SIMULATION AS A DECISION SUPPORT TOOL
Estimating the Impacts of using RFID technologies within Biobanks

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Keywords: Discrete Event Dynamic Simulation, Decision Support, RFID, Healthcare, Biobanks.

Abstract: The costs and benefits of introducing auto-identification are difficult to evaluate. The Return On Investment (ROI) may be calculated on manufacturing environments but in some service providing systems, like hospitals, it may be very hard and inaccurate to judge the relevance of a new configuration only through financial considerations. New information and communication technologies and devices appear rapidly. This study aims at quantifying the benefits of introducing new devices at different levels in a complex socio-technical system: a biobank (storage, transformation and exchanges of biological samples) using a discrete event dynamic systems simulation model as a quality measurement tool. After introducing the context, we will describe pertinent measurement possibilities adapted to the Supply Chain for Health services, and particularly to biobanks, and the way we implemented the simulation model used to get the results summarized in the last section, before concluding. The originalities of this paper are the process modeling, designed to be easily modified to test many different configurations and scenarios, and the quality indicators that are particularly adapted to health services.

1 INTRODUCTION

New legislations in France force drug pedigree, advising to replace bar-codes by data-matrix[1] containing the use-by date and lot number. By doing so, counterfeit packages are more difficult to produce, since they will contain invalid data and thus can be detected at any checking point (invalid association between lot number and use-by date). The other main advantages are that the use-by date may be checked easily and it is then easier to identify and remove lots that are subject to a sanitary alert. The Activity Based Costing (ABC) principle will also be applied in French public hospitals, and may start to be effective from January 2009. At the same time, the United States are living their third malpractice crisis (Dalton et al., 2008), physicians struggle to acquire malpractice insurance when the reasons of malpractices are more systemic than individualistic. *MISTRALS*[2] is a consortium that aims at showing the advantages of using Radio Frequency IDentification (RFID) tags instead of (or in addition to) data-matrix or bar-codes in order to assess new traceability legislations, by preparing and deploying RFID solutions in biobanks and chemotherapy treatment services. One of the main points usually advanced for deploying RFID solutions at item-level is anti-counterfeiting. This point is very important in healthcare as wrong drug administration may have dramatic consequences. Admittedly, the memory size of an RFID tag allows notably a Unique IDentification number (UID) to be set for every product, and not only lot number, as with data-matrix. Counterfeiters will have to invest in these technologies and find the correct information to store in their products. But it is not the unique advantage of deploying RFID.
Iatrogenic incidents occur in more than 10% of

[1] Data-matrix is a two-dimensional bar-code arranged in rectangular patterns.

[2] Acronym for "Mutualisation Informatique des Systèmes Technologiques pour la Recherche phArmaceutique et La Santé", which could be translated as "Mutual IT systems use for pharmaceutical research and healthcare".

the French hospitalisations (Michel et al., 2003); ten years ago, these errors were responsible for as many casualties as if a Boeing 747 crashed every 2 days (Bonnabry, 2007). The "Swiss cheese model of system accidents" (Reason, 2000) is a revealing picture showing that serious medical errors are the result of the accumulation of incidents and security deficiencies that may have occurred, like a handwritten misreading, a wrong sample labelling, information transfer, a forgotten checking or any other subprocess. One fact is commonly admitted: humans make errors (Kohn et al., 2000). These items define as a hot topic the traceability of products and information in medical systems, the labelling of drugs and their packages, and how the hospital supply chains may be affected by using an identification technology or another. *MISTRALS* suggests that RFID devices are currently the best technology to answer these problems.

