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Implementing simulation–based approaches for healthcare workflow analysis

The Case of a Department of Laboratory Medicine in South Italy

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***Abstract*—The Discrete Event Simulation (DES) approach has become a popular technique for problem solving in healthcare, as it provides a very realistic picture of the actual system. A simulation–based operational paradigm by means of the SIMUL8 software suite was implemented in the Department of Laboratory Medicine (DLM) of the "San Paolo" Hospital in Naples (Italy), as support of the Business Process Management (BPM) methodology, to analyse and improve the performances the current working performances.**

***Keywords*—Healthcare Management; Performance Evaluation; Discrete event simulation; business process management; department of laboratory medicine**

I. Introduction

Italian healthcare organizations operate in a dynamic context and need new systems, along with those from classical management control, to reproduce, as accurately as possible, the behaviour of a complex structure, in order to provide useful real-time indicators to improve the quality of the current working dynamics [1].

The use of simulations [2][3] allows to: (i) analysing, from different points of view, the "key performance indexes" (KPIs) through which the behaviour and the characteristics of the actual process (As-Is) are set forth [4], by means of a specific "simulation time" (faster than real time); (ii) evaluating the same KPIs under different operating conditions [5][6][7], in order to get the most likely response of the system in response to induced external changes, in order to improve its business process capacity.

II. Methods

A. *Business Process Management*

The business process management (BPM) [8] is a technique used to create, organize, manage and improve the business processes of a company, with the aim of creating a process geared to make efficient and effective business. The concept of BPM is achieved through the ability to analyse, manage and adapt in real-time mode a set of business operations, IT applications and people, according to a structured sequence of phases, to achieve a common goal; deploying a DES-based simulation system makes thus possible to both represent the real system from different points of view, and to analyse the behaviour and the characteristics of this system. The model so obtained is a representation of the reality built to answer specific questions, in a time faster than real, and its study leads eventually to solutions whose reliability increases with the accuracy of the model itself.

B. *Discrete Event Simulatinon*

The discrete event simulation (DES) [9][10][11] is a simulation technique developed in the 1960s as part of industrial engineering and operations research dynamics, aimed at analysing and improving business processes. The use of simulation techniques has rapidly grown in recent years in the health sector, especially as for:

- patient-flow management;
- management of resources and correlated activities.

C. *Workflow Analysis and Model Design*

The analysis conducted at the Department of Laboratory Medicine (DLM) of the "San Paolo" Hospital in Naples (Italy) aimed in the first place at defining the necessary KPIs to understand how the system evolves over time, and what the responses to changes of the environment can be. KPIs were categorized into: *Quali-Quantitative* (e.g. Number of Completed Jobs); *Timing* (e.g. Average Time in System); *Cost* (e.g. Costs per Exam). Table 1 shows DLM's working activities, along with the necessary resources to be tested. The Routine/Non-Urgent activities were organized on a single daily shift of 6 hours, for 7 days per week.

The data about the actual system were obtained through: (i) information stored in databases; (ii) information coming out from direct observations of the workflow; (iii) information obtained through the interviews submitted to the staff. Figure 1 shows the main workflow inside the DLM.

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TABLE I. ORGANIZATION OF THE DLM WORKING ACTIVITIES AND RESOURCES

Type of Activities	*Section Name*	*Resource Type*	*Role*	*Working Activities*	*# Resources*
Routine Activities/ Non-Urgent activities	Clinical Chemistry (CC)	techn_cc	Technician	Clinical chemistry tests	3
		doctor_cc	Doctor	Clinical chemistry tests	2
	Bacteriology (BA)	techn_ba	Technician	Bacteriology tests	2
		doctor_ba	Doctor	Bacteriology tests	3
	Serology (SI)	doctor_si	Doctor	Serology tests	1
	Hormones Section (SO)	doctor_so	Doctor	Hormones tests	2
	Allergy (AL)	doctor_al	Doctor	Allergy tests	1
	QPE Section (QP)	techn_qp	Technician	Serum Electrophoresis tests	1
		doctor_qp	Doctor	Serum Electrophoresis tests	2

D. *Model Analysis*

The simulation model was built by using the SIMUL8 software suite [8], which gives a realistic perspective of the current working conditions. To accomplish the research purposes, a two-step validation of the model was conducted, both formal (software debugging) and structural (comparison between the behaviour of the actual system and the simulated model). The As-Is analysis displayed information as for the considered KPIs in terms of (among the others): resource cost per minute; cost of human resources; number of activities/exams performed; average timing.

The following What-If analysis was set up after a preliminary confrontation with the actors involved in the study, so that two scenarios were defined, that did not imply any modification of the existing workflows:

- Scenario #1: increase of the number of exams (input requests).
- Scenario #2: increase of the number of exams and addition of a new resource (a technician).

The main findings, as for both As-Is and What-If analyses, are showed in the next paragraph.

