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A Multi Agent System Model for Evaluating Quality Service of Clinical Engineering Department

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Abstract— **Biomedical technology is strategically important to the operational effectiveness of healthcare facilities. As a consequence, clinical engineers have become an essential figure in hospital environment: their role in maintenance, support, evaluation, integration, assessment of new, advanced and complex technologies in point of view of patient safety and cost reduction is become inalienable. For this reason, nations have begun to establish Clinical Engineering Department, but, unfortunately, in a very diversified and fragmented way. So, a tool able to evaluate and improve the quality of current services is needed. Hence, this work builds a model that acts as a reference tool in order to assess the quality of an existing Clinical Engineering Department, underlining its defaulting aspects and suggesting improvements.**

I. Introduction

The advances in technology in the 30 years from 1960 through 1990 were so significant that hospitals found themselves on a continual equipment "buying spree", leading technologies to a rapid development and to migrate into the mainstream of clinical practice. At the beginning, instruments were definitively simpler than today, however their ability to auto-detect failures was small requiring essentially an electrical safety management. Then, the performances and the potentialities of technology increased dramatically and this change significantly affected biomedical instrumentation. Medical devices became more sophisticated and safer, and the number of devices also increased. Testing electrical safety turned into one of the activities, and the principal problems became to correctly manage the devices maintenance, to purchase the most suitable instrument, to plan device substitutions, to ensure the correct functioning of the instruments, and to guarantee the availability of critical devices every time they are needed. In this context, a figure able to manage technologies in all of their aspects (purchase of new devices, maintenance, electrical safety, etc.) had become fundamental, leading, in 1992, the American College of Clinical Engineering to recognize this role into a formal definition: a clinical engineer is "a professional who supports and advances patient care by applying engineering and managerial skills to health care technology"[1]. With the turn of the century, driven by the rise of information technology in healthcare, clinical engineers have become even an essential figure in hospital environment: their role in maintenance, support, evaluation, integration, assessment of new, advanced and complex technologies in point of view of patient safety and cost reduction is become much more inalienable [2]. Since it is now universally accepted that to assure patient safety medical devices must be correctly managed and used, and that the quality of healthcare delivery is related to the suitability of the available technology, nations have begun to establish Clinical Engineering (CE) Department. Unfortunately, this establishment has been managed in such a different ways that the CE survey is actually fragmented and diversified. For these reasons, there is the need to develop a tool for evaluating and improving the quality of the current services offered by existing CE Departments, targeting patient safety improvement and cost reduction.

Our work responds exactly to this need: building a model that acts as a reference tool in order to assess the quality of an existing CE Department, underlining its defaulting aspects and suggesting improvements. For this aim, a detailed description of basic activities for a CE Department was provided. Then, workflow diagrams were built to analyze and describe each activity. Finally, collecting all information previously detailed, a Multi Agent System (MAS) based model was designed and implemented in order to simulate a CE Department in all of its features: people involved, activities, time scheduling, and so on. In this way, using inputs that characterized the situation we wanted to study, it was possible to analyze the real situation in order to highlight drawbacks and to suggest improvements. Moreover, this work provides a new and efficient way to handle and to simulate the complexity occurring in a system with interacting processes, structures and people like a Clinical Engineering Department.

II. MODEL DEVELOPMENT

A. A model of a CE Department

Firstly, all activities carried on by CE Department were listed. All possible activities were divided basically into two classes: the first class contains the basics or core activities, i.e. activities that are inalienable for a CE Department (Table I); while the second one includes activities that are still important but not core, like health technology assessment, medical informatics, and risk management.

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After listing all activities, it was necessary to identify the main people involved into execution of those activities: essentially clinical engineers (*CEs*) and biomedical equipment technicians (*BMETs*) (Table I). By now, any difference of skills and specializations among *CEs* was supposed, while *BMETs* could be specialized in particular subgroups (as *BMETs* for maintenance or responsible of call-center activity).

TABLE I
CORE ACTIVITIES AND RESPONSIBLE AGENTS

Core activities	**Agents**
CE Department management	*CE*
Acquisition Procedure	*CE*
Safety and preventive maintenance testing	*CE, BMET*
Critical technologies management	*CE, BMET*
Inventory management	*BMET*
Maintenance procedures	*CE, BMET*
Users formation	*BMET*

The last question to be faced for the next modelling steps was to indentify variables able to describe a healthcare facility in its complexity. For this reason, parameters regarding the structure, the organization and the technological equipment were chosen (Table II).

