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RFID and logistics: a cost-benefit analysis to design the most cost-effective RFID set-up for an air cargo handler's warehouse

Elvezia Maria Cepolina [1] and Donato Aquaro [2]

[1]Italian Center of Excellence on Logistics, Transport and Infrastructure, CIELI, University of Genoa, Genoa, 16135, Italy.
[2]Department of Civil and Industrial Engineering, University of Pisa, Italy.

*Corresponding author. elvezia.maria.cepolina@unige.it

Abstract

The economic viability of RFID technology depends on its costs and benefits. Different implementation set-ups have different costs and lead to different benefits.

This paper proposes simulation as a tool to evaluate the benefits of a given RFID set-up and a cost-benefit analysis to support the choice of the best RFID set-up among alternative ones in a given warehouse.

The proposed methodology has been applied to a real case study: an overhead cargo handling warehouse. Consolidation, security checks and other logistics operations take place here. Airfreight logistics is critical for the distribution of high-value products and for the production of goods in distributed manufacturing systems, such as the pharmaceutical industry.

Keywords: RFID, Logistics, Simulation, KPI, Cost Benefit Analysis.

1. Introduction

Air cargo handling and transport is a critical phase in logistics for specific goods of industrial manufacturing, like the pharmaceutical sector. In such distributed manufacturing, risks of products or semi-products counterfeiting, deterioration of the products or semi-products due to non-compliance with their storage conditions and misdirection of the goods are very high.

Due to higher value of time for air cargo than others, delay in delivery time is a Key Performance Index (KPI) since it may degrade air cargos' original functions or reduce their surplus value.

Delay in delivery time, and more specifically in transportation time, is influenced by human performances which are affected by contextual factors, which include personal factors and environmental factors. The consequences of these errors may be limited by introducing RFID technologies in the air cargo handler warehouse where logistical operations take place. Moreover, as it concerns distributed manufacturing, the RFID technology provides the opportunity to: track inventory, track quality and state of preservation of ingredients, which mainly depends on environmental conditions, along the distributed manufacturing processes and tamper detection. Benefits of the Internet of Things (IoT) in manufacturing have been analyzed in (Bottani and Rizzi, 2008)

Different RFID implementation set-ups in an air cargo handler's warehouse are possible, depending on the aggregation level of the freight to which tags are attached and depending on the location and type (fixed vs portable) of tag readers.

With reference to an air cargo handler, a methodology for assessing economic sustainability of different RFID implementation set-ups in an air cargo handler warehouse is proposed. The method adopts a Cost Benefit Analysis (CBA).

The remainder of this paper consists of the following. Section 2 describes the logistic system under study. Section 3 describes the alternative RFID projects for the warehouse. Section 4 presents the methodology for assessing costs and benefits through simulation. Lastly, Section 5 discusses the results and concludes the paper.

2. Logistic activities in the cargo handling warehouse: the current system

Activities and problems related to the general cargo handling are reported in Cepolina et al. (2018).

Goods arrive to air cargo handler's warehouse usually by truck. Usually, other actors are in charge of this activity. Freight units arrive as bulk goods and leave the warehouse in ULDs.

In air cargo handler's warehouse, freight units are subject to the following phases:

1. Check-in: according to visual checks on package status, goods are accepted, tentatively accepted or rejected by the handler at the receiving dock. Freight units are then moved inside the warehouse. In this phase, shipping information and priorities for each freight unit are acquired and freight units are tagged with labels reporting this information.
2. Security checks: the freight is made secured following IATA (International Air Transport Association) protocol.
3. Pallet consolidation: freight units are consolidated in pallets, according to shipping information. One pallet contains 12 freight units (bulk);
4. ULD consolidation: pallets are consolidated in ULDs. One ULD contains 4 pallets. If a pallet doesn't fit in the ULD because the spare space in the ULD is too small, the pallet could be split in two parts. As described in phase 6, the first part will be put in the current ULD, the second one will wait for the next ULD, assigned to the same flight number.
5. Pallet re-assembly: the pallet is deconsolidated and the freight units in it are split in two groups and consolidated in two new pallets of smaller dimensions. This activity allows to exploit the ULD capacity.
6. Truck consolidation: ULDs characterized by the same boarding airport are loaded on the respective truck. One truck contains 2 ULDs.

The air cargo handler is also in charge of:

7. Freight transport to the boarding airport by truck
8. Freight journey by flight

These activities are characterized by process times.

