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RFID SYSTEMS FOR RISK REDUCTION IN BLOOD BAGS: A COST-BENEFIT ANALYSIS

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ABSTRACT

RFID (Radio Frequency Identification) technology has gained increasing popularity in recent years, both in the field of industrial application and in the services sector. In the latter field, in particular, many applications in the area of hospital logistics have been recently developed. This paper concerns the application of RFID systems to the control of blood bags in hospitals. The work, focused on the economic aspects of the problem, is based on a model for the economic evaluation of RFID systems based on cost / benefit analysis.
Both cases of application of HF and UHF frequencies, and different application scenarios were taken into account, based on the use of RFID in the entire transfusion loop or only to the part of it relative to the end user. The model was then tested and applied to an actual hospital reality of considerable importance from the point of view of blood transfusion. The results obtained in the different test cases were then further analysed through a sensitivity analysis in order to assess the model's response to changes in input parameters.

Keywords: Cost / benefit analysis; RFID systems; Logistic chain; Blood bags; Transfusion medicine

1 INTRODUCTION

Systems based on RFID technology (Radio Frequency IDentification) have gained in recent years a growing diffusion and importance. Their increasing success is largely due to the great number of advantages they present with respect to traditional systems such as, for example, a standard barcode (more memory capacity, read range and device robustness, possibility of more simultaneous and multidirectional readings, etc.).
These advantages have promoted its spreading in various fields of application: control of production lines (for the identification of the piece during production), industrial logistics (for goods tracking and identification), use in libraries (for managing the loans and volumes), etc.

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Systems based on RFID technology are also used for the origin certification of food products, identification and tracking of paper documents, sensors technology and geolocation (in the field of environmental control, for instance).
Finally, several studies are being recently developed on applications of RFID systems in the health sector: tracing (locating objects in hospitals), tracking of patients and carers and their identification (to reduce errors in identification or administration of therapies, to speed up procedures in intensive care, etc.), collection and management of computer data (with a significant reduction in process time), logistics and drug management, location of patients in the emergency department, managing the process of chemotherapy etc.
In recent years several studies are being carried out, in particular, on the possibility of applying RFID systems to the logistic chain of blood bags in hospitals. Their use would allow to significantly lowering the number of risks in the transfusion chain, bringing considerable advantages in all the stages of the process: donation, transportation of blood bags, validation, storage of blood bags, patient identification, testing, and bag-patient association.

The different technical studies conducted so far have clearly demonstrated the wide possibilities of the application of RFID systems to the transfusion chain and the significant benefits that this would entail, especially in terms of reduction of clinical risk and of processing times.
From the point of view of economic evaluation linked to the introduction of RFID, the classic cost - revenue analysis is clearly not sufficient to completely take into account the potential of the technology in question, which brings into play a number of advantages not easily quantifiable in monetary terms, mainly related to the lowering of clinical risk.
In this sense, it is considered appropriate to use, for this specific application, the typical technical analysis C / B, through which even the non-monetary quantities are taken into account in the economic analysis. For this purpose an economic model based on the cost / benefit analysis for the economic evaluation of RFID systems applied to the case of transfusion medicine was developed, adjusted and validated. The model, based on some average statistic data referred to the European case for the quantification of benefits, was applied to the case of the Transfusion Department of the Hospital Brotzu of Cagliari.
This model and its application are described in this paper.

2 LITERATURE ON THE TOPIC

In agreement with the increasing deployment of RFID systems, the literature on the subject has greatly developed and enhanced too, in recent years. The fields of research are manifold, including both theoretical analysis and applications of a more markedly technical-practical character. The spectrum of topics covered is very wide as well as the number of papers produced: therefore, given the limitations of space, only the most recent and significant works are reported in this paper.
Both the theoretical speculations and the practical applications concern studies on the application of RFID in various fields of application (for which we list only a few quotes for space reasons): green product design [17], pharmaceutical supply chain [67], healthcare service for tracking medical assets [41], hospitals for data treatment [49], monitoring system for ships passenger evacuation [59], apparel retail industry [27], food supply chain [22, 68], warehouse management [9, 33], pallet management [25], traceability in food industry and in general [5, 23], supply chain logistics [22, 13, 61], document management [6, 66, 37], aircraft production processes [36, 40], fashion retailing (especially in recent years) [20, 62, 31], just to name a few.
A large part of this bibliography covers case studies demonstrating both the technical and economic viability and the application potential of RFID systems in specific applications, and how these systems are able to significantly improve the efficiency of the overall system.
To these, many works must be added focused on the development of the technique, often oriented towards the problems of the safety of operation: these are articles of a more close to electronics matrix, which often propose and develop protocols for communication between tag and reader, or innovative algorithms [51, 57].
Part of the reviewed literature focuses on the economic aspects of the application of RFID, and on the attempt to take into account in the economic evaluations also several benefits determined by the introduction of RFID systems, benefits which the traditional economic analysis do not directly consider.
In particular, the bibliography concerning the economic aspects associated with the RFID technology is based on the application of various techniques, among which: AHP (Analytic Hierarchic Process) methods [17], fuzzy logic [50], Monte-Carlo method [50], analysis to draw [18] assessment and analysis of the costs and benefits [67, 27, 9, 32, 60] and cost / effectiveness [59], ABC (Activity Based Costing) methods [25], System Dynamics [19, 39, 20], simulative approaches [47, 56, 3], Markov chains [44, 64].
Coming to applications closer to the case under investigation, and then to the use of RFID in the health field, many articles can be found on the subject, dealing with general aspects; among them deserve to be mentioned: [58], which contains a framework for evaluating the performance of an RFID system in various applications in the field of health, [30], which reports a work aimed at identifying the hospital supply chain in which RFID can obtain the greater efficacy, [45] which shows how RFID can improve patient care supply chain, [54], which shows several case studies, always in the field of health care, in order to highlight and explain the benefits obtainable from the use of RFID; in addition, among the papers focusing on general aspects of RFID applications in healthcare can be included: [29, 24, 65 and 52], all of which consist of a review of RFID in the health field, highlighting problems, benefits and applications, [46, 30 and 45], which explore the limits and possible implementations using RFID in various fields of health (authentication, medication safety, patient tracking, blood transfusion medicine).

We also find [4, 64, 38 and 1] concerning the traceability with RFID systems, [58], which shows the development of an approach for evaluating RFID systems in the field of health; then there are some papers which, always in the health field, focuses on the development of protocols for the problem of security of data stored in the tag ([63, 55 and 43]), then in [12] and [34] the use of RFID for the management of physicians, patients and small clinics is illustrated; still: [44], which describes the traceability of equipment in hospitals, [41], which regards healthcare service for tracking medical assets, [26], concerning the comparison RFID - Bar-code and [42], which focuses on RFID-based systems developed to reduce the risk of incorrect administration of drugs, and then in the field of security: the application in this case covers all phases of the process of drug administration.
Particular attention should finally deserve several articles focusing on the problems arising in the transfusion supply chain: [48, 2, 16, and 53] regarding the issue of risk, [28], which focuses on the proposal of an alternative approach to

decision making, [11] and [15] concerning the application of RFID systems aimed at reducing clinical risk.

From all this vast literature on the theme of the application of RFID to the health sector, it is clear that it is well established without any doubt that RFID can improve the efficiency of all processes, the quality of the health service as a whole and improve the overall security for the patient.
Although numerous articles, as shown, are aimed at healthcare applications and at least as many are dedicated to the economic evaluation of RFID applications through various methods, including the cost / benefit analysis, however, up to our knowledge, no studies have been carried out on the economic evaluation of an implementation of RFID in the supply chain of blood, using systems based on the cost / benefits analysis.
This gap comforted us in the development of this work, together with the consideration that the chain of blood is an application which, from an economic point of view, is particularly suitable to be examined via models based on the C / B and C / E analysis, because of the numerous advantages well-illustrated in [11], many concern not directly quantifiable aspects, therefore not directly quantifiable in an economic analysis with traditional methods, such as, for example, the reduced risk of death for incorrect transfusion, or the risk of contracting diseases, etc. Based on these considerations, the work described in this article was carried on with a dual purpose: on the one hand to analyse, in general, the possibility of using the C/B method for the economic evaluation of the entire RFID system applied to the blood logistics chain; on the other hand, to evaluate, in particular, in strictly economic terms, the relative economic weight of the various benefits of implementing this technology, with the aim to evaluate which, among other positive aspects, was of greater importance, and so what better justifies its investment.

3 THE BROTZU HOSPITAL AND THE BLOOD SUPPLY CHAIN

The Brotzu Hospital (AOB), located in Cagliari, is the main hospital in Sardinia and admits annually more than thirty thousand patients in its 630 beds.
More than 400 physicians and a little more than a thousand nurses are working in the seven departments of AOB. The Blood Transfusion Centre of AOB is composed of two distinct but closely interlinked structures, the Service of Immunohematology within the Hospital and the Hall of Takings which is located in a separate building. The Service annually manages approximately 50.000 units of blood, of which about 60% comes from imports from other Italian Regions, necessary to cover the high demand of blood for patients suffering from beta thalassemia.
The logistic chain of blood from the donor phase to the final transfusion can be briefly described as follows.
The blood is donated in the taking room, and then it is transported to the collection centre where are also collected the bags from other centres in the province of Cagliari and imported from the rest of Italy and Europe.
Then the separation of the various emo-components takes place through squeezing and centrifugation and interim storage. Tests are conducted in parallel on blood samples associated with each bag; if the result is positive then the bags are validated, otherwise they are eliminated. The bags ready for donation are stored permanently in the blood bank according to the division into RBC (Red Blood Cells), platelets (PT) and plasma (FP), with different storage times depending on the hemoderivate.
In the wards of the hospital the patient identification and the demand for blood components takes place, which requires the performance of at least two tests to determine blood group, AB0 test. Once the request has correctly been made, the communication is sent to the Blood Transfusion Centre for the blood to be sent to the ward. The Chain of Blood final procedure is the transfusion, or administration at the patient's bedside, which requires the correct identification of the patient and the correct association with the requested bag.
The complete transfusion process just described (Blood supply chain), from donation to transfusion to the patient, can be subdivided into two lines, which will be henceforth referred to as "first level" and "second level":

- First Level (Transfusion Loop) includes the steps of the transfusion process in the strict sense, from the request of the blood products in the ward to the end of the transfusion (patient area);
- Second Level: it includes all the steps from the stage of blood donation to the sending of the bag to AOB departments (donor area).

