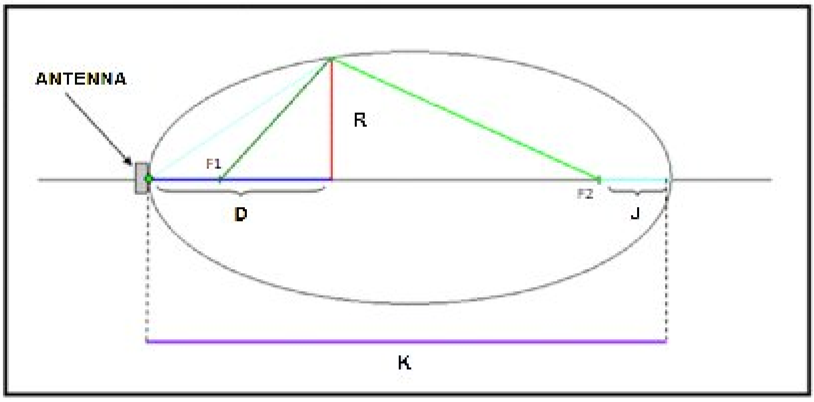

Figure 2: Ellipsoidal scanning area of the antenna

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 antenna placed at one extremity, as in Figure 2. 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 2). We assume that the power received by the tag exceeds the minimum read threshold if and only if the tag is inside the ellipsoid. With this assumption, the scanned area of a shelf is described by a circle, see Figure 3.

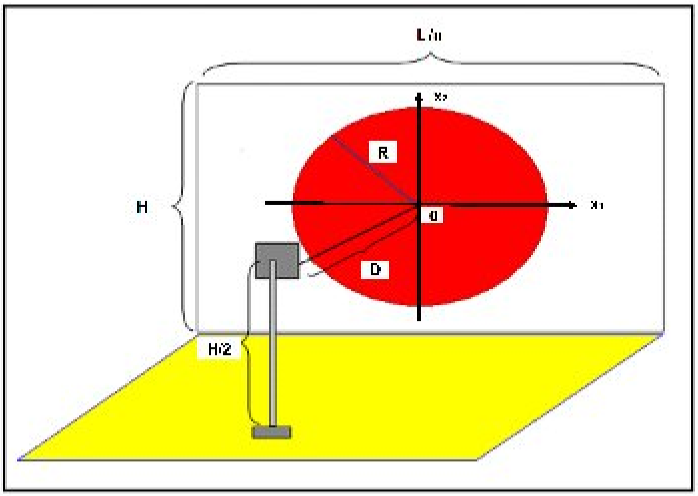

Figure 3: Circular scanned area of the shelf

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 3). Let $A_a(D, K, J) = \pi R^2$ be the total area radiated by the antenna, where the radius R of the area radiated can be computed by triangulations on the ellipsoid of Figure 2: $R^2 = \{[K^2 + (D - J)^2 - (K - J - D)^2] / 2k\}^2 - (D - J)^2$.

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

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 indicate the *measured error* $E^m(W, D, n)$ as 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:

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

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., $P_e(D, n, K^*, J^*)$.

4. RFID value

This section describes the mathematical methodology we propose to estimate the operational costs of the RFID-based package management process (subsection 4.1). We then illustrate the optimal warehouse configuration computed with this methodology (subsection 4.2). 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 4.3).

4.1 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 , Co_1 and Co_2, 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), Co_1 is the manpower cost for the process management with RFID, Co_2 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:

$$\min\left\{nC_a + \lceil n/4\rceil C_r + C_t + C_{o1} + C_{o2}WP_e^*(D, n)\right\},$$

in which $P_e(D, n)$ is the probability of tag scanning error having optimal parameters J^* and K^*as described in Section 3. 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.

4.2 Optimal warehouse configuration

The optimal solution of the cost minimization problem for the warehouse room is shown in Figure 4. The estimated probability of error for this configuration is null ($P_e(D, n)$ = 0 for n = 3 and D = 1.8 m).

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 item scanning on the additional shelves and on the rolls;
- A number of tags, depending on their type (multi-use or mono-use). This issue will be discussed in Section 4.3.