Table 1. Activity times in each phase

		Mean movement times	Mean control times	Variance
Phase 1 check in	Freight unit	13.1s	4.4s	20%
Phase 2 security check	Freight unit	50s		10%
Phase 3 pallet cons.	Pallet	135s	45s	20%
Phase 4 ULD cons.	ULD	5400s	1800s	20%
Phase 5 pallet re-assembly	Freight unit	360s		10%
Phase 6 truck cons.	truck	450s	150s	20%
Phase 7 journey by truck	truck	36000s (airport 1) 28800s (airport 2)		10%
Phase 8 journey by flight	flight	86400s (24h)		10%

Process times are given by the sum of a movement time (needed for freight physical movement and for applying tags to the logistic units) and a control time (needed to check the performed activity correctness). Movement time and control time are reported in the following table for each phase as well as the related variance value, expressed as % of the process time mean value. The times reported in table 1 refer to the corresponding freight unit. All the times are characterized by a triangular distribution, with lower vertex corresponding to: (mean time value) - (variance %* mean time value) and upper vertex corresponding to: (mean time value) + (variance %* mean time value).

These activities are affected by human errors. The human errors that will be taken into consideration are reported in the following and are the errors those consequences could be reduced by RFID implementations.

a) Tagging errors: freight units are wrongly tagged at the warehouse entrance. These errors will be identified when the goods arrive to the final destination and freight units are unpackaged. In these cases, goods are delayed more than 14 days.

b) Pallet consolidation errors: freight units are consolidated in wrong pallets; these errors are detected in the destination airport when pallets are unconsolidated. Freight units need to be sent back to the right destination airport.

c) ULD consolidation errors: pallets are consolidated in wrong ULDs. These errors can be detected:
    i. within the warehouse. In this case, the ULD needs to be deconsolidated and
    ii. reconsolidated in the right way.
    iii. or at the destination airport, when ULDs are unconsolidated.

Typology	Position of error's detection	Mitigation actions
a) Tagging errors	This error is identified when the unit is delivered to the final destination	No mitigation actions are considered possible by the air cargo handler. The delivery process can be considered failed
b) Pallet consolidation errors	This error is identified at the destination airport when pallets are de-consolidated	The freight unit is re-addressed to the right destination airport
c) ULD consolidation errors	This error can be detected within the warehouse (c1) or at the destination airport (c2)	If the error is detected inside the warehouse the pallet is extracted from the wrong ULD and consolidated in the wright one. If the error is identified at the destination airport, the pallet is re-addressed to the wright destination airport with a new cargo flight
d) Truck consolidation	This error can be spotted at the departure airport	ULDs can be delivered to the wright departure airport with an additional movement by truck

d) Truck consolidation errors: the ULD affected by this error is loaded on a wrong truck and therefore reaches a wrong departure airport, where the error is detected. Subsequently the ULD affected by the error is readdressed to the right airport by a supplementary travel by truck.

Table 2. Error matrix: Probability that a unit is affected by the given error

Error matrix e		a) tagging	b) pallet cons.	c) ULD cons.	d) truck cons
Phase 1 check in	Freight unit	0.000043	0	0	0
Phase 2 security checks		0	0	0	0
Phase 3 pallet cons.	pallet	0	0.000258	0	0
Phase 4 ULD cons.	ULD	0	0	0.001377	0
Phase 5 pallet re-assembly		0	0	0	0
Phase 6 truck con.	truck	0	0	0	0.008

We assumed a Bernoulli distribution for human errors with mean values reported in table 2. Each component eij gives the probability that a human error of the given type j (for j=a, b, c, and d) affects the reported unit in a working day, in the given phase i (for i=1..6). For instance, each day the probability a pallet is affected by an error during the pallet consolidation is 0.000258.

Table 3. Position of error's detection and possible mitigation actions

All these errors lead to delivery delays of different entity according to the amplitude of the interval of time that elapses between the moment in which an error occurs and the instant in which it is detected. If the time interval is small, corrective measures will be promptly implemented and the error consequences will be mitigated.

In case of errors during consolidation activities (b and c), only the unit affected by the consolidation error needs to be readdressed, while all the other units that have been consolidated with it, are delayed because of disassembly and re-assembly operations.

The current scenario represents the actual situation in the warehouse, where no RFID technology is implemented. The instant at which each error is detected during the logistic process and the possible mitigations actions are listed in Table 3.

3. Alternative RFID projects

RFID implementation in warehouses allows to promptly detect these human errors and to implement mitigation actions in order to reduce human error consequences.

	INTERMEDIATE project	FULL project
RFID tags applied to:	Pallet, ULD and truck	Freight unit, pallet, ULD and truck
RFID readers:	1 fixed (portal) positioned at truck loading area	1 portable reader for Phase 3, 1 fixed (portal) positioned at truck loading area

Two alternative projects have been taken into account: they refer to different RFID implementation set-ups as described in the table 4.

