Clinical risk reduction of blood transfusion through UHF RFID systems

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Abstract: Bloodgistics" is an Italian research project carried out by the Mechanical, Chemical and Materials Engineering (DIMCM) and Electrical and Electronic Engineering (DIEE) Departments of Cagliari University, with the collaboration of Parma University and "Azienda Ospedaliera Brotzu" (hereinafter "AOB": regional hospital, end-user of the application). The main aims of the project were: developing a method for patient safety improvement in transfusion medicine application, enhancing blood inventory management, process re-engineering based on RFID technology, estimating clinical risk decrease due to the re-engineered model. For this purposes, reverse engineering has been applied to current processes (As-Is scenario) and Risk Management methods have been used. Then, the blood transfusion chain has been re-engineered (To-Be scenario). For RFID optimisation, experimental UHF RFID tags have been designed and realised by DIEE. Multiple reading tests have been conducted on experimental and commercial tags applied on blood bags in an EM-isolated environment, to collect important data to enhance prototypes performance. Also, commercial tags were applied on blood test tubes and performance tests were carried out in both not EM-isolated and EM-isolated environments. The To-Be model has been implemented as a pilot plant to be tested in the laboratory and in two "AOB" pilot wards. The pilot plant has been compared to the As-Is and To-Be scenarios with respect to the chosen Key Performance Indicators, based on Risk Priority Index values, and a statistical analysis has been performed on them. After a preliminary implementation of the pilot plant in the two selected wards, a qualitative analysis has been carried out, to identify criticalities of the web-based platform for further improvements, to provide a robust system based on UHF RFID technology for transfusion medicine applications.

Keywords: Blood transfusion, Clinical risk, RFID, Traceability

1.Introduction

1.1 Overview

The three main objectives in a healthcare environment are: increasing people's health and reducing clinical risks due to human errors, improving working conditions of medical staff during patient's care operations, reducing healthcare costs (Berwick et al., 2008). To achieve these goals and to improve quality continuously, the focus should be on assessing the current state of medicine applications to provide new, more effective and efficient procedures based on innovative systems.
Process optimisation and re-engineering start by assessing the current state. With respect to the particular healthcare application of blood transfusion chain, to which this work addresses, mistransfusion could cause morbidity to mortality events, mainly because of blood incompatibility associated with human errors (e.g. different blood group or blood antibodies, due to an exchange of blood bags). Thus, an assessment of the most critical activities from the point of view of associated clinical risks and their quantification will help to reduce them, by modifying procedures and introducing new technology to trace assets (e.g. blood bags). A univocal identification of the main logistic assets in blood transfusion chains will reduce/eliminate risks of mistransfusion, due to incorrect recognition of patient's identity, an incorrect association of blood test tubes and patients during venous blood specimen collection, incorrect assignment of blood bags to patients, or errors incurred at the bedside. One of the most promising technologies is RFID (Radio Frequency IDentification). In order to reach a significant reduction of medical errors leading to clinical risk, and a higher performance related to quality and service costs, information technologies and traceability systems (e.g. barcode "BC" or RFID) have been introduced in a healthcare environment. Bunduchi et al. (2011) studied costs and benefits associated with RFID systems for process innovation, and more specifically, in health care. In accordance with their research, the main use of RFID for inventory management is asset tracking: it reduces lost items and time of manual tracking. Another

main use of this technology relates to an increase of the quality of care.

BC is the most common traceability system in hospitals, mainly due to its low cost and user-friendliness. BC shows several disadvantages compared to RFID: scarce memory capacity; no addition/modification of information after printing the code; BC has to be visible to be scanned/decoded; few meters of reading distance; BC label has to appear on the outer part of items, and it is affected by environmental conditions; it is allowed to scan one BC at a time, leading to long detecting times for a huge number of items; BC is subject to counterfeiting and easiness of replicability. On the contrary, RFID tags have a good memory capacity; tags can be reread/rewritten; Radio Frequency allows to read tags also when they are not visible (Delen et al., 2007; Dutta et al., 2007; Lee & Özer, 2007); tags are not affected by environmental conditions (see, for example, Raviprakash et al., 2009); reading distance can be of dozen meters; possibility of multiple reading.