The Figure 1 shows, in a nutshell, the block diagram that illustrates the two levels described above.

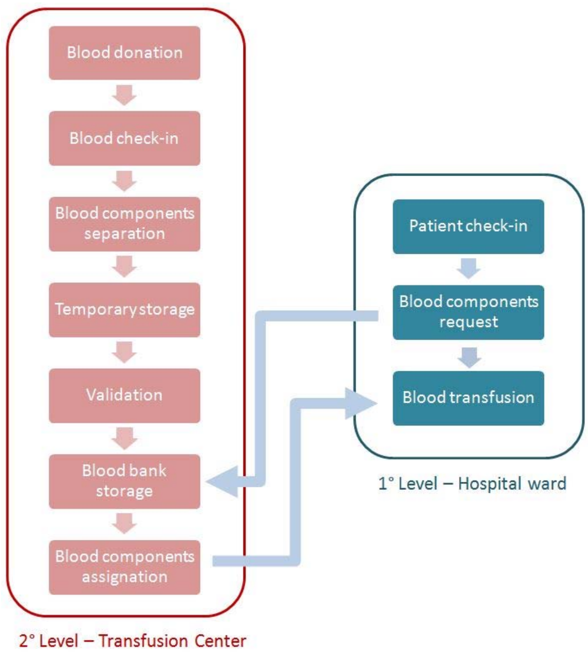

Figure 1 Scheme of the full transfusion process and its subdivision in two levels.

The use of RFID in the transfusion chain could reduce transcription errors and shorten the time of the procedure in the identification phase of the patient in the donations ward. The subsequent transmission to the Collection Centre for the identification and the validation test can be carried out with remarkable speed and a substantial reduction of the risk of human errors, thus obtaining a real-time process control until the storage in the blood bank.
From the point of view of the hospital ward, the RFID allows to quickly identify with virtually zero errors, both the patient and the associated AB0 test tube. With the integration of RFID in a hospital information system, it is possible to significantly reduce the communication time of the request to the Blood Transfusion Centre.
In the blood bank it is therefore possible to manage the inventory in real-time, to select and identify the bag to be sent to the ward, performing the delivery in reduced times, also in this case with a substantial reduction of potential human errors.

The real key point of RFID use is the correct association between the bag and the patient in the ward, reducing the risk of blood group incompatibility, which can also lead to potentially deadly haemolytic reactions.
Several studies have already been carried out at the AOB Haematology Department in order to analyse the possibility of introducing an RFID system for blood bags monitoring (see, e.g. [7]). The results of these studies have been highly encouraging, and such studies should be consulted for any technical details.
In the present study, as already mentioned, the economic aspects of the use of this technology are examined, through a comparison between the costs and the benefits obtained.
Starting from the studies already carried out at AOB, 8 possible scenarios of RFID implementation were developed, characterized by different degrees of RFID application (only in the 1st level or in the 1st and 2nd level), by different types of treated blood (RBC only or all blood types) and frequency band (HF or UHF) (chosen, respectively, the HF for its extensive dissemination and UHF for its promising employment prospects).

Table I – List of the solutions considered in the model.

Solution	Implementation levels	Blood Products	RFID frequency
1	As is	ABP	-
2	1°	RBC	HF
3	1°	RBC	UHF
4	1°	ABP	HF
5	1°	ABP	UHF
6	1° & 2°	RBC	HF
7	1° & 2°	RBC	UHF
8	1° & 2°	ABP	HF
9	1° & 2°	ABP	UHF

In Table I are presented in a concise form the conditions which characterize the 8 scenarios considered (solution 2 to 9). "Solution 1" indicates the current situation, which will then be used only as a term of comparison.
As can be seen from the Table I, the solutions 2 to 5 have a re-engineering only of the 1st level, while solutions from 6 to 9 have both levels 1 and 2 renovated with the use of RFID, and therefore an integrated redesign of the entire hospital transfusion process.

4 QUANTIFICATION OF COSTS AND BENEFITS

For each of the 8 scenarios costs and benefits were evaluated.
The costs were divided in installation costs, incurred at time 0, for the implementation of the RFID system, and in operating costs, which are necessary for the normal system operation once steady-state conditions are achieved.
As far as the benefits are concerned, the three main positive aspects resulting from the use of RFID technology were taken into consideration: clinical risk reduction, blood bags wasting reduction and process time reduction.
For all the scenarios a discount rate of 5% has been selected, a value commonly accepted for the economic analysis in the health care sector.
A time horizon of 15 years was also considered in the analyses carried out, chosen as a compromise between short-term scenarios (under 10 years), fully meeting the rapid evolutionary characteristics of RFID but difficult to achieve in the field of Public Health in Italy, and projects with a duration of more than 20 years, in which the level of obsolescence of the system would be fully evident.

Some parameters of the analysis were considered variable in time. Among these, in particular, the number of blood bags and the number of patients. As regards the former, the initial data were taken from both the 2008 Regional Blood Plan (PRS), based specifically on data retrieved from AOB and AVIS (National Blood Donors Organization), allowing to get the full picture on the basis of the types of blood products employed. On the basis of the data from the 2008 PRS, possible variations in the number of plasma, platelets, regional and imported RBC bags were then conservatively estimated, with a reduction of the latter component. Concerning the type of blood from donations carried out in the Region, annual growth rates were considered resulting in an absolute increase of 20% at the end of the 15 years of the project. For RBC bags imported extra-region, the absolute change was assumed equal to 15%.
The number of AOB patients which may be involved in the transfusion system, was based on the value provided by the AOB itself and reported in [7]. It was assumed, for this parameter, an annual increase of 10% of the patients for the AOB structure at the end of 15 years.

4.1 COST EVALUATION IN THE DIFFERENT SCENARIOS

Installation costs include the costs of hardware, software, infrastructure and development costs. The operating costs include the costs for buying tags, bracelets and barcodes (in solutions of the 2nd level), the hardware, software and infrastructure maintenance costs, and those to be incurred for the annual training of a small number of new operators ("training at tertiary level").

4.1.1 Investment costs

The initial investment costs include the initial hardware: PC, PDA (Personal Digital Assistant), portable RFID reader, massive tunnel readers (devices used for the simultaneous reading of multiple blood bags, required only in the solutions with bank blood), and finally RFID labels printers.

The cost of the software includes: PDA readers software and management software of the blood bank and of the process (related to the 2nd level of implementation).

The infrastructure costs considered include buying the Wi-Fi network and other equipment necessary for the operation of the system.

Development costs consider the costs incurred for the installation and setup of the communication network between the mobile readers and the computer network and of all the fixed devices (routers, antennas, etc.). In the development costs also those incurred for the training of personnel at various levels, differentiated between training costs for management level and for medical department operators, are included.

Table II – Detailed list of initial costs for HF frequency RFID solutions.

HF									
		2		4		6		8	
		1° Level, RBC only		1° Level, ABP		1° & 2° Level, RBC only		1° & 2° Level, ABP	
	UNIT COST	QUANTITY	COST [€]	QUANTITY	COST [€]	QUANTITY	COST [€]	QUANTITY	COST [€]
HARDWARE									
PC	1.500	15	22.500	15	22.500	18	27.000	18	27.000
PDA	1.800	70	126.000	70	126.000	90	162.000	90	162.000
TUNNEL	8.000	0	0	0	0	1	8.000	1	8.000
PRINTER	2.500	25	62.500	25	62.500	28	70.000	28	70.000
TOTAL			211.000		211.000		267.000		267.000
SOFTWARE									
PDA SOFTWARE	1.000	70	70.000	70	70.000	90	90.000	90	90.000
BLOOD BANK MANAG.	15.000	0	0	0	0	1	15.000	1	15.000
MANAGEMENT SW	2.000	70	140.000	70	140.000	90	180.000	90	180.000
TOTAL			210.000		210.000		285.000		285.000
INFRASTRUCTURE									
WI-FI NETWORK	2.500	25	62.500	25	62.500	28	70.000	28	70.000
OTHER COSTS	1.500	0	0	25	37.500	28	42.000	28	42.000
TOTAL			62.500		100.000		112.000		112.000
DEVELOPMENT COSTS									
INSTALLATION	2.000	25	50.000	25	50.000	28	56.000	28	56.000
TRAINING 1	10.000	3	30.000	3	30.000	4	40.000	4	40.000
TRAINING 2	120	120	14.400	120	14.400	150	18.000	150	18.000
TRAINING 3	120	5	600	5	600	7	840	7	840
TOTAL			94.400		94.400		114.000		114.000
TOTAL INVESTMENT COST			**577.900**		**615.400**		**778.000**		**778.000**

Table III - Detailed list of initial costs for UHF frequency RFID solutions.