Table 4. RFID implementation schemes: the FULL scenario and the INTERMEDIATE scenario

In the INTERMEDIATE project RFID tags are attached to each pallet, ULD and truck. No RFID tag is attached to the single freight unit. A fixed RFID reader is positioned in the loading bay, where trucks are consolidated. For this scenario errors of type a, b and c can occur. As it concerns the first two type errors, the detection positions are the same as in the current scenario since the intermediate RFID set-ups doesn't have any effect. Conversely errors of type c are all spotted before the ULD overcomes the warehouse exit thanks to the RFID reader in the loading bay, therefore the error consequences are reduced comparing to the current scenario. As it concerns type d errors, they do not occur since the fixed reader allows to check the compatibility between the ULD tag and the truck tag during the truck consolidation process.

In the FULL project, the freight unit accepted at the entrance of the warehouse are provided with a RFID tag. Type a errors do not occur. Moreover, RFID tags are applied to pallets, ULD and trucks during the respective consolidation process. A portable RFID reader assist the operator during the pallet consolidation process and allows to immediately detect type b errors, as a consequence no mitigation actions are needed. A fixed RFID reader (portal) is located at the loading bay, where trucks are consolidated. The portal allows to detect all type c errors from the evaluation, made by the warehouse information system, of the coherence between the pallet tags and the RFID tag. At the same time the fixed reader allows to check the compatibility between the ULD tag and the truck tag during the truck consolidation process, therefore type d errors do not occur.

4. The proposed methodology

Cost benefit Analysis (CBA) proposes as indicator the Net Present Value (NPV), i.e. the discounted value of benefits less costs that occur. Both the indicators have been taken into account in the following. Both the indicators refer to a given project.

$$NPV = \sum_{t=1}^{N} \frac{B_t - C_t}{(1+r)^t}$$

where: B_t is the benefit the air cargo handler gains at time t; C_t is the benefit the air cargo handler incurs at time t; r is the discount rate and N is the economic life duration of the project

Projects with NPV>0 have an economic sustainability. We rank the alternative projects on the basis of NPV: the greater the net present value, the more justifiable the project.

4.1 Costs assessment

While the benefits associated with organizational innovation have been widely examined in both the adoption and implementation literature, costs have received much less attention.

According to the target of the paper, only costs related to the implementation stage have been taken into account. Costs related to the implementation stage are: (i) direct costs that can be attributed to the implementation and operation of a particular technology (Irani and Love, 2001); and (ii) indirect costs, which include the organizational and human factors associated with the introduction of a new technology (Ryan and Harrison, 2000). In Banduchi et al. (2011) the direct implementation costs are divided into two major categories: up-front investment costs, such as the investments in initial hardware and software costs, and the ongoing costs associated with tags and hardware and software maintenance.

Since we are focusing on general cargo, passive and disposable tags have been selected; they are provided with UHF technology for a greater reading range.

A low-cost industrial portal reader with 4 antennas has been selected in order to cover large areas. A portable reader equipped with a battery has been selected so that it can be used on the move; it has an integrated antenna with reading capability at medium-short distances. The intended use is online: it is directly connected to both a host device (for example, to a smartphone via Bluetooth) and to the company network (via wi-fi) and transfers the data from the tags in real time. It has been designed to be carried on the operator's arm and is equipped with a display to provide the user with real-time information on the objects he is moving, with keys to activate / stop the tag reading, with feedback tools such as a buzzer or a vibrating scooter.

Table 5. Costs

	Costs [euro]
Tag	0.1
Portal reader	1700.0
Portable reader	800.0
Antennas and cabling installation	300.0
Software license	35000.0

Training of the operators	10000.0
Annual hardware maintenance	10% of the up-front costs related to reader
Annual software maintenance	10000.0

The software license allows, in the event of inconsistency between the tag on the container and the tags on the contained parcels, to give an alarm signal and to give efficient indications. Therefore, costs associated to middleware components for filtering and efficient data handling are included as well as system integration and data storage costs.

Among the implementation costs, indirect costs have been considered in relation to training of the operators and management integration (management integration cost is included in the software license). The costs that have been used in the simulation have been provided by a company that produce RFID components and are reported in table 5.

The maintenance costs have been estimated at the year 2019 – considering information provided by companies operating in the fields– and have not been implemented by inflation rate since the life span is short. The life spam for both the assessed scenarios has been assumed of 5 years, as indicated by the companies and according to the generally accepted technology obsolescence rate.

Table 6. Cost assessment (euro).