1.1 RFID Technologies

RFID is the generic acronym for Radio Frequency IDentification, regrouping all the frequency bands : from Low Frequency (125 kHz) to Super High Frequencies (5.8 GHz). The used radio frequency impacts the communication field and data transfer rate possibilities. The large utilization of RFID allows producers to lower tag prices and thus users to label items at a lower additional cost. The deployment of these technologies is eking out and the appearance of standards and protocols increases the possibilities of international exchanges and unique identification.
An RFID High Frequency (HF, 13.56 MHz) system works as follows: An RFID antenna sends electromagnetic waves that are captured by the RFID tag's antenna. These waves allow to empower the tag's chip which will modify the signal, and so the magnetic waves through. The reader's antenna decrypts the modifications applied and thus can obtain information imputed by the interrogated tag (Hedgepeth, 2007). The information are used for different purposes: simple display, statistics recorded for planning and scheduling, traceability, inventory management, order verification, quality control, and may be applied to many other domains as new applications appear at a very high rate. The new generations of RFID tags, readers and protocols allow to embed a large amount of data (a few kilobytes), multiple reading and writing, to plug sensors and even allow objects to communicate with each other.
The benefits of deploying a set of hardware (specific RFID readers and tags, sensors, ...) depend on the type and quality of the devices, the level of tagging, the use of the information read and the workflow modifications applied accordingly. This paper presents an approach and a tool designed for decision makers in healthcare. The tool could ideally replace or enhance numerous expensive pilot projects, by making decision makers model by themselves the structure they are responsible for and try to simulate different device sets and functioning scenarios.

1.2 Biobanks

Biobanks can be described as the storage, converting and handover of mainly human fast perishing, and potentially infectious samples. These samples are used for diagnosing, and for experiments associated to clinical and pharmaceutical research programs. Every sample has therefore to be associated to the information of the human it has been taken from, e.g. its phenotypic information or even the identification number of an hospitalised patient. We estimate that the activity of biobanks may increase in the next few years, because the number of cancer diseases is increasing as the French population is getting older, and some recent technologies and habits may be triggering factors. The number of handover requests may also increase because of new techniques like toxicogenomics, the using of progenitor cells and cordblood, and also the availability of on-line sample catalogs.
A generic description of the steps sustained by a biological sample (blood, marrow or organ part), from the sampling to the shipment for final users, has been made in collaboration between the two biobanks in *MISTRALS*: the Institute Paoli-Calmettes (*IPC*) in Marseille, and the CHU-CAL common biobank (*CHU-N*) in Nice. Six main steps were identified during a sample's life (Figure 1). The main processes that a biological sample undergoes are described in details in (Housseman et al., 2008a), where they are associated with improvements made possible thanks to different smart tags. Many technologies may improve those processes, from a qualitative (error avoidance) or a quantitative (automated processes mean less resources or more samples with the same resources) point of view. Various scenarios are possible for each hardware set, and a large number of materials exist and appear at a high rate. It is impossible to try out all these scenarios through pilot projects, and it would be very expensive, potentially risky and hardly extensible (Royston, 1999). This is why we work on a decision support tool based on discrete event simulation. The next section describes quality indicators adapted to biobanks and the specificities of the model we implemented.
As a first application, we will test out different ma-

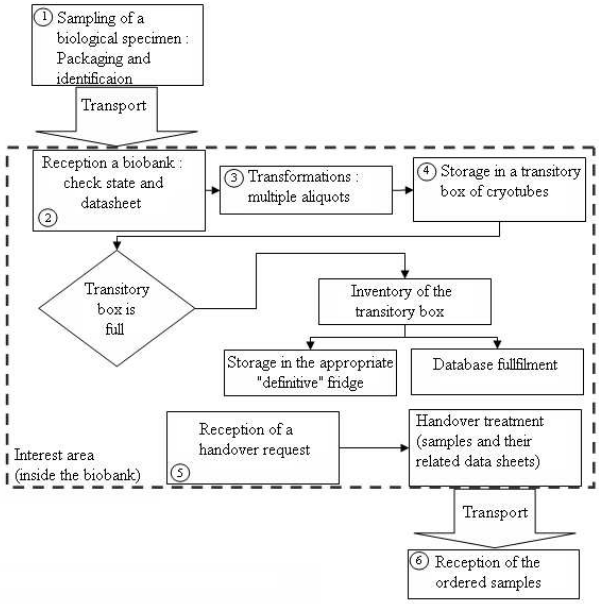

Figure 1: Biobanks macro-process chart.

terial scenarios in biobanks, including the integration of RFID tags to cryotubes and related improvements. The tool proposed to do so is based on Discrete Event Simulation for testing and 'marking' the scenarios. This choice follows from the fact that the studied system is a complex socio-technical system where errors may occur. The originality of this work lies in the modelling of a system that is positioned between inventory management and health delivery and the implementation of different materials and organizational scenarios including the so called 'smart tools' that radio-communicating devices are.