UHF									
		3		5		7		9	
		1° Level, RBC only		1° Level, ABP		1° & 2° Level, RBC only		1° & 2° Level, ABP	
	UNIT COST	QUANTITY [IT]	COST [€]	QUANTITY [IT]	COST [€]	QUANTITY [IT]	COST [€]	QUANTITY [IT]	COST [€]
HARDWARE									
PC	1.500	15	22.500	15	22.500	18	27.000	18	27.000
PDA	1.800	70	126.000	70	126.000	90	162.000	90	162.000
TUNNEL	8.000	0	0	0	0	1	8.000	1	8.000
PRINTER 1	5.000	2	10.000	2	10.000	4	20.000	4	20.000
PRINTER 2	3.300	23	75.900	23	75.900	28	92.400	28	92.400
TOTAL			234.400		234.400		309.400		309.400
SOFTWARE									
PDA SOFTWARE	1.000	70	70.000	70	70.000	90	90.000	90	90.000
BLOOD BANK MANAG.	15.000	0	0	0	0	1	15.000	1	15.000
MANAGEMENT SW	2.000	70	140.000	70	140.000	90	180.000	90	180.000
TOTAL			210.000		210.000		285.000		285.000
INFRASTRUCTURE									
WI-FI NETWORK DEPLOP.	1.500	25	37.500	25	37.500	32	48.000	32	48.000
OTHER-COSTS	1.500	25	37.500	25	37.500	32	48.000	32	48.000
TOTAL			75.000		75.000		96.000		96.000
DEVELOPMENT COSTS									
INSTALLATION	2.000	25	50.000	25	50.000	32	64.000	32	64.000
TRAINING 1	10.000	3	30.000	3	30.000	4	40.000	4	40.000
TRAINING 2	120	120	14.400	120	14.400	150	18.000	150	18.000
TRAINING 3	120	5	600	5	600	7	840	7	840
TOTAL			94.400		94.400		122.000		122.000
TOTAL INVESTMENT COST			**613.800**		**613.800**		**812.400**		**812.400**

All of these costs have been quantified as reported in Table II and Table III, based respectively on HF and UHF frequency. The costs considered were taken from market values or estimated in a conservative manner.

As for the quantities of the individual elements, they are referred to estimates based on hospital size (specifically, for example, for the PDA, it was based on the number of wards concerned by the implementation), on the size of the processes considered and on information from operators working in the existing structure.

The solutions with full implementation (6,7,8 and 9) have a higher cost compared to those of the 1st level only. In addition, of the two frequencies, the UHF has a higher investment cost, mainly due to the higher cost of the Hardware which exceeds, in solutions 7 and 9, the threshold of € 300.000.

As can be seen from Table II and Table III, in the solutions of 1st and 2nd level, costs are higher because the entire transfusion process is managed, i.e. including also the donation centre and the blood bank, which require additional components, such as the reading tunnels. The larger size of the process to be re-engineered in the second level involves a greater number of materials to be used and of operators to form. The total cost to be incurred in the various alternatives, however, does not differ greatly between solutions of 1st and of 1st and 2nd level when operating costs are considered, as they directly reflect the difference in bags volume between the two levels.

4.1.2 Operating costs

Operating costs basically concern the costs incurred for the purchase of tags, wristbands and, for some solutions, barcodes too. These cost items vary each year as they are directly linked to the number of bags and to the unit cost of the tags, both supposed to change annually.

As for the cost of barcodes, tags, bracelets, etc., reference was made to the values reported in [8].

Also the cost of RFID tags and bracelets has been hypothesized to change annually, considering a progressive reduction of the purchase price, because of an expected spread of tags diffusion and a consolidation of the technology.

The magnitude of these changes was conservatively estimated in a value of 1,5% per annum, with an absolute variation of the purchase price equal to approximately 20% in 15 years of the project. For the two types of tags, HF and UHF, the same purchase price variation are considered.

The difference in cost of a single tag for the two frequencies is not very marked (there was no desire to overestimate the benefits in the use of UHF); however, due to the number of tags used and the time horizon of the project, the total cost differences between the two technologies are substantial.

The following table shows the unit costs considered for the tags, bracelets and barcodes, the estimated annual rates of variation for different purchase prices and finally the fields of variation assumed in the sensitivity analysis.

Table IV – Unit costs [€/u] assumed for tags, wristbands and barcodes for HF and UHF technologies.

		Initial cost	Annual cost ratio
HF	Wristbands	2	-1,5%
	Tag	0,2	-1,5%
	Barcode	0,01	0,0%
UHF	Wristbands	1,8	-1,5%
	Tag	0,18	-1,5%
	Barcode	0,01	0,0%

The purchase price of the UHF tags has been estimated to be less than that of the HF frequency transponder.

For labels and barcodes, used in limited cases of the project, no annual variations were assumed, both because their influence in the analysis is decidedly limited, and for the high diffusion of this technology, which ensures a substantial stability in the purchase cost. The use of barcodes was limited to the identification of the tubes to be used in the TC (Transfusion Centre) laboratory analysis.

The costs of tags, bracelets and barcode must be increased of the costs incurred for the maintenance of hardware and software (conservatively estimated as equal to 2% of the initial investment cost and constant in the 15-year estimated life of the project), as well as the network and its devices, for fixed and mobile communications.

It must also be added the costs for the regular annually training of personnel required to integrate operators coming from other structures; in the model this item was indicated as 3rd level training.

Ultimately, the operating costs of maintenance and annual training are constant in the 15 years of the life of the project.

The following two tables (one referred to the solutions employing HF frequency, Table V, and the other to the solutions based on UHF technology, Table VI) show in detail all the constant items in operating costs, independent of the number of bags or patients.

The number of tags required for each solution was calculated considering the number of bags handled, in particular taking into account that, from a single donation bag (bag mother), satellite bags are also obtained as a result of the separation of blood components. As the distribution of mother and satellite bags varies according to demand, a subdivision of the totality of the bags mothers was assumed, thus obtaining a higher and conservative operating cost.

The number of wristbands required depends on the statistics on the number of patients and donors that refer to AOB. The total number of both categories was supposed variable over time, with an annual growth rate of 0,6%, therefore the cost to purchase the bracelets varies annually.

Table V – Constant items of operating costs for HF frequency solutions.

	HF			
	2 1° Level, RBC only COST [€]	4 1° Level, ABP COST [€]	6 1° & 2° Level, RBC only COST [€]	8 1° & 2° Level, ABP COST [€]
HARDWARE				
TOTAL HARDWARE COST	211.000	211.000	267.000	267.000
HARDWARE MAINTENANCE (2% TOTAL COST)	4.220	4.220	5.340	5.340
SOFTWARE				
TOTAL SOFTWARE COST	210.000	210.000	285.000	285.000
SOFTWARE MAINTENANCE (2% TOTAL COST)	4.200	4.200	5.700	5.700
INFRASTRUCTURE				
TOTAL INFRASTRUCTURE COST	62.500	100.000	112.000	112.000
INFRASTRUCTURE MAINTENANCE (2% TOTAL COST)	1.250	2.000	2.240	2.240
TRAINING COSTS				
3° LEVEL TRAINING	600	600	840	840
MAINTENANCE & 3° LEVEL TRAINING COSTS	**10.270**	**11.020**	**14.120**	**14.120**

Table VI – Constant items of operating costs for UHF frequency solutions.

	UHF			
	3 1° Level, RBC only COST [€]	5 1° Level, ABP COST [€]	7 1° & 2° Level, RBC only COST [€]	9 1° & 2° Level, ABP COST [€]
HARDWARE				
TOTAL HARDWARE COST	234.400	234.400	309.400	309.400
HARDWARE MAINTENANCE (2% TOTAL COST)	4.688	4.688	6.188	6.188
SOFTWARE				
TOTAL	210.000	210.000	285.000	285.000
SOFTWARE MAINTENANCE (2% TOTAL COST)	4.200	4.200	5.700	5.700
INFRASTRUCTURE				
TOTAL	75.000	75.000	96.000	96.000
INFRASTRUCTURE MAINTENANCE (2% TOTAL COST)	1.500	1.500	1.920	1.920
TRAINING COSTS				
3° LEVEL TRAINING	600	600	840	840
MAINTENANCE & 3° LEVEL TRAINING COSTS	**10.988**	**10.988**	**14.648**	**14.648**

4.1.3 Total costs analysis

The total discounted costs, divided into the two components of investment costs and operating costs, are shown in Figure 2 for the 8 projected scenarios.

It can be seen that the solutions for a total use of RFID in the process (solutions 6-9 1st and 2nd level) have a much higher cost than those of corresponding level 1 only, with increases in the range 67 ÷ 77%, with the maximum value for the pair of solutions 4-8. It therefore appears significant the difference in total cost for solutions which also manage the 2nd level because of the significant impact of the operating costs, mainly for the purchase of bracelets and tags. On the contrary, the increase of the initial investment costs, in the passage from solutions of 1st to 1st and 2nd level, is decidedly limited when compared with the operating costs.

4.2 BENEFITS QUANTIFICATION

As already mentioned, the main benefits considered in this first phase were the reduction of clinical risk for mortality from AB0 incompatibility, waste reduction and savings of time in the process, leaving more positive items, such as, for example, the quality perceived, to a next level of detail of the project.