TABLE II
INPUT PARAMETERS

Inputs
Total number of Technologies
Number of Technologies subject to Direct Management
Number of Technologies in hospital with Emergency Unit
Number of technologies in hospital without Emergency Unit
Number of speciality in hospital
Number of university department
Number of Hospital with Emergency Unit
Number of Clinical Engineer
Number of Biomedical Equipment Technician

B. *Workflow Diagrams*

A workflow is a set of activities that are ordered according to procedural rules to deliver a service. An instance of a workflow is called a case. In general, two important dimensions of workflows are the control-flow dimension and the resource dimension [3,4]. The control-flow dimension concerns the ordering of activities (or tasks) in time (what has to be done). The resource dimension concerns the organisational structure (who has to do it). Workflow diagrams were built for each basic activity, specifying cases, tasks, ordering and involved actors. The language chosen for the description of those diagrams was Petri nets [5-8], since they can be used for analyzing concurrency between processes, precedence relations amongst events or the existence of appropriate synchronization, and, above all, for measuring the performance of the underlying system. Graphically, Petri nets are described as a diagram with circles (places), bars or squares (transitions) and arrows (arcs) connecting them. Places can represent conditions (input/output data or resources) while transitions can be interpreted as events, tasks or clauses. Places can have multiple arcs from and to transitions and transitions can have multiple arcs from and to places. A place can hold one or more tokens, symbolized by one or more dots. Depending on the interpretation given to places, a token can represent resources or whether a condition is true or false. Hierarchical structuring is also permitted spreading nets across separate diagrams and maintaining simple diagram.

An example of a basic activity described through Petri nets objects (places, transitions, and arcs) is reported in fig. 1. The acquisition procedure was constituted by different tasks, such as the analysis of effective needs of healthcare facility, the definition of a plan for the acquisition, the definition of specifications for the technology and so on. These tasks were represented by white squares transitions. The double square transition indicated a hierarchical structure stating for another Petri net that described the different procedures followed depending on the acquisition cost. The results of all these actions were the passive parts of the model represented by the blue circles places. The arrows connected places to transitions, while the purple circles indicated the human intervention.

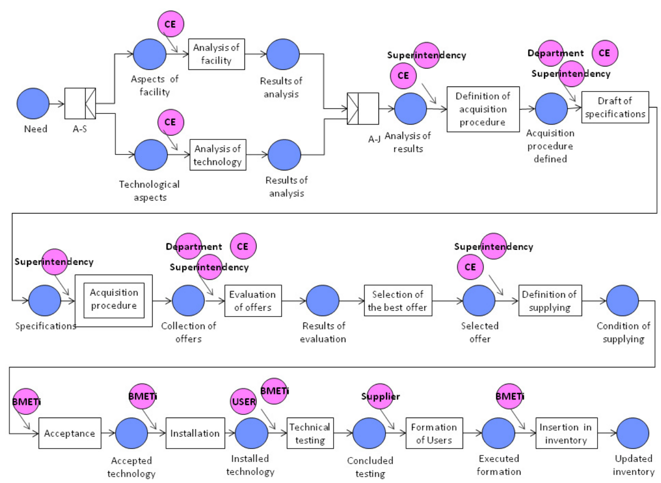

Fig. 1. Workflow diagram using Petri net of acquisition core activity.

C. *Multi Agent System model*

Hence, knowing basic processes occurring in core activities, required inputs, involved people, external facts that influenced that processes, a general *in silico* CE Department was model using a Multi Agent System (MAS) approach [9]. Briefly, agents are persistent active entities that can perceive, reason, and act in their environment, and communicate with other agents. Often, the agents are autonomous, intelligent, and sociable, forming multi agent systems. Agents are autonomous, but in order to form and participate in multi agent systems, they must be able to compromise on their autonomy somewhat just so they can coordinate with others. The agents in a multi agent system could often be heterogeneous.

Two groups of discrete agents with acronym names represented people involved in core activities: *CE* and *BMET*. Each group could have a cardinality equal to or greater than 1, depending on the simulated scenario. Like real person, each agent was able to perform specified activities (Table I), to communicate with other agents, to take some day off for vacation or for illness. Moreover, each agent was characterized by a number of hours that he could daily work, and a number of overtime that he could use for completing exceeding works. The amount of these numbers depended on employment contracts.

ACTIVITIES were passive objects, each of them characterized by a calendar that indicated, in a probabilistic manner, when a specific activity occurred over one year and the hours that each single work required to be completed. Moreover, a priority list was compiled in order to complete the activities on the basis of their urgency.

Inserting a series of inputs (Table II) that characterized a specific healthcare facility, the simulation of the corresponding *in silico* CE Department started covering one year. The simulation outputs were showed through an opportune interface and a summary of which activities were not completed within a reasonable time. In this way, an evaluation of quality service essentially in terms of completed/not completed activities, answer delays to customer requests, mean overtime, was given.

The design of the model and the simulation was performed using NetLogo (http://ccl.northwestern.edu/netlogo/).

III. RESULTS

The simulation covered 365 days. Briefly, the user inserted the input parameters and he/she defined also the number of CE and BMET. After that, the simulation started. At the beginning, the starting time of every activity and the hours amount necessary for completing that activity were scheduled in a stochastic way. In this way, each day, a certain random number of events related to the different activities occurred. Graphically, this was rendered by the creation of different bars formed by coloured patches in Netlogo (fig. 2,3). The height of each bar was proportional to the number of hours necessary to complete the corresponding activity. During the simulation, the agents went on those bars and reduced the amount of coloured patches, i.e. the amount of hours. In so doing, agents filled their daily working time, that was 7 hours and 21 minutes (as the local employment contract regulates). If, at the end of the day, some patches of one or more activities still remained, i.e. one or more activities were not concluded, those remaining patches were rescheduled the day after and overtime started to be counted, At the end of simulation, a report summarizing the number of completed/not completed activities, overtime of each agent, waiting time for each request, and so on, was generated.

