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Opportunities for using RFID in the aircraft production process

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Abstract. This paper presents the results of the economical evaluation of the possibility of RFID technology adoption in an European company involved in the manufacturing of the fuselage of a new long-range, mid-size, wide-body jet airliner made of carbon fibre reinforced polymer. The peculiar constraints to the management of some of the raw materials – Time And Temperature Sensitive (TATS) materials – has pushed the Company to consider RFID tags introduction despite the fact that the material supplier did not provide any support. Thus, the most important impulse to the introduction of the RFID system in the Company has been given by the problems encountered in the management of TATS materials. However, further analyses are presented on the opportunity for the Company of extending RFID application to non-TATS materials. In this sense, several scenarios are presented, evaluating investment in hardware and tags costs with respect to advantages in terms of time savings in material handling processes or costs saving in terms of inventory misalignment reductions. In most scenarios, RFID introduction resulted to be profitable.

Keywords: Time and Temperature Sensitive (TATS) materials, pre-impregnated composite fibres polymers, RFID applications, material management, jet airliner manufacturing

1. Introduction

The main application of RFID (Radio Frequency Identification) technology is to identify or locate something through a radio frequency device associated to it. In logistics and supply chain management, general advantages from RFID traceability are already acknowledged (Holzer, Byrnes & Simchi-Levi, 2009; Sabbaghi & Vaidyanathan, 2007, 2008) despite the non-negligible costs of its adoption. Thus this technology forces industrial companies to perform a detailed cost-benefit analysis before considering any opportunity for implementation.

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RFID has been considered an on-the-edge technology for several years. However, despite the fact that many large organizations, such as Wal-Mart or the U.S. Department of Defense, have endorsed this technology years ago (Narsing, 2005; Ferrer & Dew, 2008) - requiring their key suppliers to be RFID compliant as well – many other industrial companies are still now fighting against its limits (Wu, Nystrom, Lin & Yu, 2006). However a final methodology for the implementation of these projects has not been yet clearly identified, and only few models are today presented in literature (Bottani, Hardgrave & Volpi, 2009). Despite this fact a big amount of studies have been presented and implemented in a wide range of sectors, for instance in the fashion industry, evidencing the impact of RFID and EPC system on the main processes of the fashion industry supply chain (Bottani, Ferretti, Montanari, Rizzi, 2009), or in the short-life products management, underlining how many and how difficult the practical challenges encountered are (Vecchi, Brennan, 2011). Moreover some successful RFID implementations are reported also inside the aeronautic industry: for instance RFID technology for tool and toolboxes management has been successfully implemented at Boeing (Horng & Bozdogan, 2007). Since the 2000 s Airbus has been using RFID tagging for its ground equipment and tools. Moreover, in May 2008 Airbus received "The Best RFID implementation" award, by demonstrating the successful implementation of RFID technology with the aim of improving the company's operational efficiency in its complex supply chain. This result has been pursued involving multiple assembly plants and thousands of suppliers, gaining business benefits such as inventory reduction, stock reconciliations, labour productivity increase and suppliers control (Ong, 2010).

This paper aims at presenting one of these efforts: the analysis of the opportunity for RFID technology adoption in an European company involved in the manufacturing of the fuselage of a new long-range, mid-size, wide-body jet airliner made of carbon fibre reinforced polymer. The peculiar constraints to the management of the most important raw material - a Time And Temperature Sensitive (TATS) material - has forced the Company to set-up specific structures aimed at storage and conservation, and to consider RFID introduction for time/temperature monitoring and real-time management of logistic information. In the literature, TATS management with RFID has been analysed through simulation (Mills-Harris, Soylemezoglu & Saygin, 2005), while in this paper the results of the economical evaluation of an industrial project are reported. In most cases that describe RFID introduction in supply chain management, the purchaser has enough bargaining power to impose the adoption of RFID technology to the vendor. For example, Wal-Mart and Metro-Group forced their suppliers (Gillette, L'Oreal, Kellogg's, Nestlé, Danone, etc.) to install RFID in order to maintain their supplying contracts (Schmitt & Michahelles, 2008). However, in this case the raw material supplier did not accept to invest in the new technology because of its dominant position in the market. However, some studies have shown that, in the case of a dominant position of the supplier, there is still a possibility for both companies to adopt, together, the RFID technology with profitable results (Diekmann, Melski &

Schumann, 2006). In this case, the Company's management was forced to determine if and how they could autonomously introduce RFID at their own expenses. Further analyses have also been performed in order to verify the opportunity of the extension of RFID application to external non-TATS (auxiliary) materials either at package level or at item level.