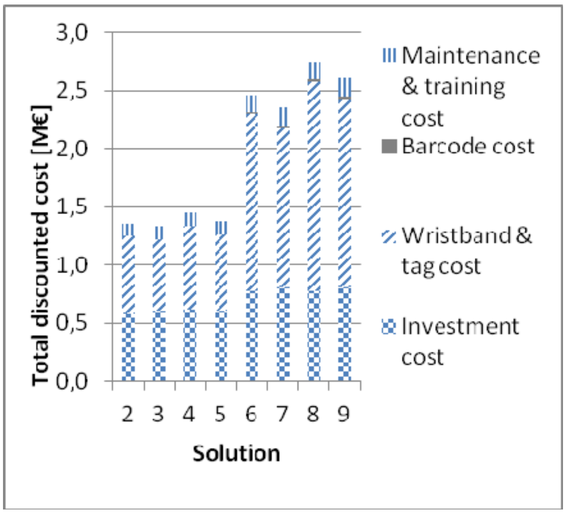

Figure 2 Division of total cost in initial investment cost and operating costs.

4.2.1 Reduction of clinical risk

One of the benefits expected from the use of RFID in the transfusion sector is a reduction of the clinical risk, in particular that of an incorrect association patient-bag of blood, whose main effect is the haemolytic reaction AB0 which, in approximately 10 % of cases, can be lethal [21].
The statistics on the risk of AB0 incompatibility reported very different values depending on the health care system to which they relate, on the technologies employed and methods used to assess the clinical risk. It was decided therefore to use a mean value between the two extremes that can be found in Europe [2]: maximum risk value: Germany, 1/36.000, minimal risk value: France, 1/135.207.
The coefficient 0,1 was added in order to consider the incidence of mortality from acute haemolytic reaction. The value chosen for the calculation, 1/85.603,5, was obtained as an average between the two values above.
In the present study benefits for temporary or permanent damage in transfused patients were not considered. In the first case due to lack of reliable data on compensation, in the second case because the work was concentrated on AB0 incompatibility, the main problem related to the exchange of bags.

In the absence of reliable data about the risk reduction with RFID in transfusion monitoring structures, studies of massive and intensive application of the barcode system or in systems similar to RFID were considered (in particular, the studies [16] and [53]), according to which an advanced system for the identification and management of the entire supply chain of the blood bags can lead to an increase in the safety of blood transfusions of the order of 90% or greater; it is then possible to attain a risk reduction of up to an order of magnitude, that is, with a procedure 10 times less risky for the patient subjected to transfusion. This result is achievable with analogous association of bag-patient-donor systems, or with extensive use of process information technology and barcode technology.

Although RFID allows to obtain and overcome these results obtainable with analogous systems and barcode, for the calculation a precautionary value of the security increase equal to 90% was chosen in the case of implementation in the whole blood chain, that is, for both levels 1 and 2.
Concerning the estimate of the risk reduction in the solutions of level 1only, reference is made to the study of Linden [35]. It shows that the total number of handling errors for the RBC type, not due to the blood bank, amounts to approximately 56%. As in the solutions of the first level, the use of RFID from the blood bank is not foreseen, it was therefore assumed a 50% reduction of the effectiveness from the maximum value obtained in the 1st and 2nd level.
Therefore, having chosen a 90%, increase of security for the 1st and 2nd levels, a value equal to half, 45%, for the solutions of the first level is found.
In both cases were therefore chosen two conservative values of the reduction of the risk compared to the possible performance obtainable from RFID systems.

For the CBA this lower risk determines an avoided cost for the structure and for the NHS (National Health System) which should pay the compensation to the families.
The extreme values of the compensation were taken from the data of the Milan court, assuming the average value between € 130.000 and € 1.6 million, the highest value reported for these cases in 2012. These compensations applies only to the case of mortality occurred as a result of a transfusion.
Not all of the claims, however, arrive at a positive judgment for the patient, usually after 10 years of proceedings. In the Region of Tuscany, for example, only 14,72% of the claims against the NHS was paid in 2003-2008, a value similar to those reported in 2002 by CINEAS (University Consortium for engineering in insurance) [14]. For this reason the benefit of compensation is conservatively underestimated, considering only 15% of the value of compensation. The result is a hypothetical value of the compensation amounting to € 129.750.

In Figure 3 the number of avoidable deaths in the various solutions are shown.
The security increase of the process is present both in the transition from RBC to ABP, and in the transition to solutions also including the implementation of RFID in the hospital CT (1st and 2nd level). The increase in security achieved exceeds the "psychological" threshold of a mortality averted during the 15 years of the project only in the solutions 8 and 9 (all blood types, 1st and 2nd level), with an efficacy approximately 3 times higher than that obtainable in solutions 2 and 3 (only RBC, 1st level).

4.2.2 Waste reduction

The reduction of waste is considered as a benefit in the solutions of levels 1 and 2 only, because only in level 2 a blood bank computerized with RFID systems is set up to manage the bags in order to reduce waste. The benefits are also due to the reduction of false negatives, to the fewest bags past its use-by date and to a better management of the existing stock on the basis of the donations occurred.

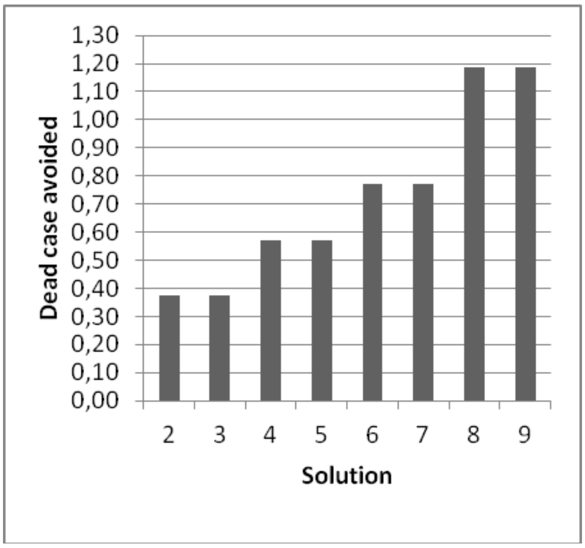

Figure 3 Number of deaths avoided over 15 years in various solutions.

The quantification of the benefit is based on the current efficiency percentage, assuming a process efficiency increase, due to the RFID introduction, equal to 3,5% according to information obtained by direct discussions with the sector operators and according to [7].

As a calculation choice, not being known specific sources on platelets and plasma bags, the value of increase in efficiency was assumed identical for all three types of blood.

The main benefit from the smaller number of expected waste is due to the cost avoided by the elimination of the bag before it has carried out the function for which it is intended. The cost of the bag refers to the infrastructure, personnel and all entries that have created added value, following the voluntary personal donation. The value of the bags was calculated starting from the value reported in [7], and updating it with the value 1,205 (ISTAT coefficient for December 2013).

As shown in the Table VII, also other medical assets bearing a cost related to the process were also included in the calculation, therefore a reduction of waste would involve directly their associated savings.

Table VII – Actual and estimated economic values of the bags and other associated assets.

		Sicilian Region, 2004		Estimated, 2013	
		Regional	Extra regional	Regional	Extra regional
Blood products	RBC	€ 129,76	€ 153,00	€ 156,36	€ 184,37
	FP	€ 20,00	€ 20,00	€ 24,10	€ 24,10
	PL	€ 115,00	€ 115,00	€ 138,58	€ 138,58
Assets	Consumables	-	-	€ 0,10	€ 0,10
	Medical disposables	-	-	€ 3,00	€ 3,00

Each not discarded bag can be considered as a not wasted value of the structure, a saving which, in the differential analysis with respect to the current situation, can be considered as a revenue in the CBA. The total value of revenues is then obtained by multiplying the waste avoided each year by the value of the bags considered constant in the 15 years.

As the reduction of waste was assumed only for the 1st and 2nd level solutions, in the Figure 4 only the solutions from 6 to 9 are shown, i.e. those in which the re-engineering of the blood bank is included in the process.

In this case there are no differences in efficiency in the use of tags with HF or UHF frequency, therefore the only variable that changes the result of the expected deviation is the amount of bags handled, which varies greatly between ABP and RBC only.

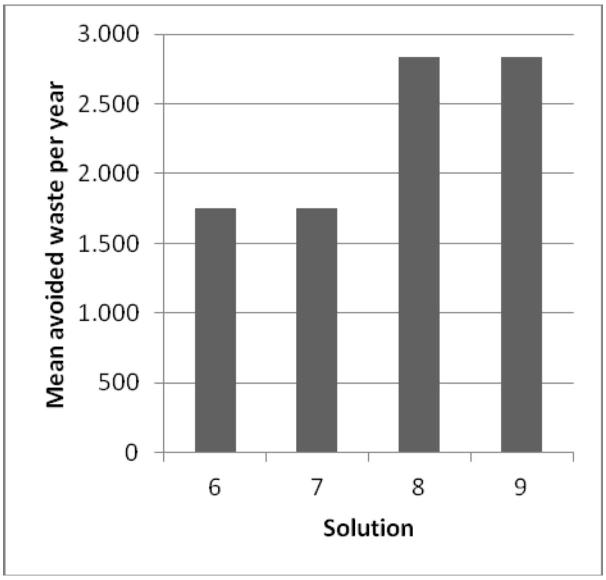

Figure 4 Average number of not discarded bags per year in the 1st and 2ndlevel solutions.

4.2.3 Time savings

In order to perform a more complete analysis, the quantification of the benefits arising from time savings obtainable in various stages of the process has been introduced (see [7]), considering the operations carried out by doctors, nurses, laboratory technicians and auxiliary workers (for the transportation). The average wages for each category, as indicated in the National Collective Work Labourcontracts (CCNL) was reported in €/min, and then multiplied by the number of bags produced in the process.

The Table VIII shows changes in the cycle timing considered.

The hemocomponents separation phase was considered as not affected by the use of RFID as they are not included in such operations. As can be seen from the table 8, not all of the operations have reduced process times and some were assessed as slightly pejorative (negative values) compared to the current situation (in terms of time).