The most significant disadvantages consist in reading problems when electromagnetic (EM) interference of different sources occurs in the operative environment, and in higher costs compared to BC.

As reported by Chu & Cheng (2015), actually, BC is common in healthcare applications, but systems employing RFID are slowly catching up. A widespread type of tags is HF (High Frequency), which the main characteristic is near-field reading distance. UHF (Ultra High Frequency) RFID tags use higher frequencies than HF, allowing the identification and traceability of items at distances significantly longer than HF tags. Thus, UHF tags show higher efficiency, smaller size, but higher costs (Delen et al., 2007). Moreover, using UHF tags could be more complicated than HF in healthcare, due to potential electromagnetic (EM) interference with medical devices (Spano et al., 2014), higher EM emissions, lower reading performance for liquid or metal proximity (Delen et al., 2007; Wu et al., 2006).

This paper tries to provide an answer to the question posed by Ayob (2016) about fixing the problem of how to get the right blood unit to the right patient, by optimising blood transfusion chain, and by introducing RFID to trace patients and blood material, with the main objective of reducing clinical risks associated with current procedures. Nowadays, traceability systems are being implemented in hospitals, also in blood transfusion applications. The most common traceability systems are BC and HF RFID, but UHF is still innovative in the above-mentioned field. Thus, more research and pilot tests should be carried out to better define its applicability and usefulness in a real context. This is why Sardinia Autonomous Region and Fondazione Banco di Sardegna have financed a research project called "Bloodgistics", which has involved the AOB's Transfusion and Thalassemia Centres, which manage blood materials for thalassemic patients. Indeed, Sardinia shows the highest number of blood transfusion requests at a national level, due to a huge number of people affected by this hereditary disease. Thus, transfusion medicine is one of the sectors with the greatest potential of intervention, in which clinical risk reduction can be relevant.

The most significant innovation of "Bloodgistics" is the use of UHF frequencies (frequency range 865 MHz - 868 MHz)

to trace the main logistic assets of the blood transfusion chain, integrated to new processes, through risk assessment and re-engineering of the most critical activities carried out in the two hospital wards. The structure of the research project is in accordance with the approach suggested by Adarsh et al. (2014). The authors have analysed the state-of-art of HF RFID applications in transfusion medicine, and they stated that, before a full implementation of an optimised system based on RFID technology and information technology to manage blood transfusion chain, pilot activities should be carried out in pilot wards on a small scale. It will provide very useful and necessary information for system improvements, and some information on real benefits to be communicated to end-users (medical staff, patients), and to senior management to receive their social acceptance, and for scaling up the proposed system.

Figure 1 describes the main work phases:

Figure 1: Consequential scheme of "Bloodgistics"

1.2 Brief literature analysis of tracking technologies in healthcare environment

In accordance with a recent literature review carried out by Coustasse et al. (2015), to analyse how healthcare supply chains might benefit from the use of RFID systems in transfusion medicine:

- The root causes of transfusion errors occur during the correct identification of the blood drawn at the time of donation, the correct identification of the intended recipient at the bedside, errors in laboratory testing and screening, and error in labelling of blood samples

- Human error is accountable for these errors and it has been suggested (Goodnough et al., 2009) that electronic technologies, such as RFID, can reduce errors related to blood ordering and patient-specimen identification

- RFID-enabled transfusion has been successfully performed and has increased provider productivity and product quality.

As demonstrated by Adarsh et al. (2014), an effective blood management should be based on real-time RFID systems. In their system, HF has been used. HF RFID tags have been accepted by the International Society for Blood Transfusion (ISBT) and the United States Food and Drug Administration (FDA) as data carriers to integrate with and augment ISBT 128 barcode data carried on blood products. In the present work, experimental UHF RFID tags have been designed for blood bags, preliminarily tested in an EM-isolated environment to assess their performance in multiple reading conditions (both static and dynamic), to be compared to commercial tags. Effects of UHF EM fields on blood bags have been analysed. Any relevant interaction has been recognised, with respect to biological issues (Casu et al., 2015).

2.Description of the work and adopted methods

Process Analysis - As reported in Fig. 1, the project is made of four main parts: 1. Assessment of current processes, 2.

