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A SIMULATION MODEL FOR ANALYZING THE NURSE WORKLOAD IN A UNIVERSITY HOSPITAL WARD

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ABSTRACT

The aim of the present work is to propose a prototype simulation of a hospital ward which permits the study of the workload and task distribution among nursing and auxiliary personnel. In our study, we took both X a generic ward in a complex healthcare structure (University Hospital "Federico II" – Naples, Italy) and a case study of a hospital immunology department as reference models. Both analyses were carried out together with a team of expert head nurses and following a specific simulation model developed in the Simul8 environment, which allowed the calculation of patient assistance timing as well as the efficiency of personnel use depending on the patient autonomy.

1. PREMISE

The management techniques currently used in the health sector allow the adoption of solutions (Cerimele et al. 2003) which fulfill the goals of care efficiently, effectively and economically only in part. This fact exposes the managers to the risk of making decisions which may give rise to problems omissions and thereby inefficiencies, despite the fundamental soundness of the project, thus undermining its efficacy. In addition, unsatisfactory management solutions could lead to the inefficient use of the available economic resources (Gunal and Pidd 2005; Robinson et al. 2014).

The definition of needs in terms of nursing and support personnel that ensure adequate and appropriate levels of care is necessary in order to ensure efficiency and effectiveness in a hospital department.

Several papers have proposed studies and experimental methods for measuring nursing resources and each has developed its own conceptual and methodological approaches. Some of these methods have been developed internationally and have undergone repeated revisions and had many updates over the years.

Few of these methods, at least in Italy, have found practical application for two main reasons:

- the need to make a large number of on-site measurements,
- the results of all these models report one-off observations and therefore do not lend themselves to following the evolution of department dynamics.

In this paper, the discrete event simulation (DES) (Banks et al. 2009; Jacobson, Hall and Swisher 2006; Victor et al. 2013; Kim et al. 2013; Rau et al. 2013) technique is implemented, as a support to the Business Process Management (BPM) (Van der Aalst, ter Hofstede and Weske 2003) methodology, in order to study and improve the performances of healthcare facilities.

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

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

The DES approach is founded on the fact that assumptions are independent from the model and can be generally administered at any time or resized in a feasible way. This enables users to make a systematic examination of their assumptions rather than guiding them in the construction of the model and the solution to the problem.

In this scenario, the deployment of simulation-based tools permits the study of the dynamics of the organizational system rather than one single observation on the basis of a statistical hypothesis. This fact makes it possible to reproduce the functioning of a system or part of it as faithfully as possible in order to study its responses to further modifications by then analyzing the *Key Performance Indicators* (KPI) (Torri et al. 2015). More generally, the simulation may be considered a useful instrument for studying real system organizational models in order to analyze and forecast their behaviour.

Based on these premises and by means of a simulation model, the study analyzed the behaviour of a generic ward in the University Hospital (AOU) "Federico II" in Naples, Italy focusing on the activities of the non-medical personnel (nurses and support workers). More particularly, the nursing or support activities were studied by means of the RAFAELA method (Rauhala and Fagerstrom 2003).

The aim of the study was to identify and analyze a series of KPIs capable of providing information on the functioning of the model in normal conditions as well as forecasting their behaviour due to variations in its current status (Torri et al. 2014).

2. MATERIALS AND METHODS

A combined, two-phased qualitative-quantitative approach was adopted.

2.1. Phase I: information collection

In a first phase, information was collected from the study of the current Italian regulations, internal hospital guidelines and from non-structured interviews with head nurses from the nursing management of the University Hospital since they have considerable experience regarding staff-related organizational issues. The work started from a basic principle scheme (see. Fig. 1).