The values of time for each phase have been assumed on the basis of the information provided by the operators of the hospital [8]; all estimates have been made in conservative terms.
By multiplying the time savings and the delays by the corresponding operator salary, the economic benefit (or loss) can be obtained, then all the various contributions can be added to find the overall result in the two hypothesized levels.
In the last two columns to the right it is possible to see how in the first level the cases involving the blood bank (blood donation and acceptance) were not considered, while they are fully covered in the second level of implementation.

Table VIII – Cycle time modifications considered for the different operator categories and process phase.

Process phase	Operator	Cycle time [min/cycle]	Salary [€/min]	Economic benefit [€/cycle]	
				1° level	2° level
Blood request	Physician	0,5	0,4	0,2	-
	Nurses	1,5	0,25	0,375	-
	Lab Technicians	0	0,25	0	-
	Auxiliaries	0	0,12	0	-
Blood transfusion	Physician	0	0,4	0	-
	Nurses	-1	0,25	-0,25	-
	Lab Technicians	0	0,25	0	-
	Auxiliaries	0	0,12	0	-
Whole blood donation	Physician	0	0,4	-	0
	Nurses	-2	0,25	-	-0,5
	Lab Technicians	0	0,25	-	0
	Auxiliaries	0	0,12	-	0
Whole blood check-in	Physician	0	0,4	-	0
	Nurses	0	0,25	-	0
	Lab Technicians	2,5	0,25	-	0,625
	Auxiliaries	0	0,12		0
Blood components assignation	Physician	0,05	0,4	0,02	-
	Nurses	0,25	0,25	0,0625	-
	Lab Technicians	0,2	0,25	0,05	-
	Auxiliaries	0	0,12	0	-
Blood components check-out	Physician	0	0,4	0	-
	Nurses	-0,5	0,25	-0,125	-
	Lab Technicians	0	0,25	0	-
	Auxiliaries	0	0,12	0	-
Total economic benefit				0,3325	0,125

In order to obtain the economic benefit the number of bags in the first and second level was multiplied for a coefficient respectively equal to € 0,3325 and € 0,125 (coefficient obtained as a product of time per cycle multiplied for the salary per minute).
In the 2nd level the RBC bags from outside the region are not considered because they are not attributable to savings being blood samplings made outside the hospital structure.
Although the time reduction may be at first sight regarded as not very significant, as the saving in the case of the first level is of only 1 minute and 1.5 minutes for the complete implementation, it assumes a great importance when it is multiplied by the number of bags managed with RFID in the various solutions.
As far as the productivity increase calculation is concerned, it was performed separately for the levels 1 and 2, subsequently adding up the two in order to obtain the total value. In solutions of level 1 (solutions 2-5) the value of the benefit for the part relating to the 2nd level is zero.

4.2.4 Total quantification of cba benefits

As illustrated, all benefits have been converted on a common monetary basis for each year of the project. The three benefits were calculated separately, by calculating the total economic value for each period and discounting the cash flows.
The calculation was performed both for the three types of blood (RBC, plasma, and platelets), and for the other elements of consumables and medical devices associated with individual bags.
Figure 5 summarizes the results obtained from the benefits calculation.

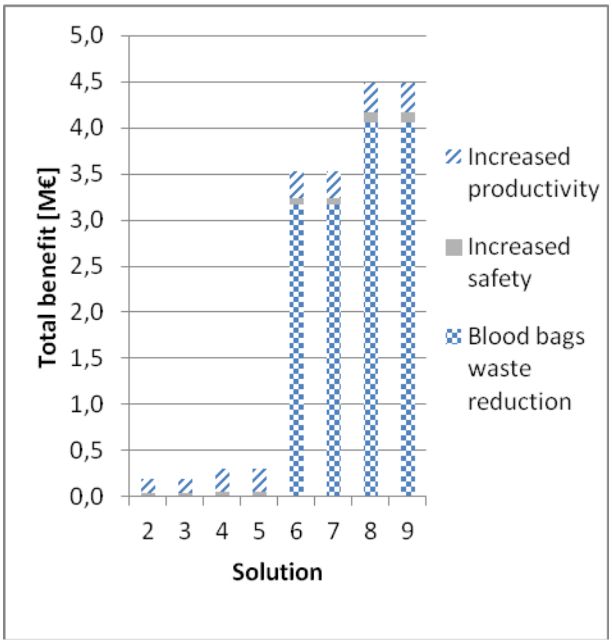

Figure 5 Total economic benefits subdivided in the 8 different solutions.

It is possible to observe that there exists a considerable disproportion between the economic benefit of reducing waste compared to the other two benefits considered: the gap is of an order of magnitude compared to the increase of productivity, and even of two orders in the case of the safety increase of clinical risk.
It also appears clearly that there is a strong imbalance in the economic benefits derived from the solutions of the first level and those with full implementation of RFID. In fact, although the bags have a very low and even insignificant value compared to the scale of compensation for mortality, their number is several orders of magnitude greater than the number of adverse events avoided. Instead, we can appreciate how in the solutions of the first level, the magnitude of the benefit of increased productivity prevails over the reduction in mortality.

After the quantification of all the benefits in monetary terms and of the costs of the various solutions, several indicators were calculated in order to assess the economic quality of the various investments.

5 RESULTS

On the basis of the benefits and costs calculated as described in the previous paragraphs, the calculation of the cash flows was performed, over the 15 years of life expected for the project and for the different solutions considered, thus forming the basis for the calculation of the economic indicators used in the economic analysis: NPV, ROR, Pay-Back Time (PBT) and benefit/cost ratio (B/C), all calculated at i=5%.
The results of the economic calculation are shown in the following summary Table IX, where for each year and for the different scenarios are reported the values of progressive discounted NPV. Table IX also shows the values of all the calculated economic indicators.

Table IX – Results of the economic analysis.

Economic Indicator	Year	Solution 2	3	4	5	6	7	8	9
NPV	0	-577.900	-613.800	-615.400	-613.800	-778.000	-812.400	-778.000	-812.400
	1	-620.695	-652.183	-652.876	-645.873	-579.378	-603.537	-513.345	-535.525
	2	-660.994	-688.325	-687.999	-675.895	-389.411	-403.908	-259.690	-270.339
	3	-698.940	-722.355	-720.909	-703.992	-207.703	-213.084	-16.565	-16.332
	4	-734.668	-754.394	-751.739	-730.279	-33.878	-30.658	216.479	226.982
	5	-768.307	-784.558	-780.614	-754.866	132.422	143.757	439.873	460.067
	6	-799.976	-812.953	-807.651	-777.856	291.538	310.530	654.027	683.369
	7	-829.789	-839.682	-832.962	-799.346	443.796	470.014	859.335	897.311
	8	-857.853	-864.841	-856.650	-819.428	589.505	622.542	1.056.174	1.102.300
	9	-884.269	-888.520	-878.813	-838.188	728.962	768.434	1.244.902	1.298.722
	10	-909.132	-910.804	-899.544	-855.707	862.448	907.992	1.425.864	1.486.947
	11	-932.531	-931.775	-918.930	-872.060	990.231	1.041.506	1.599.389	1.667.329
	12	-954.552	-951.507	-937.053	-887.320	1.112.567	1.169.251	1.765.793	1.840.207
	13	-975.273	-970.073	-953.989	-901.554	1.229.700	1.291.489	1.925.377	2.005.903
	14	-994.770	-987.539	-969.810	-914.825	1.341.862	1.408.469	2.078.428	2.164.726
	15	**-1.013.114**	**-1.003.970**	**-984.586**	**-927.192**	**1.449.276**	**1.520.431**	**2.225.223**	**2.316.971**
PBT		**> 15**	**> 15**	**> 15**	**> 15**	**4,19**	**4,17**	**3,07**	**3,06**
ROR		-	-	-	-	**26,41%**	**26,55%**	**35,98%**	**35,98%**
B/C		**0,16**	**0,16**	**0,23**	**0,24**	**1,70**	**1,76**	**1,98**	**2,07**

As can be noticed, positive values of the cash flows are obtained only for the solutions that implement RFID also in the 2nd level of the Blood Chain; vice versa the solutions that operate only on the 1st level result, from the economic point of view, are not advantageous.
This result is confirmed by the ROR indicator, which is defined only for the solutions 6-9, with higher values in the last two alternatives. The order of magnitude of the indicator ROR may appear high when compared with the classical values for the economic analyses of other investments; however, it is fully within the range of the CBA analysis of service companies. (see [10]).

Concerning the PBT, the solutions achieving the best performances are the 8 and 9; however, even 6 and 7, both with full RFID implementation, attain similar overall results. All solutions of 1st level instead are not able to guarantee a return on investment within the 15 years of the project life.
Finally, the most important indicator for the CBA, the B / C ratio, confirms what was above said and indicates solutions 8 and 9 as the most attractive, followed by the solutions 6 and 7, both valid in allowing B / C ratio higher than unit. All 1st level solutions instead fail to get B / C higher than unit, therefore no economically valid solutions result from the CBA analysis.
A better view of what has been said can be obtained from the Figure 6, in which the evolution of the various progressive VAN computed for the 8 solutions is represented.

The difference of economic attractiveness between the solutions of 1st and of 1st and 2nd level appears clearly; the main reason for this may be sought in the weight which the waste reduction has played in the calculation of benefits.
The Figure 6 also highlights significant differences between the RBC and ABP solutions in the case 1st+2nd level, and how the differences between the solutions of the first level are decidedly small.
Concerning the frequency of the RFID systems used, only for applications of 1st+2nd level there are, for the indicators calculated, appreciable differences between HF and UHF, with a slight (<10%) economic benefit to the latter frequency.