Re-engineering (with its sub-phases), 3. Preliminary pilot tests on a small scale, and evaluation of results for further improvement.

Assessment of current processes - Current processes ("As-Is" scenario) in the Thalassemia and Transfusion Centres (the latter supplies blood components to the former for transfusions) of AOB were assessed through questionnaires and interviews with the medical staff, and by collecting quantitative data during their working shifts.

Current processes have been assessed by applying the IDEF0 (Integration Definition for Function Modeling) method (Bevilacqua et al., 2015). Firstly, flow charts and activity forms (which provide more information about each main activity reported in a flow chart, e.g. effectiveness and efficiency, possible improvements) have been used, to obtain a detailed mapping of the blood supply chain. Then, to analyse criticalities, Risk Management methods have been applied for mode errors detection. Among the methods developed for this purpose, an inductive/proactive approach has been chosen. Particularly, FMECA (Failure, Mode, Effects, Criticality Analysis) and ABC analyses have been selected.

- FMECA analysis: for each activity, error modes and possible reduction measures have been defined. RPIs (Risk Priority Index) have been calculated to reach the main aim of the study (clinical risk reduction related to mistransfusion). RPI is an index obtained by multiplying three parameters: "Severity", "Frequency", and "Possibility of Detection" of potential error causes. The higher the RPI of an activity, the higher the possibility to be subject to human errors. Thus, subsequent re-engineering should focus on the most critical activities based on RPI values.

- ABC analysis: according to their RPIs, activities have been ranked in A, B or C categories depending on the assessed RPIs. Histograms and Pareto charts allow to conducting accurate analysis and effective evaluations. The main aim is to obtain a classification of the analysed error modes. Within each process, three basic error mode classes can be identified: A class (error modes with a high RPI are of primary importance - Criticalities relate to transfusion safety: their elimination is the main target of this study), B class (error modes with moderate RPI are of secondary importance - Criticalities relate not only to transfusion safety, but also to Transfusion Centre productivity, and their elimination would lead to an increased process efficiency and a marginal decrease in clinical risk), C class (error modes with low RPI are of marginal importance – Criticalities lead to negligible impact on patient's safety and productiveness of the involved Centres). As a theoretical indication, the Pareto theorem suggests an 80/20 subdivision, but variable thresholds have been used to discriminate A, B, C classes, enabling more efficient evaluations of the areas of intervention. Three KPIs (Key Performance Indicators) have been chosen, depending on the below listed measurable parameters and on the main objective of the study: number of processes and activities for each macro-process under study; associated number of error modes; RPIs.

Average RPI: is the arithmetic mean of the RPIs≠0 found into a macro-process.

Peak RPI: is the maximum RPI found into a macro-process.

Number of Activities: is measured as the number of activities making up a macro-process.

Process re-engineering - After assessing the As-Is scenario, the most critical activities have been re-engineered, and a "To-Be" scenario has been defined, with the aim of reducing/eliminating clinical risks. The To-Be scenario describes activities of re-engineered processes from both technological and operational points of view. Many activities, such as data transcription, or visual reading of codes and data, have been automated through UHF RFID technology. FMECA and ABC analyses and KPIs have been assessed for the To-Be scenario, and results have been compared to those of the As-Is scenario, to define the performance enhancement (Borelli et al., 2015a, b).

RF optimisation - RF optimisation (Melis et al., 2016) has been conducted on both blood test tubes and blood bags, which are two main logistics assets (the third one is the patient's ID card), labelled with UHF RFID tags. Multiple reading performances have been evaluated. Reading tests on blood test tubes have been performed on commercial UHF RFID tags in EM-isolated and not isolated environments; tests on blood bags have been carried out on both commercial and experimental UHF RFID tags in an EM-isolated environment only. The last ones have been designed and realised by DIEE for the specific application.

Engineering HW and SW, laboratory tests - The To-Be scenario has been modified to be applied in the two pilot hospital wards. A first version of the pilot model has been realised in 2014 and, then, modified to be more applicable in pilot wards in 2016. The Pilot model 2016 consists in an ad-hoc web-based management platform, using RFID hardware (UHF RFID printers and readers) to be accessed in real time from each terminal of the two wards, and in an application installed on mobile devices, supporting transfusion processes at the bedside (patient's identity recognition, matching patient ID and assigned blood bag). The pilot plant has been tested in the Laboratory of Logistics and Traceability of DIMCM before being installed in the pilot hospital wards.