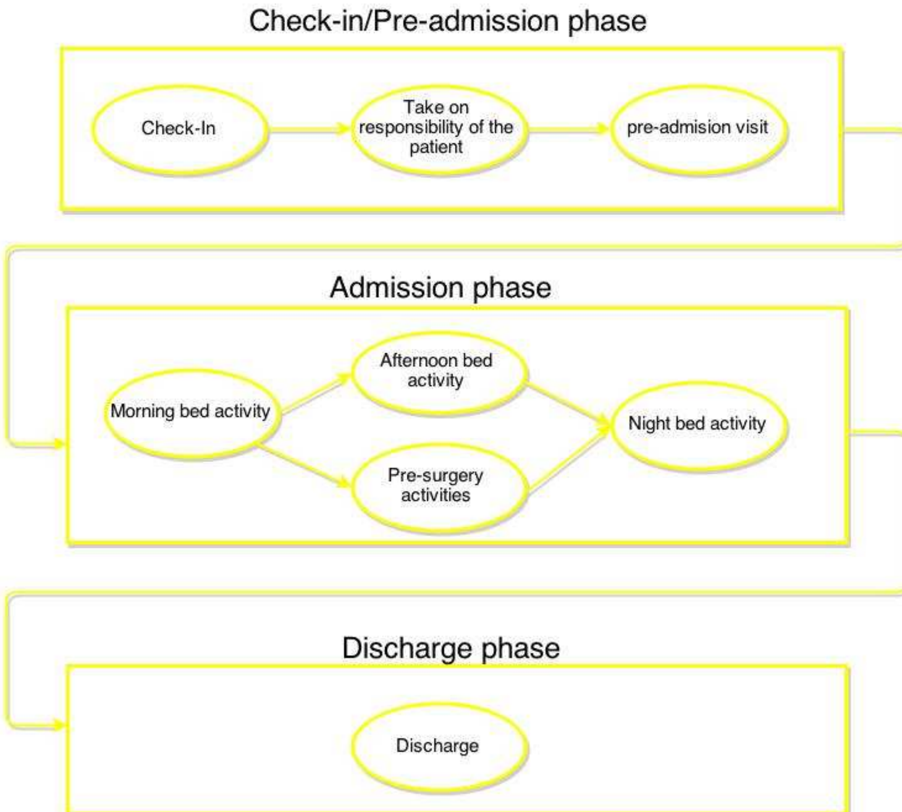

Figure 1: Activity diagram.

Two types of resources were considered for the implementation of the model: nurses and support personnel. Two of the most important Italian guidelines were followed, namely: the Italian Official Gazette n.29/1995 (from now on, “GU29”; Ministero della Sanità 1995) as regards the evaluation of the case mix index value, and the Official Bulletin of the Abruzzo Region n.22/2008 (from now on, “BURA22”; BURA 2008). On the other hand, we have referenced to the RAFAELA method to classify and providing a metric to the nursing workload (Rauhala and Fagerstrom 2003). According to such method, the nurse working load is measured by assigning points to the cure intensity and comparing the obtained points to the optimal assistance required by the ward – of course, deploying the RAFAELA method requires very detailed analyses and tests. The following are the main areas of concern to measure nurses’ working load:”)

In order to classify and provide a measure of the nursing workload, the RAFAELA method (Rauhala and Fagerstrom 2003) was referred to:

- Classification and planning of nursing assistance;
- Breathing, blood circulation and symptoms due to pathologies;
- Nutrition and medication;
- Personal hygiene and secretion;
- Movement, sleep and rest;
- Cure training and guide, emotional support.

The evaluation of the nurse working load by assigning points to the intensity of the cure and comparing the points accumulated to the optimal assistance required by the ward is at the basis of the RAFAELA method. Of course, the RAFAELA method requires very detailed analyses and tests.

This method classifies the patient by assigning a grade for each aspect, from A to D, and focusing on their level of autonomy.

A. mostly auto sufficient;
B. sometimes requires assistance;
C. repeatedly requires assistance;
D. totally dependent.

On the basis of this methodology, we carried out a series of interviews and meetings with a group of senior nurses in order to develop the general architecture of the model that best fitted the workflow characteristics and, at the same time, allowed a classification and qualification of the nursing activities consistent with the RAFAELA method.