Thus, the scenarios that have been evaluated are the following:

1. Apply RFID to TATS materials.
   The aim is to evaluate the benefits of applying RFID tags into the epoxy resin pre-impregnated carbon fibres ("pre-preg") with the main purpose of streamlining the management of these special materials during the production process and automatically update the remaining shelf life of each item after their exposition at room temperature;
2. Using RFID for auxiliary materials at package level.
   The aim is to evaluate the possibility of using RFID, applied by the suppliers, to save costs and time by the automation of manual operations in internal logistic processes mainly related to the acceptance and management of auxiliary production materials. The analyses have been performed in two different cases considering the application of RFID by the material suppliers:
   2.1 all the auxiliary materials are tagged. However, to obtain this result all the supplier companies should be involved, extensively adopting RFID along the supply chain, and this hypothesis is difficult to grant;
   2.2 only the auxiliary materials which come from internal suppliers are tagged. Internal suppliers are those belonging to the same industrial group of the analysed Company, which owns four manufacturing plants in Europe where aeronautics components are produced.
3. Using RFID for auxiliary materials at item level.
   The aim is to verify the effectiveness of RFID used for reducing the misalignment between physical and logical inventory levels, thus reducing the cost related with the probability to lose track of the stored items. Here, four different cases have been considered combining the following variables:
   3.1 traceability of all items versus traceability of the low-value items only;
   3.2 high effectiveness of the RFID system (i.e. the system may allow to reduce the misalignment to 10%) versus low effectiveness (i.e. the system may allow to reduce the misalignment by only 50%).

The name of the Company, some details on the project and specific data on process costs and plant characteristics could not be reported in the paper due to strict confidentiality reasons and the presence of a Non-Disclosure Agreement with the Company.

2. TATS materials

2.1. Management of time and temperature sensitive materials

The use of carbon fibre in the aircraft industry has offered new technologies industrialization opportunities, such as the manufacturing of a single-piece fuselage barrel. This specific technology provides the fuselage with top-level mechanical characteristics, together with some main advantages such as a lower amount of joints, parts and fasteners, simplification of the assembly process and weight reduction. For airline companies, this results in lower fuel consumption or larger operational range, lower maintenance costs, larger transportable payload or greater comfort for passengers and larger windows. These features seems to be the most important in order to obtain the needed competitive advantages in the modern air transportation market.

Pre-preg carbon fibre management however suffers of a complex criticality. Due to the special resins used in the production process, pre-preg must be kept at a temperature close to -20°C until the cure cycle is finished. Exposure to different temperatures modifies the lifetime of the material, which is expressed in Exposition Units (EU). Inevitably, it is not possible to maintain the material at -20°C forever since some transportation, handling and production phases occur outside the storage refrigerator and are performed at room temperature. Thus, the remaining material life must be precisely updated. An error in recording the remaining EU leads to a high probability of wasting the final product due to the degradation of the bonding capability of the fibres in the cure cycle.

Thus, RFID tags have been considered for temperature recording at any exposure instant and for the communication of such data to the enterprise resource planning system (ERP). Pre-preg spools are manufactured by only one qualified supplier. This supplier is required to certify the product at the time of delivery, to provide the whole documentation related to laboratory tests (Test Report), as well as to give evidence of compliance to the requirements (Certificate of Compliance) and the instructions for managing the remaining exposition units.

The activities carried out by the supplier for each shipment are:

a) attach the Certificate of Compliance and the Test Report to each lot of material;
b) attach the list of possible defects to each spool of material;
c) attach the package list containing the identification information of the shipped spools;
d) install one or more thermographs with the aim of recording temperature changes inside the shipping container;

Upon arrival of the material to the Company's plant, the following operations are performed:

e) unload the material from the container and check the number of packages;
f) collect the shipment documentation;

g) check the thermographs;
h) enter the identification information of the material in the ERP, which issues a material entry bulletin;
i) temporary store the material in a refrigerated buffer, labeling it "under testing";
j) transmit the certifications to the testing team.

The tests are performed at room temperature, which affects exposition times, and proceed with the following preliminary activities:

k) analyse the temperature changes the spools were exposed to during transport and compute the remaining exposition units;
l) record the identification information on a "perishable material inspection form";
m) associate the spool with the label material status on which the number of consumed exposition units are reported;
n) enter the start date in the enterprise resource planning systems, in order for the system to compute the expiration date of the product.