KPIs analysis and statistical analysis - Statistical data processing has been derived from the FMECA analysis. Considering RPIs of each process as a random variable, the normal distribution curves of the As-Is and To-Be models have been calculated. Thus, a visual and immediate comparison of clinical risks has helped to conduct the subsequent process re-engineering. Moreover, it shows graphically the reduction levels of the most significant statistical parameters: mean, variance and variation range. The probability density curve has been obtained according to the Eq. 1. For each scenario (As-Is, To-Be, Pilot model), mean μ, standard deviation σ and range have been evaluated and compared.

$$f(x, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2} \tag{1}$$

Preliminary hospital wards tests - The pilot plant has been installed in the pilot hospital wards, to carry out preliminary tests, in order to improve the management platform and the mobile application for a routine use by medical staff. Preliminary tests have lasted 10 consecutive days, and have involved 30 thalassemic patients participating in this trial. The medical staff has been trained during normal work

shifts. During the pilot activities, current and new procedures have been assessed, by using the database of the web-based platform. The platform contains the history of transfusion chain activities (to log errors).

3. Results analysis

Results analysis is presented by following this sequence: i. Assessment of current processes (As-Is scenario), which presents the main outcomes provided through the FMECA and the ABC methods, ii. Process re-engineering, by introducing RFID UHF technology (To-Be scenario); iii. RF optimisation, which shows the most important results of tests of multiple reading performances carried out on UHF RFID tags applied on blood bags and blood test tubes; iv. Engineering HW and SW, laboratory tests, for the definition of the Pilot model; v. KPIs analysis and statistical analysis, showing the performance improvement of the blood transfusion chain; vi. Preliminary hospital wards tests, to collect data on a small scale, for the RFID-based system improvement, as well as for a scaling up of the same.

Process analysis – Current processes make use of many paper documents: request sheets, accompanying sheets, agendas, etc. Information exchange between the two wards takes place by means of fax or sheets transported by a courier. Transcription errors and reading errors might compromise transfusion, leading to high risks for human health. At present, blood materials are being labelled with BC, encoding a univocal donation identification number, used throughout the transfusion chain. Blood test tubes are used for patient-donator blood compatibility. Blood test tubes travel from the Thalassemia Centre to the Transfusion Centre, while blood bags travel from the latter to the former; thus, they need inventories to compare actual number and EPCs (Electronic Product Code) of tags and the expected ones.

FMECA -The most critical activities relate to manual procedures recognising the three main logistic assets: patients, blood test tubes, and blood bags. Furthermore, criticalities relate to information flows management between the two wards.

ABC – Results are shown separately for specific processes carried out in the Thalassemia Centre and in the Transfusion Centre.

Thalassemia Centre: blood components request - Blood components request shows few, but significant activities with RPIs higher than 100. The most critical activities (A class) are represented by control failure of blood test tubes temperature, leading to possible biological damages of blood samples; errors during patient's identification and his/her selection into the patients' database, actually performed as a manual procedure. B class activities, related to data entry by typing, and for which errors probability is high, but without relevant effects on patient's health, show RPIs between 100 and 30. C class activities refer to automated tasks with RPIs less than 30.

Transfusion Centre: blood test tubes reception and blood bags assignment - A Class activities show RPIs higher than 40. It relates to possible human errors during blood units assignment, such as error of labelling bags, wrong choice in selecting the correct blood treatment to bags. Impact on patient's health is high, as it may lead to some immunological reactions, or to patient's death, if not detected immediately. B class activities, likewise due to human errors, are related to bag assignment, but with smaller effects on clinical safety. However, it may lead to delays in providing services. The most of the activities fall into C class, thus optimisation levels achieved are good.