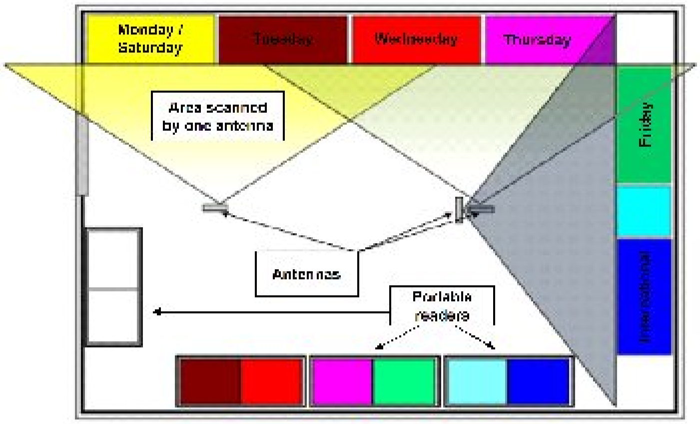

Figure 4: RFID-based warehouse configuration

4.3 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 while multi-use tags are plastified and can be used several times. We consider a plastification cost of 0.25 euro per tag.

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

Table 1: Multi-use and mono-use tags

Table 2 presents a comparison between the two optimal configurations for the given costs of the two types of tags and the actual daily warehouse operations ("as is"). The three configurations are compared in terms of daily working hours for the elementary activities at the warehouse. The results are obtained by the analysis of 729000 elementary activities during the period 1 September 2009 - 28 November 2009.

Activity	As Is	Tags RFID Mono-use	Tags RFID Multi-use
Update Last Status	1.10	0.14	0.14
Interchange at Warehouse	2.59	1.82	1.96
Return to Sender	4.31	1.90	2.00
Package Loading	1.22	1.33	1.33
Interchange at Reception	1.22	1.25	1.31
Total	10.44	6.44	6.74

Table 2: The "as is" situation versus the "to be" situation with mono-use tags or multi-use tags

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 novel configurations based on RFID tags: the “to be” one based on mono-use tags is the best in terms of reducing the operators workload (precisely, - 4 hours for mono-use tags and - 3.7 hours for multi-use tags compared to “as is”), while the other “to be” one is the best in terms of reducing the cost of daily operations (- 7% for mono-use tags and - 25% for multi-use tags compared to “as is”).

5. Conclusions

This paper presents a novel 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. 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 models and architectures for storing and processing the RFID information, leading to a new level of expectations in daily operations.

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.

Acknowledgements

This work has been funded by the Italian Ministry of Research, Grant number RBIP06BZW8, project FIRB “Advanced tracking system in intermodal freight transportation”.

References

1. Ganesh, K., Narendran, T.T., 2005, “CLOSE: a heuristic to solve a precedence-constrained travelling salesman problem with delivery and pickup”, International Journal of Services and Operations Management, 1(4), 320-343.
2. Gaukler, G.M., 2005, “RFID in supply chain management”, Ph.D. Thesis, Stanford University, U.S.A.
3. Hozak, K., and Hill, J.A., 2009, “Issues and opportunities replanning and rescheduling frequencies”, International Journal of Production Research, 47(18), 4955-4970.
4. Holland, W.S., Young, R.F., Weckman, G., 2009, “Development of a Low-cost, Real-time Location System using Passive RFID Tags”, Proc. of the IIE Annual Conference and Expo 2009, 30 May - 3 June, Miami, Florida, 1310-1314.
5. Langer, N., Forman, C., Kekre, S., Scheller-Wolf, A., 2007, “Assessing the impact of RFID on return center logistics”, Interfaces 37(6), 501-514.
6. Lee, H.L., and Özer, Ö., 2005, “Unlocking the Value of RFID”, Production and Operations Management, 16 (1), 40-64.
7. Pacciarelli, D., D’Ariano, A., 2009, “Assessing the value of RFID in pharmaceutical production scheduling”, Proc. of the 13th IFAC Symposium on Information Control Problems in Manufacturing, 3-5 June, Moscow, Russia, 1101–1106.
8. van den Berg, J.P., Zijm, W.H.M., 1999, “Models for warehouse management: Classification and examples”, International Journal of Production Economics, 59(1–3), 519-528.
9. van Hoek, R.I., 2002, “Using information technology to leverage transport and logistics service operations in the supply chain: an empirical assessment of the interrelation between technology and operations management”, International Journal of Information Technology and Management, 1(1), 115-130.
10. Zhou, J., Shi, J., 2009, “RFID localization algorithms and applications – a review”, Journal of Intelligent Manufacturing, 20(6), 695–707.