Depending on the criticality of the material at design level, a sample acceptance testing – with destructive inspections – or a 100% testing procedure – with non-destructive inspections – is performed on the received lot, in order to assess its compliancy.

Once the receiving and testing operations are terminated, all TATS materials are stored in an automated refrigerated storage system that can hold up to approximately 1000 loading units (trays). When the spools are picked up from the storage system (as a consequence of a job order) they are brought in a clean-room in which the temperature is approximately 22°C, thus much higher than the one defined for material storage. The temperature monitoring continues until the spools are loaded on a rolling mill. Eventually, the spools may be temporarily placed in a stock buffer where they wait until their loading turn. After the cure, the fuselage is brought in the fabrication area for the subsequent processing, but at this point the resin is no longer in a critical phase as far as the chemical stability is concerned, due to the fact that the polymerization is completed. Under the logistic point of view, this means that the production processes may proceed without temperature monitoring.

As far as information management in the Company is concerned, it is possible to re-arrange the most important phases of the pre-preg spools handling in the following seven steps:

1. Identification data of the received material are copied on the perishable material inspection form and the presence of the temperature recorder is checked;
2. the temperature recorder data are evaluated in order to check if remaining exposition units have to be updated;
3. the material status card is filled up for each spool by entering the relevant identification data (material, P/N or batch number);

4. after having analysed the thermographs data, the total number of remaining exposition units is printed on the material status card of each spool before it is transferred in the refrigerated storage system;
5. workers pick up the spool listed on the work order from the refrigerated storage system and copy exit time and date on the material status card;
6. the clean room testing people periodically update the exposition units of the spools on the material status cards, either at the beginning of the shift or when a spool is processed;
7. workers update the exposition units in material status cards also for the spools that have been only partially used and are brought back to the refrigerated system; these spools can be reused if the EU value is compatible with further processing requirements.

2.2. Opportunities for RFID technology in TATS material management

RFID tags allows to easily manage several aspects of the material handling procedure for the pre-preg spool, automatically update the critical information which affects the characteristic parameters of the process (due dates, shelf life, storage life, handling life, mechanical life, etc.). Moreover, they ensure an effective integration with the existing information management systems. The required functions for the RFID system are thus the following:

- to uniquely identify the single spool in each material batch;
- to automatically monitor and update:
  - ○ each temperature at which each spool of material is exposed, with a predefined sampling interval;
  - ○ exposition units and cumulative exposition times of the material in a given observation period;
  - ○ material life, state and expiry date, together with an alarm system;
- to allow information reading/writing on multiple tags, taking into account the plant layout;
- to return, upon query, any tracking data;
- to store the historical data relevant to spools consumption;
- to communicate with the information system in order to trigger specific alarms when a certain spool is about to expire, i.e. a pre-selected number of days before the end of material life, in order to allow a prompt scheduling of the spool to the next processing phase.

These results can be obtained applying two RFID tags on each pre-preg spool:

– a passive tag which records all the material data;
– an active tag to record the temperature variations.

With the RFID solution, steps no. 1, 2, 3, 5, 6 and 7 of the previous list can be skipped, thus eliminating some of the most important phases of the pre-preg spools handling. Step 4 instead is still needed in order to register the remaining EU in the tag memory. After such step, the monitoring of the EU continues automatically.

In traditional cost-benefits analyses relevant to RFID introduction, benefits are generally classified in the following categories:

– tangible benefits related to efficiency increase, i.e. resource productivity increase or process quality increase, with a consequent decrease of resource costs;
– tangible benefits related to effectiveness increase, i.e. improvement in the critical-to-quality levels or in customer satisfaction with a consequent increase of revenues;
– intangible benefits related to company image improvement;
– intangible benefits related to improvements in data management, i.e. increase in quantities, quality and timeliness of information available to managers;
– intangible benefits related to a compliancy with eventual legal requirements.

In these analyses, quantifying the benefits is far more complicated with respect to the costs. This analysis has primarily relied on tangible benefits related to efficiency increase and the increase was specifically evaluated in terms of process acceleration and used resources reduction. In other words, only the benefits relevant to the skipped steps in the spool handling process have been taken into account.