Thalassemia Centre: blood bags management for bedside process - Blood bags management at the Thalassemia Centre relates to the lowest Activity Amount. Nevertheless, there is a huge number of activities in A class with RPIs between 90 and 100. Errors are due to the wrong assignment of beds to patients or unsuitable blood units, mainly due to high blood temperature into bags, not monitored without temperature sensors. Consequences on patient's health are severe, with high possible immunological reactions. Possible solutions may be: adopting RFID tags for bedside identification, monitoring blood bags temperature. The unique activity in B class presenting an RPI of average value relates to human errors of grouping accompanying paper sheets and blood bags per patient before transfusion: the patient could be forced to go back for transfusion, or it could occur an increase of hospital stays.

Process re-engineering - Based on the As-Is results, an RFID-based technology solution using UHF hardware and tags, supported by an ad-hoc web-based platform for a real-time information exchange between the two wards, has been proposed for the AOB Management System, allowing to break down the criticalities detected during the process analysis, to achieve a substantial increase in patient's safety. The To-Be scenario has been designed and KPIs have been evaluated and compared to the As-Is scenario. Results have shown a significant clinical risk reduction, but the To-Be number of activities is higher than the current ones (As-Is) (Figures 2 to 4). However, the most part of activities will be performed through RFID systems, which will allow a decrease of operative times.

RF optimisation - Results of tests performed on RFID UHF tags applied to blood test tubes in EM-isolated and not isolated environments have shown different accuracies, consisting in a worsening in multiple reading accuracies for tests performed in a not EM-isolated environment. Spatial location of tags is relevant in reading performance of commercial tags. Tests performed on commercial and experimental RFID UHF tags applied on blood bags have not shown relevant differences of accuracy. Optimisation of experimental tags is good in dynamic reading conditions, but not if reading is performed in static conditions.

Engineering HW and SW, laboratory tests - UHF RFID hardware and software have been chosen with respect to the activities planned in the To-Be scenario. Laboratory tests performed in the Laboratory of Logistics and Traceability of DIMCM have not shown particular problems and criticalities, thus the preliminary tests in the two wards have been important to improve the proposed system for a further application on a broader scale.

KPIs analysis and statistical analysis - Performance improvement of the blood transfusion chain and reduction of the number of failure modes potentially causing critical adverse events have been detected. To assess the impact of UHF RFID technology on processes, the chosen KPIs of the four scenarios have been compared. Average RPI, Peak RPI, Activity Amount are reported in Figures 2, 3, and 4,

for the most relevant macro-activities. By considering procedures and clinical risk reduction, the Pilot models 2016 and 2014 show a good improvement compared to the As-Is scenario. This is more evident in blood bags management at beside than in the other main activities, because of partial inclusion of re-engineered activities planned in the To-Be scenario. Anyhow, improvement levels of pilot models are very close to the optimised scenario. About Peak RPIs of activities affected by the most serious errors, both about consequences on patient's safety and process optimisation issues, it can be stated that:
-By considering the Pilot model 2016, the Transfusion Centre has almost achieved the objectives set by the To-Be model.
-At the Thalassemia Centre, blood components request and management still show medium to high risks. With respect to blood components request, it has not been possible to modify some activities, because of the specific IT infrastructures, which do not allow interfacing different platforms for automated data entry by operators.