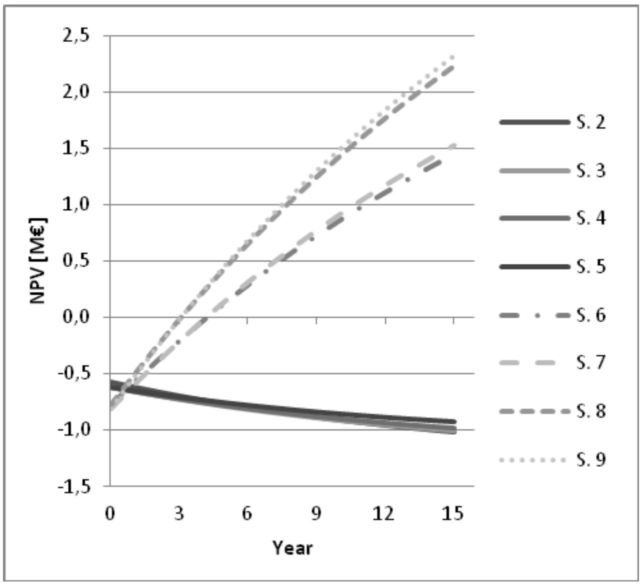

Figure 6 Progressive NPV trend.

In conclusion, the more attractive solutions are the 8 and 9 (both ABP), followed by 6 and 7 (RBC, always 1^{st} and 2^{nd} level); they give a cost-benefit result considerably greater than those of the first level, therefore a health investment should be focused towards complete implementations of RFID.

6 SENSITIVITY ANALYSIS

A sensitivity analysis was therefore carried out in order to test the robustness of the model; the parameters on which the analysis is based and their values are shown in table 10.

Table X – Summary of parameters considered in the sensitivity analysis.

				Standard value	Sensitivity analysis range
Discount rate				5%	0 - 7%
Blood bags waste reduction	1° & 2° level			3,50%	2,5 - 4,5%
Clinical risk reduction	1° level			45%	42,5 - 47,5%
	1° & 2° level			90%	85 - 95%
Tags cost	HF	Wristband	Initial cost	2 €	1,6 - 2,4 €
		Tag	Initial cost	0,20 €	0,16 - 0,24 €
		Barcode		0,01 €	-
	UHF	Wristband	Initial cost	1,80 €	1,44 - 2,16 €
		Tag	Initial cost	0,18 €	0,144 - 0,216 €
		Barcode		0,01 €	-

No variation range was selected for the barcode cost of acquisition, as this technology is now mature and settled.
In order to limit the number of graphs concerning the progressive NPV, only the results for the solutions 4 and 8, both HF solutions and ABP will be exposed, as representative of the alternatives 1^{st} and 1^{st} + 2^{nd} level.

6.1 DISCOUNT RATE

The discount rate trend is shown in Figures from 7 to 11, which show as it significantly modifies the economic output of the solutions. In particular, it remarkably alters the NPV which, as seen in the figure below, is reduced by more than half in solutions 6 and 7, while it is slightly lower in the solutions 8 and 9. The first level solutions results are less influenced; however, they have an opposite trend compared to the other four, as they increasingly reduce their negative economic result.

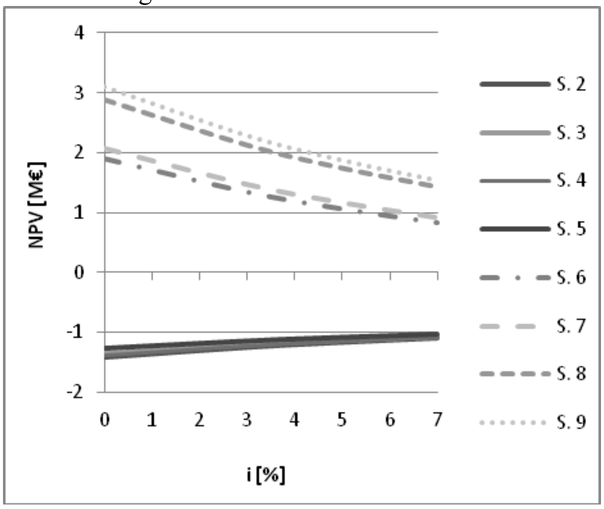

Figure 7 NPV vs. discount rate.

Concerning the PBT (Figure 8) it is possible to make reference only to solutions with a positive NPV; the time of return on investment grows of about one year in the case of solutions 6 and 7, and of about half a year for the other two. Therefore in the latter there is a strong NPV reduction, with a variation greater than that of the solutions 6 and 7 but for the PBT there is an increase slightly more limited (16% against about 23% of the 6 and 7).

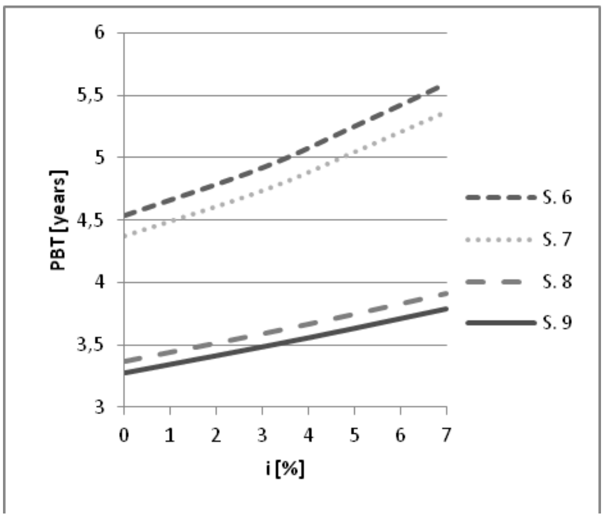

Figure 8 PBT vs. discount rate.

The benefit/cost ratio shown in

Figure shows a trend similar to the NPV, although this indicator is almost linear; there is a reduction of the B/C ratio with the growth of the discount rate. The reduction is almost null for the 1st level solutions.
Figures 10 and 11 show, respectively, the progressive NPV trend for solutions 4 and 8. The findings found in previous diagrams are confirmed. It can be noted how, in the case of solution 4, the increase of i results in a shift of the curves above the straight line corresponding to the case i = 0; vice versa, in the solution 8, the increase of i determines a progressive worsening of the economic result, as can be noted by the progressive distancing of the curves from linear solution below the straight line characterized by i = 0.

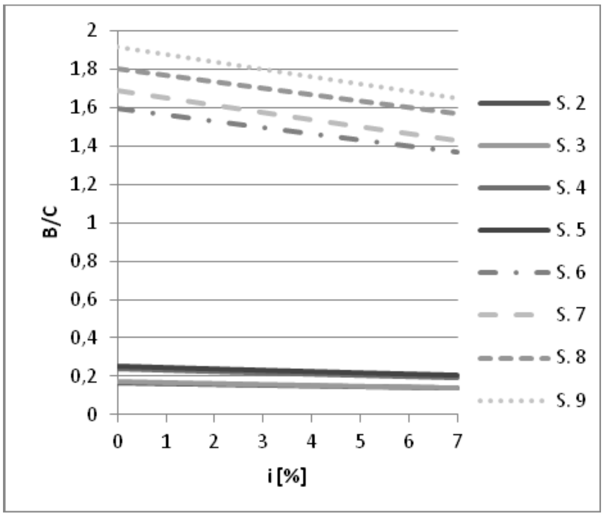

Figure 9 Costs/benefit ratio vs. discount rate.

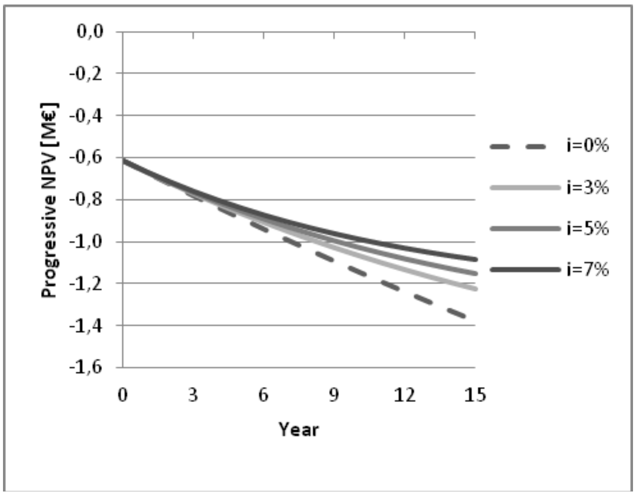

Figure 10 Progressive NPV trend vs. discount rate, solution 4.

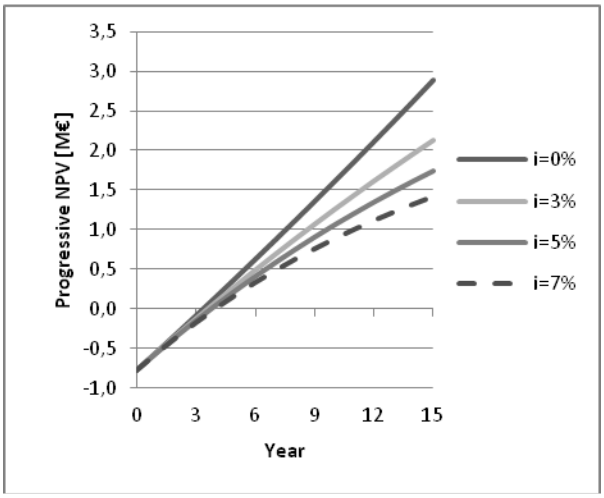

Figure 11 Progressive NPV trend vs. discount rate, solution 8.