2 Simulation as a decision support tool

The tool we are presenting aims at allowing decision makers of healthcare supply chains to model the institute they are responsible for, and to try out many different hardware and organizational configurations according to appropriate indicators. Simulation is used to estimate the resulting performances. (Kleijnen, 2005) distinguishes four kinds of simulation that could be used for supply chain management and optimisation: spreadsheet simulation, system dynamics, discrete event dynamic systems (DEDS) and business (or management) games. The choice of using DEDS simulation to estimate the performances of the studied systems was headed by the fact that human modelling must be precise to consider some Performance Shaping Factors (PSF) and errors (Park and Lee, 2007), since most of the processes in healthcare are human, or include human compounds.

Errors result in the accumulation of incidents and missed verifications within modern health structures (Reason, 2000). This complex situation is an argument that led us to choose simulation to 'mark' the large number of scenarios we wish to compare to each other. One of the main difficulties in elaborating a simulation model is acquiring the related data; (Boginski et al., 2007) shows that RFID actually can be a good tool for doing so. Our work is cooperatively achieved with the IPC and the CHU-N; although the data are not direct outputs from their biobanks, they are validated as realistic by health professionals.
We chose to use the simulation software ARENA, described by (Law and Kelton, 2000) as a general purpose simulation software, because it allows the creation of customized modules and templates, and user friendly front ends. It can easily be connected with other softwares (Seppanen, 2000), which is useful to implement custom performance indicators.

2.1 Performance indicators

Evaluating the performance of a health service is a difficult topic (Minvielle et al., 2007). The main measures to consider when estimating the performances of an healthcare system are:

- Safety evaluation of patients and employees, including a hardware reliability part.
- Satisfaction of patients.
- Return on investment (ROI), related to financial considerations.
- Reluctance and/or understanding of employees.

The indicators we consider to be adapted to biobanks will now be detailed.
Variation on the number of errors that can potentially occur. To evaluate this variation, the model manages two databases having the same structure; the first one represents what actually happened (IRL), and the second one (IIS) contains the data of the information system (e.g. a set of paper sheets). By doing so, it is possible to see a virtual technician making an error, e.g. miswriting the place he stored an object. Then another technician will waste time trying to find this tube because he noticed the one he first took was not the good one, or will make a diagnosis error because he did not notice it. He might also be able to repair the IIS errors accordingly to the IRL database.
We can modulate the error probabilities of individuals by modifying their associated "education level", that is a multiplier of the error probabilities we assigned to every task, in order to perform sensitivity analysis. The IRL database also contains all the temperature modifications that the samples and cryotubes suffer

in order to be able to estimate if their states have been impacted. Unfortunately, we do not have data on how fast samples get damaged.

Improvements on the processing times. There are three processing times that have been aggregated into one: sample arrival to sample storage, sample arrival to update of information system and handover request reception to samples delivery. This indicator can be considered as part of the client and patient satisfaction. For experiments, long processing times may lead to the use of a damaged sample. Moreover, short processing times will help to complete a diagnosis before a pathology worsens.

Acceptance by employees of changes in their work. We believe that the more employees use their core competences, the more they feel useful and fulfilled. In other contexts than biobanks, this could help to improve the satisfaction of customers since health professionals such as nurses and physicians could spend more time with the patients.

Costs and Return On Investment. This is the main performance indicator when considering industrial investments. The previous indicators could possibly be reduced to their financial impacts, even if we consider that it is quite inaccurate to calculate a cost related to the death or infection of a human. We refer the reader to (Howard et al., 2005).

2.2 Model implementation

The model we implemented has been designed so it can be easily, or automatically, modified to run multiple scenarios including the introduction of communicating devices. This is why the modifications of information transfers are important. Our goal is to compare device configurations. This is why we use a spreadsheet file format, in which modified variables impacting process times and error probabilities define the "device part" of the scenarios. This file also contains travel times and workload information, including the transformation requests. Every process has been described using a set of three subprocesses: the "Medical act", the "Information asset", and the "Verification subprocess". The functions and uses of these subprocesses are more precisely described in (Housseman et al., 2008b).