The activity amount of each hospital ward is reported in Fig. 4. The difference between the four scenarios is not significant. Except for the As-Is model, the number of activities of the other ones is identical, but not of the same type. By comparing the To-Be scenario and the Pilot 2016, differences are mainly due to blood components temperature checking and monitoring, and to the identification of beds assigned to patients through RFID. Differences concerning data management are related to a lack of joint between the platforms used in the two hospital wards and the new management platform based on RFID systems, which has been introduced in the Pilot 2016. With regard to the Pilots 2014-2016, differences in terms of KPIs are almost equal to zero (the only change is a to 1% increase of Average KPI in Pilot 2016). This is because that activity amounts and risk indexes are very similar for the two pilot models. In addition, it has to be considered that deviation of types of activities carried out in the Pilot 2016 is not significant compared to those of the previous pilot model. By comparing the curves in Fig. 5, it can be seen that:
•NPD curve of the As-Is model looks flattened and with the right tail more pronounced than the other models. Indeed, RPIs of actual processes are considerably higher than those of the optimised scenarios.
•RPIs of the To-Be model are more concentrated around the mean, due to a low standard deviation. Thus, most of the activities have RPIs close to mean value.
•NPD curves of the two pilot models are almost coincident (the two curves in Figure 5 are overlapped). Compared to those of the To-Be model, their mean values are greater than that, and they show a greater dispersion of data towards very high RPIs (RPI = 144).
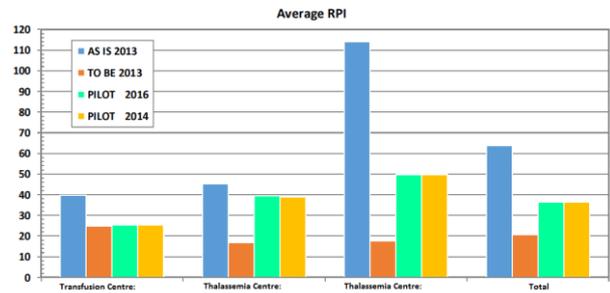
Figure 2: Average RPIs of the four scenarios
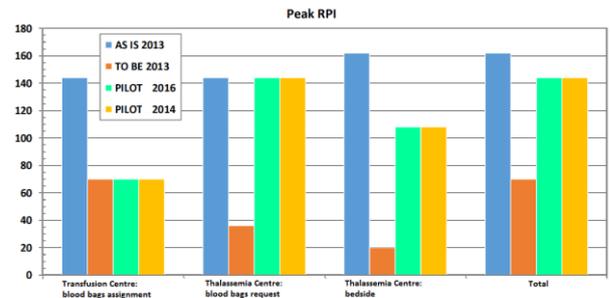
Figure 3: Peak RPIs of the four scenarios
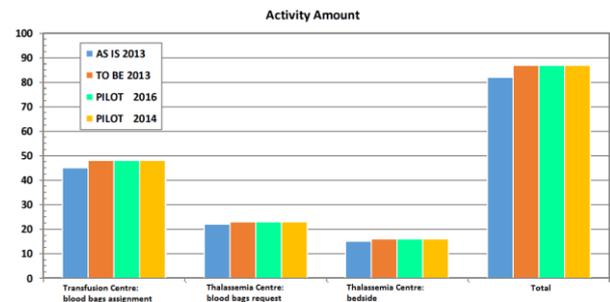
Figure 4: Activity Amount of the four scenarios

Table 1: mean, standard deviation, variation range

As-Is		
μ	σ	variation range
63.9	53.9	156
To-Be		
μ	σ	variation range
20.7	11.3	64
Pilot 2014		
μ	σ	variation range
36.4	33	138
Pilot 2016		
μ	σ	variation range
36.4	32.9	138
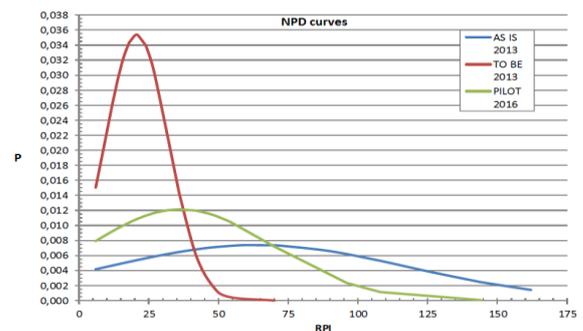
Figure 5: NPD curves of the four scenarios

Preliminary hospital wards tests - Preliminary tests have been performed for 10 consecutive days, by involving 30 thalassemic patients participating in this trial by signing informed consents. The management platform based on RFID technology has been installed in the AOB server, to be used in real-time, along with the selected UHF RFID hardware. Assistance and training to medical personnel have been provided during normal working shifts.