6.2 WASTE REDUCTION

The variation of the coefficient employed for the waste reduction calculation has a significant effect on the economic results of the process model, as shown in
Figure 12; In fact, its increase greatly amplifies the NPV, with a divergence rewarding ABP solutions; obviously the sensitivity with this parameter affects only the alternatives providing for the reduction of waste (solutions from 6 to 9).
The PBT graph (Figure 13) shows, however, that there is a transition interval in which the economic result changes rapidly: progressing from low values to higher levels of waste reduction, it appears that at around 3% PBT starts to decrease less quickly, in particular for RBC solutions. Operating in the 2,5% to 3% range or even lower, the investment could show capital recovery times too high, with the solutions 6 and 7 quickly above the threshold of 15 years of the life of the project. However, it is in this range that the major variations in the economic performance in terms of PBP determined by the new technology occur.
It can also be noted that for values of waste reduction close to or above 4% the two types of frequencies, HF and UHF, lead to identical PBT results, while for the B/C indicator the UHF is still advantageous (see Figure 14).
In the field 3% ÷ 3,5%, both in the RBC and ABP case, the HF solutions show a slight advantage compared to UHF.
The ROR trend (Figure 15) leads to conclusions similar to what we saw in the PBT; there is a substantial equality of economic appeal between HF and UHF solutions, identifiable in the field over the threshold of 4% of waste reduction.
The B/C indicator confirms what related above for NPV.
The curves of progressive NPV as a function of the change in percentage of waste reduction (Figure 16) does not show changes in the shape of the curve, as was the case with the variation in the discount rate. The final NPV, however, grows significantly with the increase of waste reduction.

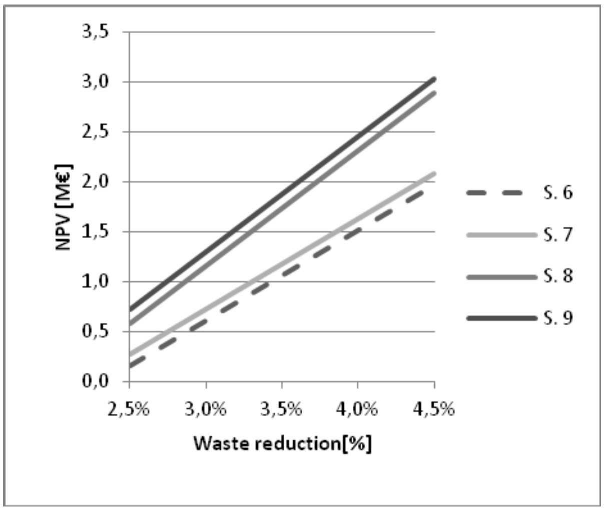

Figure 12 NPV vs. waste reduction.

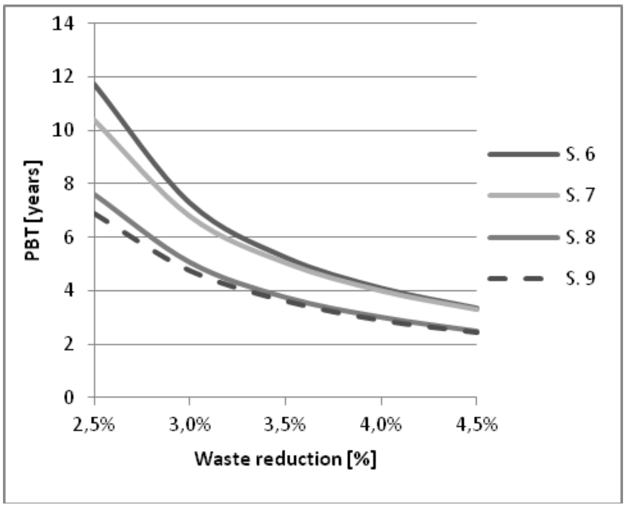

Figure 13 PBP vs. waste reduction.

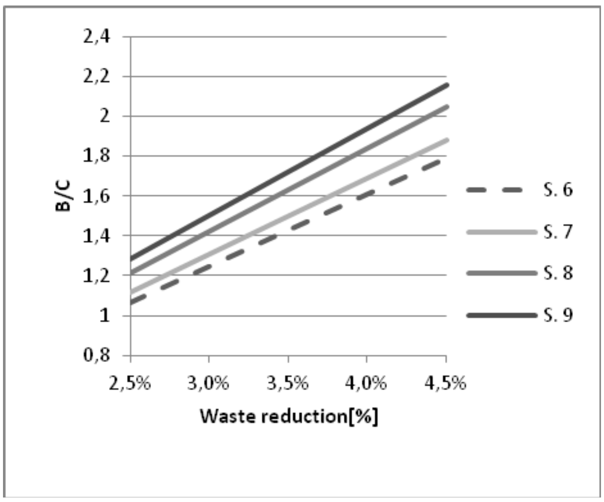

Figure 14 B/C Ratio vs. waste reduction.

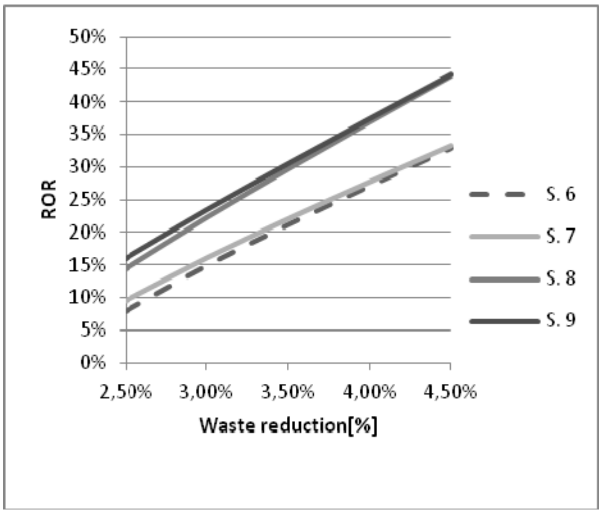

Figure 15 ROR vs. waste reduction.

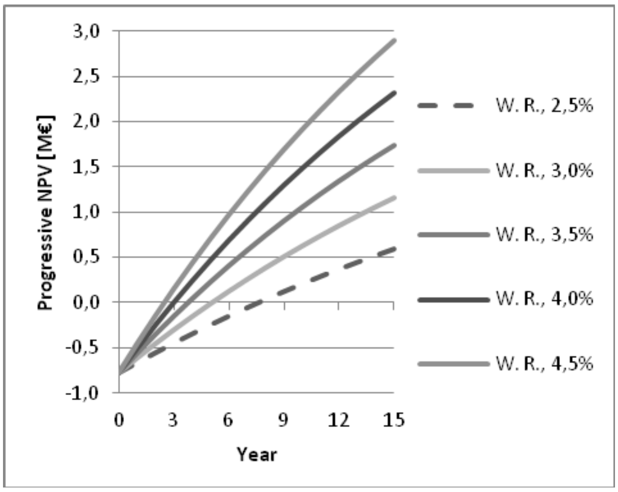

Figure 16 Progressive NPV vs. waste reduction (solution 8).

It can be concluded that the monitored parameter influences decisively the economic result. This is immediately verifiable in the same Figure 16, from which it is clear that both the PBT and the NPV go, respectively, from 8 to 2,5 years and from € 500.000 to almost € 3 million.

6.3 CLINICAL RISK REDUCTION

A variation in the efficacy of the clinical risk reduction, according to the model developed, determines very small and substantially constant changes in the economic results for the various solutions, as shown by the curves of Figures 17 and 18 (for this reason the results concerning ROR and B/C ratio were not reported).

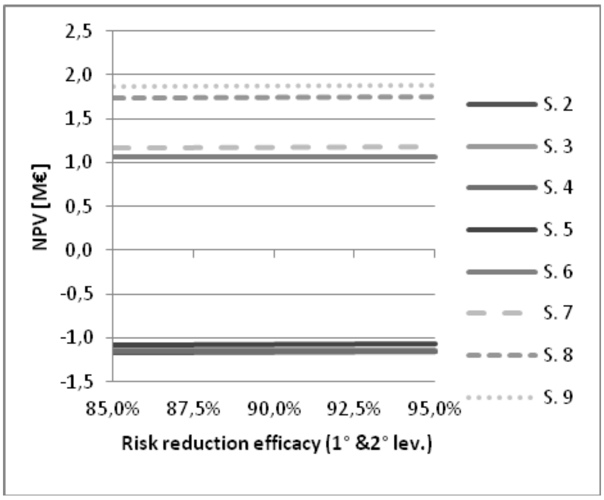

Figure 17 NPV vs. clinical risk reduction efficacy.

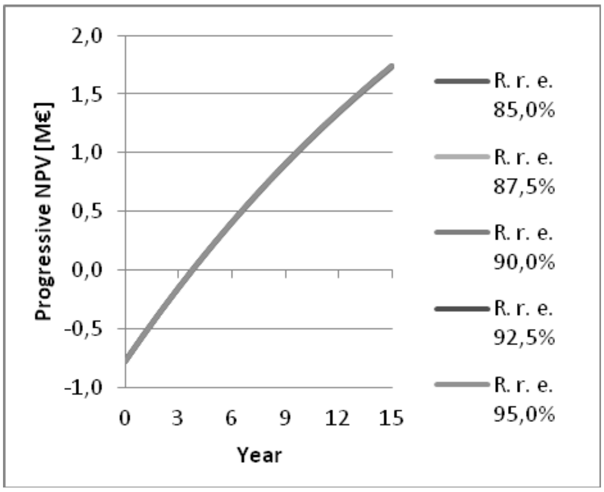

Figure 18 Progressive NPV vs. clinical risk reduction efficacy (solution 8).