				INTERMEDIATE	FULL
Direct costs	Up-front investment costs	Initial hardware costs	Readers + installation	2000	2800
		Initial software costs	Software license	35000	35000
	Ongoing costs (euro/year)	Tags		1597	15536
		Hardware maintenance		200	280
		software maintenance		10000	10000
Indirect costs	Training of the operators			10000	10000

The following data have been assumed for costs assessment (table 6):

- the flow density is equal to 576 load units/day. In this context, we consider flow density as the number of load units that flow through the logistics processes on a daily basis. The loading units arrive in bulk and are grouped into 48 pallets which in turn are grouped into 12 ULDS which finally leave the warehouse with 6 trucks.
- 242 working days/year

4.2 Benefits assessment and KPIs identification

In order to evaluate performance measurement, it is necessary to know the ways RFID can contribute to performance improvements. In general, the Internet of Things (IoT) usage can affect financial and non-financial performance characteristics of business processes via three bottom-up and non-exclusive effects. Following Tellkamp (2006), these can be categorized as:

- automation of information acquisition process that formerly was manual: for example, RFID gates at a company’s goods receipt area can eliminate the need for employees to capture data of incoming pallets manually by applying mobile barcode scanners;
- informatisation related to an increased information quality: for example, automated real-time comparisons of to-be-picked and actually picked positions can improve manual picking processes, enabling better decisions, such as, in the case of detected picking errors, the beginning of rework and mitigation measures, in order to reduce the severity of mistake consequences;
- transformation related to new or re-engineered business processes: for instance, the provision of new services and products (e.g., tracking and tracing services) is possible.

The proposed study assesses RFID benefits related to automation and informatisation through 2 KPIs.

4.2.1 KPI1: Direct labor cost reduction

One clear benefit of RFID deployment is the reduction in direct labor required for performing routine tasks such as inventory control and system update entries (Veronneau and Roy, 2009). The cost of labor in a warehouse decreases with a RFID system that can tackle various tasks at once such as scanning, tagging and counting items.

Process times are given by the sum of a movement time (needed for freight physical movement and for applying tags to the logistic units) and a control time (needed to check the performed activity correctness). This last time is reduced to zero in case of RFID reading in the specific phase.

For each alternative project S, benefits related to reduction of labor cost $B^{S}_{KPI1_t}$ are assessed as the difference between the labor cost in the current scenario and the related labor cost in the alternative scenarios in a reference time period t.

$$B^{S}_{KPI1_t} = \text{labor cost}^{0}_{t} - \text{labor cost}^{FULL}_{t}$$

The benefits related to reduction of labor cost result equal to:

$$\mathrm{B}^{INTERMEDIATE}_{KPI1_{day}} = 6.75 \left[\frac{\text{euro}}{\text{day}}\right]$$
$$\mathrm{B}^{FULL}_{KPI1_{day}} = 22.95 \left[\frac{\text{euro}}{\text{day}}\right]$$

4.2.2 KPI2: Reduction in delivery delays due to picking errors

RFID will decrease errors overall, but especially picking errors which can be particularly costly and time consuming (Bruzzone et al., 2007). The benefits of RFID tags in picking start with the fact that a warehouse picker can know what's in a box even before opening it and conclude in being able to verify that the correct item was picked.

Each RFID set-up (each scenario) determines the amplitude of the interval of time that elapses between the moment in which an error occurs and the instant in which it is detected. If the time interval is small, corrective measures will be promptly implemented and the error consequences, in terms of delivery delays, will be mitigated.

For each scenario, the benefit related to the reduction in delivery delays due to decrease in picking errors $\mathrm{B}^{S}_{KPI2_t}$ is evaluated as the difference between the Risk in the current system $risk^{0}_{KPI2_t}$ and the Risk in the scenario related to the RFID implementation $risk^{S}_{KPI2_t}$.

$$\mathrm{B}^{S}_{KPI2_t} = risk^{0}_{KPI2_t} - risk^{S}_{KPI2_t}$$

Risk is the air cargo handler average monetary loss due to delivery delays in a reference time period t. This KPI takes into account the high value of time for air cargo.

Monetary loss is directly proportional to freight unit delivery delay: as the delivery delay increases, the monetary loss increases because extra travel costs and extra labor are required in order to deliver the freight unit to the right place.

For each scenario, the risk is assessed using the Monte Carlo technique. In each run of the Monte Carlo process the following steps are performed:

Step1. A run of a discrete event simulator, described in Giusti et al. (2019). During the run the following activities are performed:

I. The simulation of the logistic activities through which the unit is processed, for each general cargo freight unit that arrives in the warehouse in the reference time period.