Human resources are modelled as simply as possible, knowing the states 'Available', 'Busy' and 'Unreachable'. We implemented a basic PSF that is the visible queue length; we considered that an amount of 5 visible awaiting jobs improves the error rate of 7% of its basic value. Other dysfunctions than human failures should be added, such as a network crash, or electromagnetic interferences between the RFID readers and the machines, that can make some material configurations impossible or dangerous (Togt et al., 2008).

The following section describes the studied scenarios, and presents computational results using the model and indicators listed in the previous section.

3 Case study

The model described in Figure 1 has been implemented, from Step (2) to Step (5). Step (1) and (6) are not precisely modeled. We assume that there is no patient misidentification in the first step, and that the data sheets are sent with the samples.

The following scenarios have been tested:

- ***"Current scenario"*** (Curr.Scenar), where paper sheets are associated to samples.
- ***"RNA Automation"*** (RNA Auto.), where we added a RNA extraction machine, since it is currently happening at the IPC. This machine will be installed in the room where the other transformations happen, while the manual extraction was taking place in another room at another floor, and so the transportation included a time to wear the mobcap, white coat and shoe covers, and wash hands.
- ***"Smart cryotubes and pen-size antenna"***(RFID & penRder), where the data sheet is accessible from the RFID label, and the information is written in the database without the need of a manual copy of the information in the Information System. The pen-size antenna allows for the inventory of boxes by pointing all the cryotubes, one after the other. We estimated that the average time needed is reduced from 24 to 8 minutes, and uses only one human resource instead of two.
- ***"Matrix reader's antenna"*** (RFID & 2DRdr), which consists of adding a particular antenna, that allows for the inventory of a whole box of cryotubes recognizing their position automatically. The time needed for inventorying a box using this device is set to 2 minutes.

The time between arrivals are exponentially distributed. The opening hours include a *rush time*, i.e. a time period during which the arrivals mean are 1.6 times larger than during the rest of the day. These values are set so the overall mean is the total number of incoming samples divided by the number of hours the IPC is opened yearly. The "Transformation" protocols implemented are the DNA and RNA extractions, white-cells (that are a part of the previous ones), blood serum, plasma, and viable cells. Some of these protocols are different whether the arriving sample is blood or marrow.

Table 1: Average results after 20 replications of each scenario and education level.

Scenario Name (*Ed.Level*)	Inv. error	Comp. error
Curr.Scenar(2)	1.350%	0.546%
Curr.Scenar(1)	2.600%	0.960%
Curr.Scenar(0.5)	5.935%	2.260%
RNA Auto.(2)	1.663%	0.510%
RNA Auto.(1)	2.866%	1.202%
RNA Auto.(0.5)	5.049%	2.250%
RFID & penRder(2)	0.000%	0.004%
RFID & penRder(1)	0.000%	0.008%
RFID & penRder(0.5)	0.000%	0.028%
RFID & 2DRdr (2)	0.000%	0.013%
RFID & 2DRdr (1)	0.000%	0.016%
RFID & 2DRdr (0.5)	0.000%	0.028%

The processing times of the transformation have been implemented using the data at IPC. In order to estimate the different error rates, we inventoried a few boxes randomly chosen within the stock. The results of this study are still subject to confidentiality and relevancy studies, so our simulations use estimated values.

The basic probability of making an error computerizing a data file by hand is set to 1.1%. This rate corresponds to the 11% of the probability of retranscription error, which is fixed to 10%, as reported by (Marcellis-Warin, 2003). This error probability is reduced to 0.01% when tubes are tagged.

The probability that an error occurs during the inventorying of a full box of cryotubes is set to 3% when it is done by hand, which is an estimated value fixed after discussing the results of (Garnerin et al., 2007). This value has been set to 0.1% if the employees have an RFID pen size antenna to perform the inventory. These assumed probabilities are divided by the employees "education level", that reduces the importance of having very acute values. This "education level" is the same for all the employees during a replication of the simulation. The values of the "education level" are 0.5, 1, and 2.