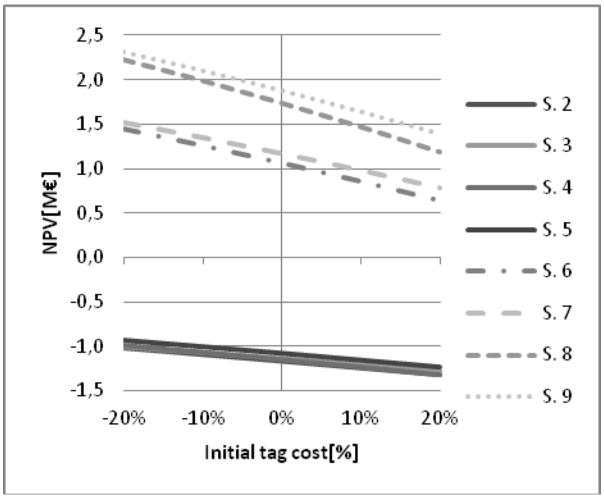

Figure 19 NPV vs. tag differential initial cost.

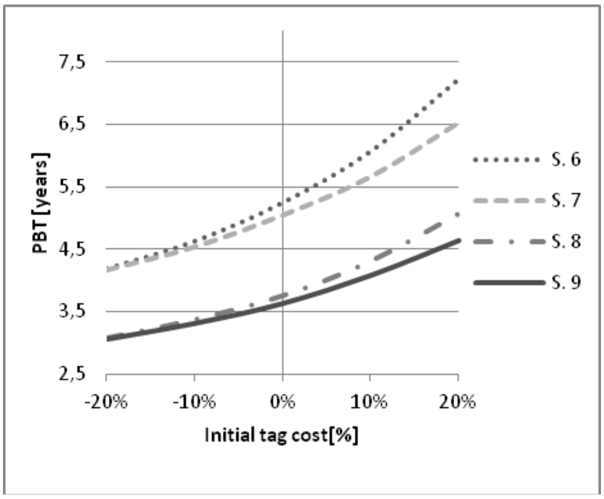

Figure 20 PBT vs. tag differential initial cost.

In particular, as progressive NPV is concerned (Figure 18), it does not allow to appreciate minimum variations in the trend of the various curves, which result substantially superimposed; therefore there are no changes in the solution PBT. As already shown in Figure 9 and related comments, this is substantially due to the fact that the benefit resulting from a reduction of clinical risk is, in strictly economic terms, about two orders of magnitude lower than the benefit of waste reduction of blood bags.

6.4 TAGS DIFFERENTIAL INITIAL COST

The fourth and final parameter considered in the sensitivity analysis was the tag differential initial cost compared to the "standard" case, analysed in Figure 19.

In this picture it is possible to see the trend of the NPV for each solution: it can be noticed that the cost of tags is crucial for the economic result in those alternatives requiring a large number of tags; the variation is in fact significant between the two extremes of -20% to 20% for the 1st and 2nd level.

For solutions with positive economic result it is interesting to note (Figure 20) the performance of the PBT; it can be noticed that the return time grows more for HF than for UHF frequency tags with increasing purchase price.

Concerning the B/C ratio (Figure 21), it was noted that the cost of the tag has a very limited influence over the economic output of the solutions of the 1st level, while appreciable changes occurs in those of 1st and 2nd level.

The convenience of UHF is also evident from the results obtained in the calculation of the ROR, as shown in Figure 22.

The cost of the tag also greatly influences all progressive VAN trends (Figures 23 and 24); therefore if they were readily available at a lower cost, the economic result will have a substantial improvement in all the alternatives.

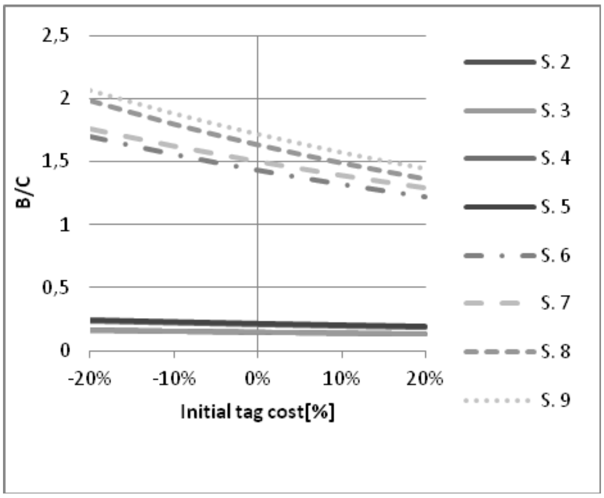

Figure 21 B/C Ratio vs. tag differential initial cost.

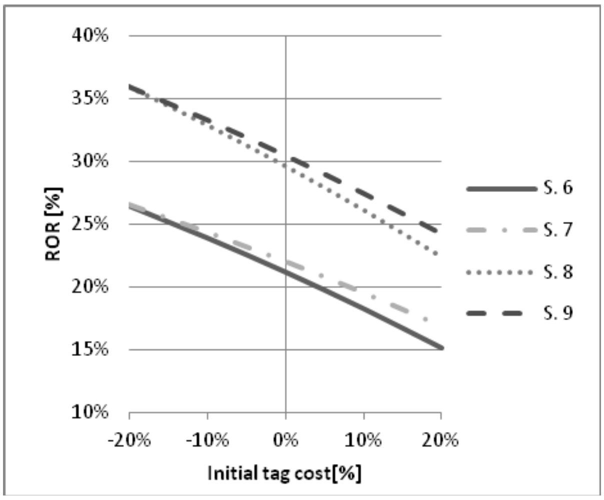

Figure 22 ROR vs. tag differential initial cost.

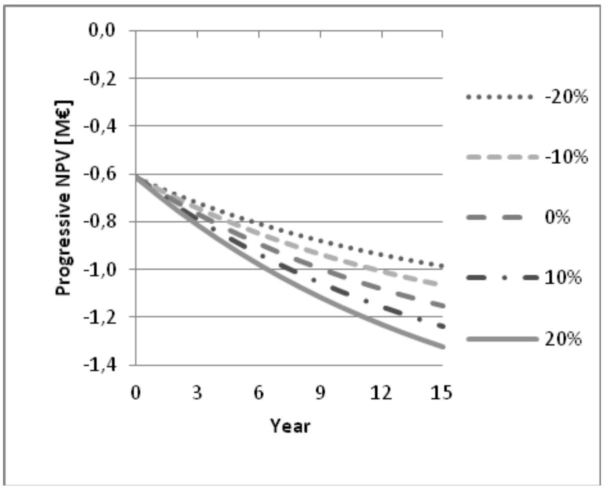

Figure 23 Progressive NPV vs. tag differential initial cost (solution 4).

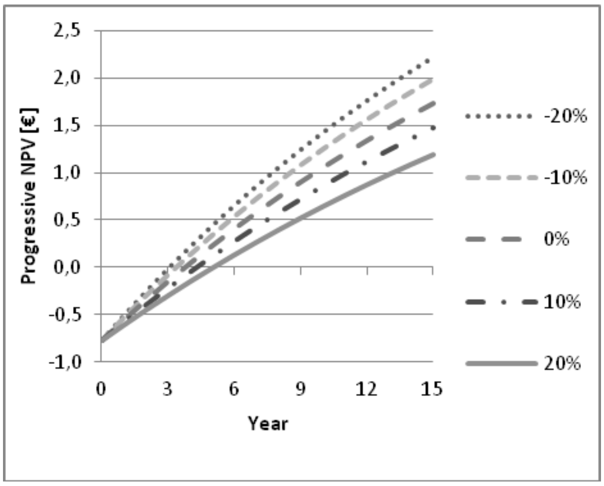

Figure 24 Progressive NPV vs. tag differential initial cost (solution 8).

7 CONCLUSIONS

The study performed has allowed to quantify the extent of the benefits that RFID technology is able to produce in the transfusion sector, from the point of view both of the patient safety and of the improvement of the process.
The cost-effective solutions have been identified in the solutions of 1st and 2nd level, with a fair margin for the solutions 8 and 9 compared to the only RBC solutions, which however are also fully acceptable for the economic sustainability.
The sensitivity analysis did not alter significantly the results obtained; it nevertheless allowed to show how the economic result is very sensitive to the variation of the bags waste reduction in the process and to the initial differential cost of the tag. In this sense, the choice between HF and UHF may fall on the latter frequency up to the limit case in which the cost of the tag is 15% higher than that assumed in this calculation as standard, and when the waste reduction is close to 2,5%.
A limited sensitivity of the model to clinical risk reduction was also noticed, the true primary objective in the use of RFID; as mentioned earlier, the reason may be sought in the limited impact that this benefit has in the global economy of the solutions addressed with the CBA method concerned.
From the results of the analysis it can be concluded that the most interesting solutions for RFID implementation, among these discussed in this study, are those requiring the extension of the RFID systems to the entire transfusion process, with management of all types of blood products used.
Although the benefit of the clinical risk reduction does not result economically viable in the CBA, the extension of the use of RFID for the management of the whole blood chain allows to fully compensate for this disadvantage. It is important to remember, however, that some RFID technology implementation risks, to be evaluated in an advanced stage of design were not considered in the analysis; they refer to organizational risks, related to public

opinion or operational difficulties, or due to unforeseen circumstances, etc.. A correct management set up is able to evaluate case by case the extent of these risks and operate accordingly.
From the point of view of the technology to be used, it has been finally highlighted, for some ranges of values of input parameters, a slight advance of the UHF frequency band over the HF; however, only a more detailed analysis on the particular case of use may indicate whether such convenience is able to compensate for the various additional difficulties that presently characterize such technology.

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