Obviously, cost reduction opportunities are strictly linked to the number of spools handled per month and this is directly related to the plant production rate. Unfortunately, this information cannot be reported in this paper, together with the timing of the phases in the management procedure. However, it can be said that the production rate was estimated to face an "S-shaped" growth up to 230% in five years, which represented a conservative hypothesis in accordance to the business plan forecasts and the trend of the sales of the jet airliner. The expected time reduction in spool handling, multiplied by the forecasted amount of spools to be monitored, allowed computing the overall saving in terms of human resources cost. Considering that the analysis was performed on a time horizon of 5 years, a positive compound annual growth rate (CAGR) of the human resources cost has been taken into account, but the specific datum is classified too.

Other types of benefits could not be exactly quantified due to lack of historical data, and thus have not been taken into consideration, such as:

– risks reduction related to the use of not compliant pre-preg spools, which can lead to the waste of the entire fuselage section;
– risks, and consequently costs reduction, related to the waste of a compliant pre-preg spool, which is a less severe problem with respect to the previous one;
– optimization of material consumption, thanks to the implementation of the First Expires/First Out (FEFO) logic in material management;
– costs reduction related to the reduction of record keeping and paperwork activities;
– simplification of inspection/audit activities on material documentation.

The recurring and non-recurring costs elements that have been taken into account are listed below. The reported investment values come from the best quotations provided by suppliers at the time of the project implementation:

- active and passive tags: their overall costs obviously depend on the number of spools to be monitored, and these data are classified, due to the direct correlation to the production rate, covered by a non-disclosure agreement. The active and passive tags unitary cost Compound Annual Growth Rate was estimated to −5%;
- 10 RFID gates, placed near the entrance and exit of the warehouse and between the warehouse zone and the clean-room, for an approximate cost of €100,000;
- handheld computers (PDA) for the workers in the warehouse and in the clean-room, for an approximate cost of €50,000;
- Wi-Fi antennas covering the areas for the use of active tags: this supply was appositely developed by another Company of the Group, and the relevant cost data are classified, covered by non-disclosure agreement;
- server computer to host the RFID management system, for an approximate cost of €70,000;
- system installation cost and software development cost, which are classified data covered by non-disclosure agreement;
- sensors for temperature control, monitors to display the position of the RFID tagged spools inside the area, training of the operators and project management for a total cost of approximately €500,000.
- The operating costs, including software and hardware maintenance, were estimated as 25% of the total investment cost for the first year. In order to contemplate costs improvement opportunities, a 5% reduction of this percentage has been applied each year.

As already stated, due to confidentiality reasons the cost-benefit analysis cannot be reported in details. With the hypotheses of a +5% financial discount rate (according to the indications of the *Guide to cost-benefit analysis of investment projects*, issued by the Evaluation Unit DG Regional Policy European Commission, 2008), RFID installation project relative to pre-preg tagging has returned to be profitable, with a positive net present value (NPV) and a payback period of approximately 5 years.

This payback period in particular is compatible with an aircraft production program that is estimated to last at least thirty years. For this reason the Company decided to implement the project and, thus, at the present time the pre-preg spools logistic processes are carried out with the support of RFID.

3. Auxiliary materials

3.1. Management of auxiliary materials

The path of external auxiliary materials inside the Company's plant differs from the one followed by pre-preg spools. The operations sequence is listed below:

1. reception: documents are checked for each package received from the supplier;
2. acceptance: packages are opened and items number and status is verified. This verification phase is very labour-intensive and there is a high risk of generating errors;
3. inspection: items certificates are analysed in order to verify the compliance of the parts according to the specified requirements;
4. accounting entry: the materials information are entered in the information system;
5. test and storage: all items are tested and then brought to the destination warehouse.

3.2. Opportunities for RFID technology in auxiliary materials management

In contrast from what is proposed for pre-preg materials, for auxiliary materials the RFID label is supposed to be applied on each package by the supplier. Additionally, another important difference from the pre-preg case is that auxiliary materials packages are very different in kind, size and content type. For this reason, the receipt, acceptance and accounting entry times may be very different from package to package.

In order to estimate the benefits from the introduction of RFID, in terms of management time reduction, almost 2,000 incoming packages of auxiliary materials were tracked in less than one month, measuring the time spent for the receipt, acceptance and accounting entry phases. This analysis returned that in 70% of the cases, the duration of these three phases was approximately 2.5 minutes; in 25% of the cases, 17.5 minutes; in 3.5% of the cases, 45 minutes and in 1.5% of the cases the time spent was more than one hour. The introduction of RFID would grant the complete automation of these phases, thus reducing their lead time to a negligible value. Thus, the expected time reduction through RFID usage for a generic incoming package of auxiliary material was conservatively estimated as 5.15 minutes, using a 40% knock-down factor upon the simple weighted mean on the previous values, which returned a possible reduction time of 8.6 minutes. This expected time reduction per-package, multiplied by the forecasted amount of auxiliary material packages, allowed computing the overall savings in terms of human resources cost. Again, the same positive CAGR of the human resources cost has been taken into account.