3.1 Results

The scenarios described above have been tested through 1.5 month of work. Twenty replications of the four material scenarios were ran for each of the three "education levels" of employees. The results shown in Table 1 summarize the observed percentages of the inventory errors ("Inv. error") and computerization errors ("Comp. error"). The number in parenthesis corresponds to the *"education level"*. Table 2 shows indicators that are, within this simulation, not impacted by the "education level" of the human resources. The results correspond to the proportional value gained compared with the first scenario (Curr.Scenar). These indicators are:

Table 2: Average proportional time and gains on human resource after 20 replications of each scenario.

Scenario Name	Human utilization	Troughput time
Curr.Scenar	0.000%	0.000%
RNA Auto.	10.560%	2.788%
RFID & penRder	36.400%	16.574%
RFID & 2DRdr	38.050%	16.648%

- the percentage of time gained between the arriving of a new sample and the time when it's information has been computerized (*Throughput time*). The throughput time is an interdisciplinary performance indicator, which in our case study could make a patient obtaining his analysis results faster and its potential illness be taken care earlier.
- the proportion of human resources gained (*Human utilization*).

The initial value, corresponding to *Curr.Scenar*, for the proportion of seized human resource utilization is 50.46%, which seems right considering that the employees also spend some of their free time working for a different service and that the amount of work to do depends on the arrivals, that are not constant. The worst scenario corresponds to *Curr.Scenar*; the results in Table 2 are the percentage of improvement compared with this scenario.

The average number of arriving samples is about 800; and the average number of information sheets computerized is 1208, including an average value of 33.2 full boxes (and so box inventories). Table 1 shows that the "education level" has a high impact on the number of errors for the scenarios *Curr.Scenar* and *RNA Auto.*. RFID technologies remove many critical processes like handwriting and manual computerizations, so the "education level" has less impact for the two scenarios including auto-ID.

Table 2 shows that the proportion of used resources is reduced by 10.56% when adding the RNA automation within the biobank, because the RNA extraction needs less human intervention and the time needed to transport the samples to the place where this transformation takes place is highly reduced as soon as the automation is in the same clean area. The gains related to RFID technologies are very large. The saved time is mainly composed of computerization, handwriting and bringing information leafs. The job of the technicians would consist of tasks that are more

specific to their core competences. As mentioned in Section 3.1, we believe this is an indicator of the employee welfare. The difference between the use of a pen reader or a matrix antenna is small. Thus, using the matrix antenna would at first require to compare the earnings with the cost of such a device. On the other hand, the use of a 2D position reading antenna could help to reorganize boxes when performing inventories, thus leading to potential large savings.
Our results do not include a financial part yet for two reasons. First, the costs of emerging technologies decrease quickly with the increase of their use. Second, the market for tagged cryotubes and matrix readers is not very large, so the prices are not stabilized yet.

4 CONCLUSIONS

In this paper, we address the impact of RFID technologies in a specific healthcare application using Discrete Event Dynamic Systems (DEDS) simulation used as a decision support system. Our study helps to quantify the benefits of integrating new auto-ID technologies and devices at different levels of a biobank. The results show that auto-ID technologies may considerably improve the performances of the biobank when taking into account the percentages of errors as well as the reduction of resource uses and processing times as performance indicators. We still have data to analyze in order to configure the simulation and validate the relevance of some of our assumptions. This part of our work should be possible only after the pilot results have been observed for a long enough time period so they are stabilized.
The proposed model should allow us to model other biobanks and/or material configurations quite quickly, including organ sample arrivals. This can be made using the same basic model file and only modifying the specific configuration file. A graphical user interface could allow biobanks managers to model themselves their biobank. These types of tools could be very helpful when auditing and expertizing structures that must adopt new technologies because of new legislations.

ACKNOWLEDGEMENTS

This study is partially financed by the *Conseil Général 13* of the *Bouches du Rhône*, the MISTRALS project is funded by the MINEFE, French Ministry of Industry, Economy and Employment.
The authors gratefully thank all the collaborators of the MISTRALS project who always answered quickly and carefully to our questions, and particularly Lise-Marie Daufresne, from the IPC, and Olivier Bordonne from the CHU-N.

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