Tag design and survivability is an issue due to blood bag centrifugation and irradiation (Hohnberger et al., 2011): during the pilot activities carried out at the AOB Transfusion Centre, it has been possible to test the resistance of RFID tags chosen for blood bags. Indeed, one patient has required specific blood treatments (washing and filtering of packed red cells). The assigned bags have been diluted by physiological solution and, then, centrifuged at 3000 rpm (rounds per minute) for 10 minutes. Bags have been subjected to mechanical pressing, to separate red cells and physiological solution. After treatments, the involved tags have not shown any deformation/variation of appearance, and reading performance has not changed. Preliminary tests involving automated actions through RFID systems, with special attention to multiple readings to check the correct delivery of blood test tubes and blood bags, and to patient-blood bag matching at bedsides, have not led to errors. Only one error has been detected for blood test tubes, related to RFID tag coding, making impossible to associate this test tube to the patient through the web-based platform. The first version of the platform does not allow eliminating a blood test tube form and immediately creating a new one for the same patient, by coding and associating a new RFID tag. Future enhancement of the proposed system will include a solution to this important problem. Actually, blood bags RFID tags do not show patient's visible data printed on the paper face. Medical operators have suggested printing patient's personal data, for visual identification of him/her during transfusions at the bedside, especially during emergencies.

4. Conclusion

As mentioned in Section 1, this work has tried to provide an answer about how to get the right blood unit to the right patient, through a re-engineered blood transfusion chain, introducing UHF RFID technology to trace patients and blood material, with the main objective of reducing clinical risks. The most important innovation in this field has consisted in using UHF frequency, which is still rarely implemented in transfusion medicine. Thus, both methodological approach and preliminary results obtained by performing tests in hospital wards have provided new information for patient's safety improvement, blood transfusion management and logistics, but also from a technological point of view.

Tests performed on commercial and experimental UHF RFID tags have allowed assessing multiple reading performances for a quick and safe tracking. Results on blood test tubes have shown differences in multiple reading accuracies, consisting in a reduction of multiple readability in a not EM-isolated environment. Tests performed on blood bags have shown that multiple readings in dynamic conditions do not affect the performance of the considered commercial and experimental tags. Currently, experimental tags do not have a sufficient optimisation level for multiple reading in static conditions. The assessment of RPIs of the current processes has allowed identifying the most critical activities and planning for an optimised model. Modifications to the latter (Pilot 2014, Pilot 2016) have been necessary to design a more easily applicable pilot plant, to get relevant information for further improvements. Preliminary tests in the two pilot wards have been an important step to implement the proposed system in AOB wards as a routine in the close future.

Moreover, assessing KPIs of the four scenarios has allowed determining performance increase, when passing from current to re-engineered processes, with a transition represented by the pilot models.

By FMECA and ABC analyses, it can be stated that:
- With respect to the As-Is scenario, improvements related to the Pilot 2016 are more considerable for transfusion activities at the bedside. For the other macro-activities, decrease of KPIs is less marked.
- The Pilot 2016 activities carried out by the Transfusion Centre have almost achieved the objectives fixed by the To-Be scenario. The two pilot models have not shown any differences in terms of the analysed KPIs. Indeed, the Pilot 2016 activities are very similar to those of the Pilot 2014 in terms of Activity Amount and Risk Indexes. NPD curves have confirmed the above-mentioned results.
- UHF RFID technology, applied in transfusion medicine processes carried out by the two AOB hospital wards, has shown considerable advantages. Despite the pilot model deviates from the optimised model (To-Be), evident advantages about clinical risk reduction and activity amount have been reached with respect to the current situation. Further improvements will consist of automated control of blood temperature, and in an identification of beds through RFID. It will be also crucial to create an interface between the IT platforms currently adopted by AOB, which, because of limitations of database management at national level, do not allow customisations at a regional level.

Further enhancements of the system will refer to blood donation process. RFID labelling of bags during blood donation will allow a more efficient inventory management. Moreover, the use of thermal containers endowed of temperature sensors for thermal control of blood material will decrease clinical risk due to transfusion of blood exposed to high temperatures during transportation. These aspects will be a subject of future investigation, along with experimentation involving a higher number of patients and operators.

The medical staff has acknowledged the considerable potential of the proposed system in terms of clinical errors and processing time reduction. As an example, blood bags delivery by the Transfusion Centre to the Thalassemia Centre currently involves an optical reading of 4 BC codes for each bag to be delivered; the proposed RFID system recognises and matches all the present EPCs and the expected ones (those assigned to requiring patients in previous steps) through simultaneous reading, which therefore reduces processing times. Thalassemia patients

have noticed higher levels of safety during transfusion at the bedside.