Costs entries have been evaluated similarly to the pre-preg case although active tags have not been considered for this application and €0.25 tags have been chosen for auxiliary materials management. Contrary to the previous case, the RFID tags CAGR has been now estimated at −8%, which is slightly higher than the one used for pre-preg tags, due to the higher technological complexity of the latter. For auxiliary materials management, the overall system cost (including RFID gates, PDA and smart label printer) can be disclosed and it resulted to be equal to €220,000. Again, the operating costs were estimated as 25% of the total investment cost with a 5% reduction each year, thanks to costs improvement opportunities.

With these data and hypotheses, the NPV resulted to be approximately €75,000, with a 15.8% of internal rate of return (IRR) and a 4 years payback period.

A sensitivity analysis has been performed to measure the influence of changing the tags CAGR and costs improvement percentage, and the results are shown in Figs. 1 and 2. The results show that the investment is profitable even in a practical worst case.

Moreover a sensitivity analysis has been performed by changing the price of tags and the amount of the initial investment. This analysis showed that NPV

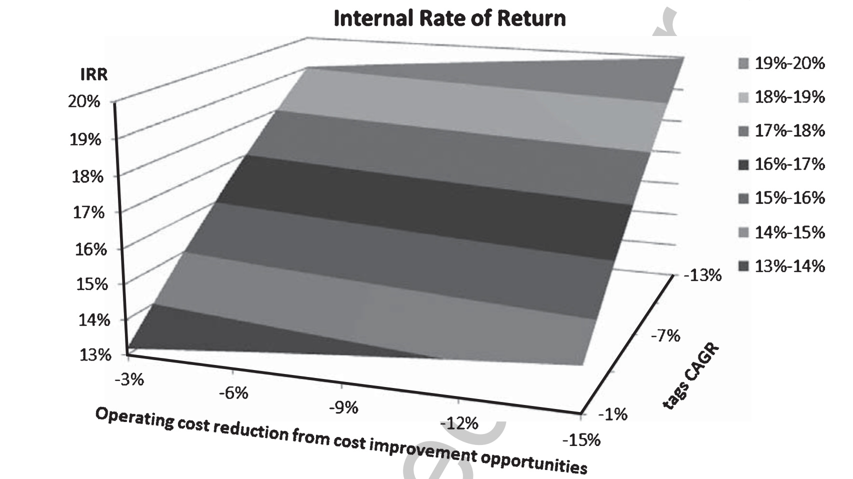

Fig. 1. IRR sensitivity to tags CAGR and operating costs improvement.

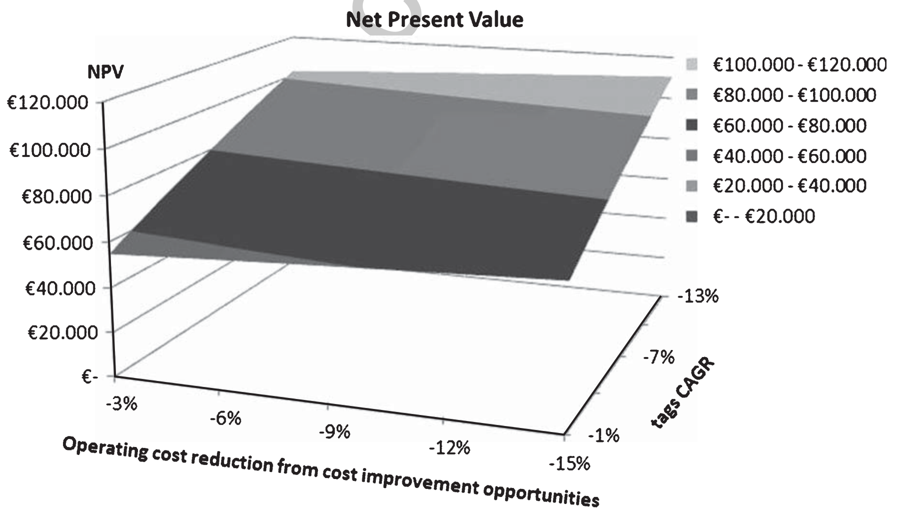

Fig. 2. NPV sensitivity to tags CAGR and operations costs improvement.

reached zero with an investment of €258,000 and €0.25 tags or, as an alternative, a €220,000 investment and €0.76 tags. This means that a growth of more than 200% in the tags price can be compensated by a decrease of only the 14.7% of the total investment.