The initial step was a validation phase that indicated this model as a good representation of a CE Department. Using input data from local healthcare facilities, in fact, it was possible to test the model on well-defined scenarios. The subsequent step was to apply the model to Clinical Engineering Departments of 16 local facilities evaluating, in so doing, their quality. In most cases, the quality level was found low, especially due to the work generated by the maintenance and acquisition processes. The model was also able to highlight the cause of this low quality. The manpower shortage was found to be the main cause of those situations. For example, the simulation of the same healthcare facility with different number of *CE* and *BMET* agents led to a very different results. Fig. 2, represents the current real situation, while fig. 3 represents the ideal one. The little icons stand for agents in their specializations (such as the phone represents *BMET* responsible for call-center activity). It is clear how the current situation (fig. 2) is characterized by some activities overloads, i.e. remaining patches that have to be rescheduled the next day. In this case, increasing the *CE* agents of 1 unit and *BMET* of 2 units, the situation becomes more manageable, as it can be easily seen through the reduced bars in fig. 3, even if in that precise moment (30° tick) one *CE* is off for illness.

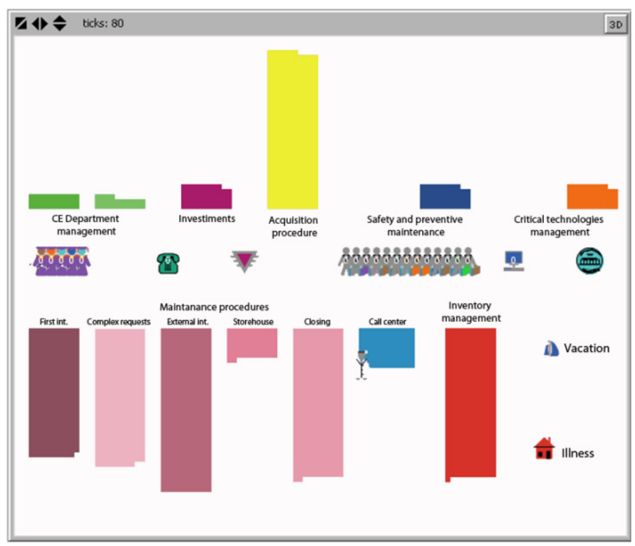

Fig. 2. Simulation of the CE Department of a local healthcare facility: current situation.

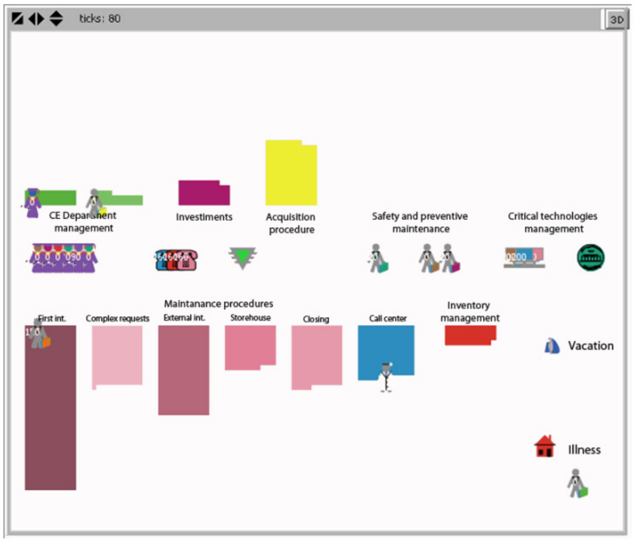

Fig. 3. Simulation of the CE Department of a local healthcare facility: ideal situation obtained from the current one (fig. 2) increasing CE agents of 1 unit and BMET agents of 2 units.

In a more formal way, comparing the mean daily overtime and the number of events/works not completed in a reasonable time for both situation (Table III), it is clear how the real situation is far from a higher quality of the service employing 3 people more.

TABLE III
COMPARISON BETWEEN REAL AND IDEAL SITUATION

Agent	Current real situation		Ideal situation	
	Mean daily overtime	Not completed events	Mean daily overtime	Not completed events
CE	1h 30’	257	19’	33
BMET	1h 40’	257	40’	84

IV. CONCLUSION

The initial testing allow us to believe that the model can be a suitable tool for evaluating the quality level of any Clinical Engineering Department. Modelling and analysis by using workflow technology can standardize processes, find the unreasonable links, optimize and reorganize the process. Moreover, the simulation through a MAS approach allows to identify in a very immediate way the drawbacks of the current situation.

This is only the first step to guide clinical engineers to apply basic quality principles in their work, such as having the right people doing the right thing at the right time, understanding how their work can best contribute to improved quality of care.

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