II. Human error occurrences.

III. Freight unit delivery time assessment which is a consequence of: the elapsed time between the error event and the error detection, the application of mitigating actions

IV. Freight unit delivery delay assessment:

$$\text{delivery delay}_i = time\ real_i - time\ ideal_i$$

where:

$time\ real_i$ is the actual delivery time of freight unit i at the right destination airport. It is a consequence of the possible occurance of human errors, of the error detection time and of the application of mitigating actions. It is assessed by simulation.

$time\ ideal_i$ is the delivery time of freight unit i at the right destination airport in case of no error occurrence. It is assessed by simulation, assuming process times (movement time+control time) equal to the respective mean values. In all the scenarios, timeideal are assessed in the same way.

V. Freight unit vulnerability assessment as a function of the delivery delay value: the function that links delivery delay and vulnerability has been qualitatively assessed discussing with experts from an air cargo handler company and taking into account the value of travel time saving perceived by the company.

VI. Freight unit damage assessment: for each freight unit i, damage level d_i is assessed by the product between its vulnerability and the exposition value.

Step2. The assessment of the total damage level D_t, extended to all the freight units (FUN) processed in the reference time period t.

$$D_t = \sum_{i=1}^{FUN} d_i$$

Step3.The assessment of the respective damage class, D_{dc}.

Step4. The updating of the occurrence number of the identified damage class.

Step5. The check on the Monte Carlo process stopping criterion.

When the Monte Carlo process stops, the risk matrix for the simulated scenario is available. Given the risk matrix, $risk_t^S$ is assessed by summing for each damage class dc, the product between the average of the total damage levels belonging to the class, AD_{dc_t}, and the occurrence probability, $H_{D_{dc}}$, related to the respective class:

$$risk_t^S = \sum_{dc} AD_{dc_t} * H_{D_{dc}}$$

The simulation results for the analyzed scenarios are reported in Table 7 reports the. The risk of daily damage drops from 151.3 euro/day down to 21.4 euro/day in case of INTERMEDIATE scenario and down to 4.5 euro/day in case of FULL scenario.

Table 7. Risk value Rs resulting from the Monte Carlo simulation.

NO RFID IMPLEMENTATION	INTERMEDIATE RFID IMPLEMENTATION	FULL RFID IMPLEMENTATION
151.3 euro/day	21.4 euro/day	4.5 euro/day

The benefits related to the decrease in picking errors result equal to:

$$B_{KPI2_{day}}^{INTERMEDIATE} = \text{risk}_{day}^{0} - \text{risk}_{day}^{INTERMEDIATE}$$

$$B_{KPI2_{day}}^{INTERMEDIATE} = 151.3 \left[\frac{\text{euro}}{\text{day}}\right] - 21.4 \left[\frac{\text{euro}}{\text{day}}\right] = 129.9 \left[\frac{\text{euro}}{\text{day}}\right]$$

$$B_{KPI2_{day}}^{FULL} = \text{risk}_{day}^{0} - \text{risk}_{day}^{FULL}$$

$$B_{KPI2_{day}}^{FULL} = 151.3 \left[\frac{\text{euro}}{\text{day}}\right] - 4.5 \left[\frac{\text{euro}}{\text{day}}\right] = 146.8 \left[\frac{\text{euro}}{\text{day}}\right]$$

5. Results and discussions

Assuming a discount rate value equal to 0.1, the NPV for the INTERMEDIATE scenario is 39366 and the NPV for the FULL scenario is 10553.

The INTERMEDIATE scenario results preferable than the FULL scenario since its NPV results higher. The reasons are:

- Benefits are more sensible to KPI2, i.e. delivery delay related to picking errors, than KPI1.
- KPI2 is highly influenced by truck consolidation errors (d) and ULD consolidation errors (c2) that are detected respectively at the departure airport and in the destination airport in the current scenario. The consequences of these errors are kept limited in both the alternative RFID projects since both are characterized by a portal reader in the loading bay and tags on pallets and ULDs. This allows to detect c2 errors and to mitigate their consequences in the warehouse, much sooner than in the current system.

The additional hardware in the FULL scenario increases costs and slightly increases benefits. However, it should be noted that, as with many new technologies, cost of adoption decreases yearly and therefore the FULL scenario could become preferable in the next future.

The proposed approach made it possible to design the most economically viable RFID set-up for the case study. The results refer to the specific case study; however, in other logistics contexts where delivery delays due to picking errors lead to significant economic damage, the benefits of RFID can be very significant. This is the case, for example, in long-distance transport of goods that undergo consolidation or deconsolidation logistics activities or in distributed manufacturing systems, such as pharmaceuticals, of products with a high economic value.

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