The analyses were performed under the hypotheses that all suppliers would apply the RFID labels on their products. However, this may be a problem for auxiliary materials in the aeronautics industry because the range of qualified suppliers is very narrow, and the lack of competition does not play in favour of the purchaser. Thus, the Company was thus pushed to evaluate the option of only adopting RFID with its internal suppliers, i.e. suppliers belonging to the same industrial group. This implementation would have affected only 12.5% of all auxiliary materials processed through the plant and, assuming the same investment of €220,000, the NPV would have resulted to be well below zero. Consequently this alternative was definitely discarded.

A third scenario with an intensive use of tags has then been evaluated: the application of the tags to auxiliary materials at item level instead of packages. Tagging at item level could lead to major simplifications in maintenance operations and customer support, as it has been shown by Brintrup et al. (2009), and it could allow a precise monitoring of the manufacturing process. The process completion percentage could be updated in real-time and this would lead to a significant effectiveness improvement of the final product, to a significant efficiency improvement in audit activities and a reduction of the occurrence of discrepancies between "as built" (what the operators have really integrated) and "should build" (what the design foresees to be integrated) configurations. Moreover, item level tagging aligns logical inventory levels - as reported in the ERP - and physical inventory levels - available in the warehouses. The cost of inventory misalignment includes the cost of lost items (assuming that a positive misalignment is associated to a lost item) and audit costs (arising from the need to periodically check the inventory). Some studies report that an inventory misalignment of up to 3% can be considered as physiological (Atah, Lee & Ozer, 2006). However, in aeronautics industry the traditionally high costs of materials impose to work with much lower percentages. In the analysed Company, the inventory misalignment affected only 0.5% of the items.

In order to estimate cost advantages from accurately tracing items, the opportunity of using RFID technology to reduce inventory misalignments has also been evaluated. The analysis started from the assumption that the introduction of RFID would reduce the cost of misalignments (de Kok et al., 2006), but a certain percentage of misalignment would inevitably be present even though RFID is used. This percentage – which is related to the RFID system effectiveness – obviously influences the maximum bearable tag cost. The cost data of the misalignments recorded in the manufacturing of five aircrafts have thus been computed, item per item (these data are classified and cannot be reported in the paper), as the sum of the values of all the items which are lost in the process, due to inventory misalignments. Then, two cases have been considered: the case in which the misalignment can be reduced to 50% and the case in which the misalignment can be reduced to 10%, thanks to RFID tagging. These percentages have been multiplied with misalignment cost, and compared with the cost of the RFID tags for all the items to be traced. Solving in the RFID tag cost, the maximum bearable tags cost is computed. This resulted to be €2.50 if misalignments were reduced to 50% and €4.00 if misalignments were reduced to 10%, in the manufacturing of each aircraft.

However, misalignments typically do not affect expensive materials because much more attention is paid in their handling and storage. For this reason, a second analysis has been performed considering only the misalignment cost relevant to low value items. The misalignment cost reduction was obviously lower than the previous case, but the tags cost was much lower too, considering that not all the items were to be tagged. As a result, tracing only low values items with RFID tags, maximum tag cost resulted to be €0.90 if misalignments were reduced to 50% and €1.30 with their reduction to 10%. It is important to highlight that all of these prices are compatible with the actual forecasts in tags costs.

4. Conclusions

This paper presents the results of a cost-benefit analysis related to the introduction of RFID system in an European company involved in a new long-range, mid-size, wide-body jet airliner, where the manufacturing process involved intensive use of carbon fibre reinforced polymer. A 5-years Pay Back Period with positive Net Present Values demonstrated the opportunity of using RFID tags to support Time And Temperature Sensitive materials management; thus the Company decided to adopt RFID technology even though the material supplier refused to provide any kind of assistance in this project.

Furthermore the application of RFID tags on the packages of other external (named as auxiliary) materials was evaluated, and a positive conclusion has been reached. The analysis returned a 4-years Pay Back period, under conservative hypotheses in terms of the number of handled packages. The alternative of adoption RFID only within the suppliers belonging to the same industrial group than the analysed Company did not justify the business case.

At last, the analysis of the application of RFID tags at item level was performed. This confirmed that high-value items are the best candidates to support the technology introduction even if the economic advantages are computed only with the reduction of inventory misalignments.

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