The challenges for the future and the open questions of research remain: to receive the same acceptance of HF for UHF RFID tags at an international level (e.g. ISBT) for blood chain traceability; to reduce costs of tags, and to improve their reading performance for liquid (e.g. blood) proximity, by developing ad-hoc tags.
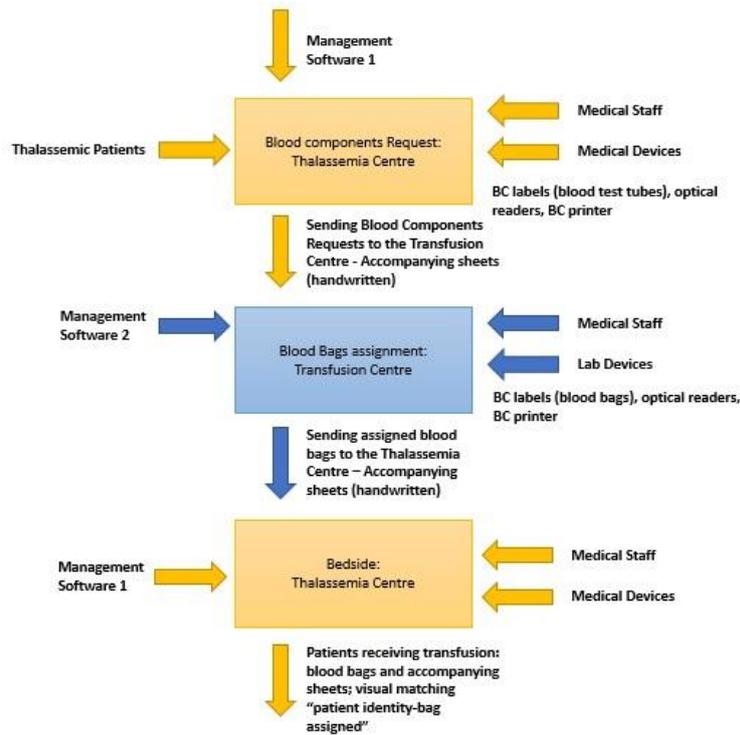
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Appendix A. Schemes of the As-Is and To-Be scenarios

A.1. As-Is scenario

Management Software 1

Thalassemic Patients

Blood components Request:
Thalassemia Centre

Medical Staff

Medical Devices

BC labels (blood test tubes), optical readers, BC printer

Sending Blood Components Requests to the Transfusion Centre - Accompanying sheets (handwritten)

Management Software 2

Blood Bags assignment:
Transfusion Centre

Medical Staff

Lab Devices

BC labels (blood bags), optical readers, BC printer

Sending assigned blood bags to the Thalassemia Centre – Accompanying sheets (handwritten)

Management Software 1

Bedside:
Thalassemia Centre

Medical Staff

Medical Devices

Patients receiving transfusion: blood bags and accompanying sheets; visual matching "patient identity-bag assigned"

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A1.2. To –Be Scenario

Unique Management Software: web-based and real-time

Thalassemic Patients: UHF RFID card

Blood components Request:
Thalassemia Centre

Medical Staff

Medical Devices

UHF RFID tags (blood test tubes), UHF RFID readers (fixed and mobile readers), UHF RFID printer. Blood temperature monitoring through sensors

Sending Blood Components Requests to the Transfusion Centre – Automated lists generated by the Unique System. It can be seen in real-time at the PC workstations

Unique Management Software: web-based and real-time

Blood Bags assignment:
Transfusion Centre

Medical Staff

Lab Devices

UHF RFID tags (blood bags), UHF RFID readers (fixed and mobile readers), UHF RFID printer. Blood temperature monitoring through sensors

Sending assigned blood bags to the Thalassemia Centre – Automated lists generated by the Unique System. It can be seen in real-time at the PC workstations

Unique Management Software: web-based and real-time

Bedside:
Thalassemia Centre

Medical Staff

Medical Devices

Patients receiving transfusion: blood bags and accompanying sheets; automated matching "EPC of the patient's RFID card – EPCs of the RFID tags of the bags present at the bedside – expected values od the EPCs of the RFID tags of bags assigned to the patient". This matching is realised through an App installed on mobile devices, connected to the Unique Management Platform, and a Bluetooth UHF RFID reader. Beds are identified by means of RFID tags applied on bed emplacements.