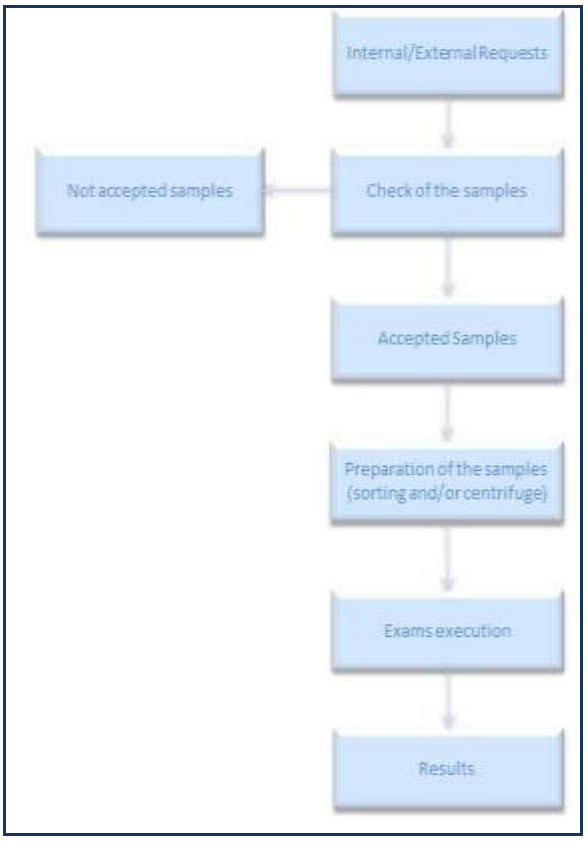

Figure 1: Workflow of the DLM

E. *Validation of the Model*

The model created with the SIMUL8 software was validated by means of a two-step method, articulated in: (i) formal validation; (ii) structural validation.

The formal validation consisted in the evaluation of the architectural characteristics of the simulated model as well as the computing code used to implement it; this type of validation can sometimes be called "software debugging". In the structural validation the behaviours of the actual system and the simulated model were compared, through the execution of two different types of check:

1) *Open Box Validation*: the model was shown to all the operators of the structure, who verified its functioning, in particular:

- Medical Directors;
- Biologist Managers;
- Lab Technicians;
- Medical Chief.

2) *Black Box validation*: the results of the "As-Is" analysis were compared to a set of data, gained from the real system, to verify the compliance between the simulated system and the actual one, in particular:

- Total number of requests for examination;
- Number of requests per exam;

- Total number of tests performed;
- Number of examinations performed, broken down by type of examination;
- Time lapse between the examination requests and tests execution.

The comparison made clear that the simulated model provided a good simulation of the real system, meaning that a suitable representation of the working activities carried out in the DLM was performed.

III. Results

The simulated model was implemented for 395 runs to obtain statistically valid results. The simulation time was fixed in a week.

Table 2 shows the value obtained from the analysis, concerning both the costs and the quantity of the exams performed in the DLM.

Table 3 shows then the variation of the values obtained: for scenario #1, the increased number of input-requests makes possible scale economies that lead to a general decrease of the costs; the presence of a new asset in the scenario #2 brings a further decrease. The difference between the results shows that for some exams the cost decrease is not so substantial between the two scenarios displayed (e.g. Serum3, GHB), while it is instead for others (e.g. Base Exams, Urinoculture and Blood Colture).

TABLE II. COMPARISON BETWEEN COSTS PER EXAM

Cost Category	*Normal Condition*		*Scenario #1*		*Scenario #2*	
	N. Exams	**Cost (€)**	**N. Exams**	**Cost (€)**	**N. Exams**	**Cost (€)**
GHb	15	4.1	25	3.93	25	3.93
Allergology	10	5.33	10	5.29	10	5.28
Base Exams	426	3.26	755	3.26	755	3
CBC	358	2.84	634	2.73	634	2.61
Coagulation	190	3.97	331	3.89	331	3.73
Urine	179	3.24	309	3.19	309	3.19
Serum Electrophoresis	180	8.86	297	8.81	300	8.8
Hormones	132	1.59	180	1.57	180	1.54
THORC	10	20.4	30	17.03	30	17.03
Serum3	10	17.13	30	16.22	30	16.22
Urinocoltures	39	12.95	63	12.9	63	10.79
Tampons	3	15.34	5	13.08	5	13.01
Blood Coltures	2	28.58	2	28.55	3	20.79
VES	22	2.73	33	1.21	33	1.08

TABLE III. VARIATION RESULTS

Cost Category	*Decrease % of costs*		*Increase % of Exams Performed*
	Normal Condition vs. Scen. #1	**Normal Condition vs. Scen. #2**	**Normal Condition vs. Scenarios #1 + #2**
GHb	4.146341	4.14634	40
Allergology	0.750469	0.93809	0
Base Exams	0	7.97546	43.57616
CBC	3.873239	8.09859	43.53312
Coagulation	2.015113	6.04534	42.59819
Urine	1.54321	1.54321	42.0712
Serum Electrophoresis	0.564334	0.6772	40
Hormones	1.257862	3.14465	26.66667
THORC	16.51961	16.5196	66.66667
Serum3	5.312318	5.31232	66.66667
Urinocoltures	0.3861	16.6795	38.09524
Tampons	14.73272	15.189	40
Blood Coltures	0.104969	27.2568	33.33333
VES	55.67766	60.4396	33.33333

The What-If analysis made clear that both the increase of the input-request and the insertion of a new asset can determine an improvement in terms of number of exams performed as well as for the costs of each single exam.

The main findings of the simulation analysis point out the Scenario #1 as the best choice to pursue to improve the current system dynamics, since the addition of a new asset could determine an increment in the total costs due to the cost of the resource itself.

IV. Discussion and Conclusions

Discrete event simulation (DES) is a generally accepted tool in management decision making. In this paper, the use of the DES/BPM approach for the workflow analysis of an Italian Department of Laboratory Medicine made possible to show both quantitative and qualitative implications of the operative choices performed; in particular, the implementation of such a novel approach led to verify that: (i) the use of simulation grants the right access to the outcomes of a BPM-related logic for all the professionals involved; (ii) the ex-ante evaluation of the most timely benefits is closely related to the positive impact of the system on the whole DLM internal functioning; (iii) the possibility of a multiple choice among the KPIs to work on with can lead to work out as many "What-If" scenarios as requested from the actors interested in the simulation; (iv) developing plausible scenarios has the main purpose to get to better conditions through which improve the quality of care; (v) a properly performed DES/BMP approach can be seen as an advanced form of robust design, so that the initiative costs will be carefully sized since the beginning.

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