2.2. Phase II: model building

The group work, which lasted some months, developed a simulation model by using the SIMUL8® software, represented in Figure 2, which reproduces and better details the activities in Figure 1. The model described in the present work aimed to reproduce the non-medical personnel activities in a generic hospital ward while bearing in mind the regulations in force. For this reason, a series of variables, to be set by the user, have been introduced into the model thereby allowing it to be adapted to different operative situations. More particularly, the values which can be set are:

- Number of beds in the ward;
- Occupational index (N beds occupied / N beds available);
- Discharge value (number of patients discharged from the ward per day);
- Only the non-medical resources were considered i.e. nurses and support personnel (social assistance operators – OSA) in the model
  - Number of nurses present for each X shift (morning, afternoon and night)
  - Number of support personnel present for each time shift

. In this model we find all the activities shown in Figure 1. Being an interactive model, it was also possible to reproduce all the operative conditions found in the real system.

- Check-in: all the activities preliminary to hospitalization;
- Morning activities: all bedside activities from 7.30 to 13.50;
- Afternoon activities: all bedside activities from 13.30 to 19.50;
- Night activities: all bedside activities from 19.30 to 07.50;
- Discharge: all the activities preliminary to the patient's discharge and the results collection.

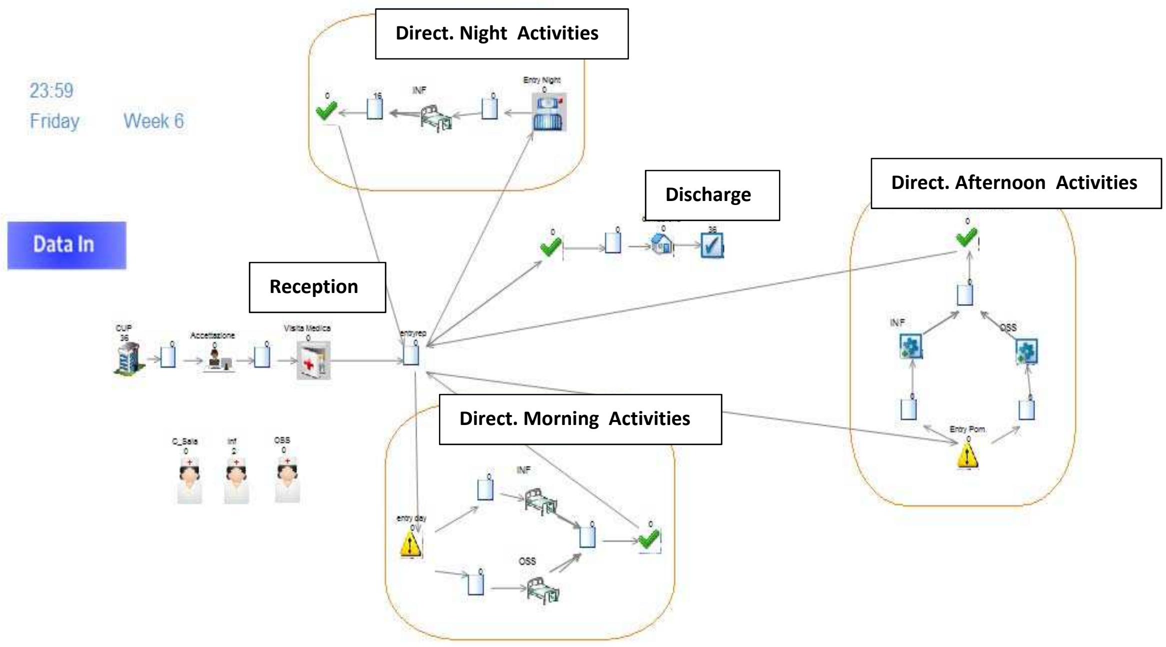

Figure 2: Simulation model.

It is possible to define timing and the required resources, contingent activity shifts and much more information which allows the workflow timing, the resources utilized and eventual queues which may occur due to an insufficient availability of these resources to be reproduced for each activity block.

The model being studied was constructed in order to consider all the possible tasks carried out by nurses and support personnel; more particularly, both direct and non-direct activities during the three different time slots (morning, afternoon and night). The model does not explicitly take into account the transport time between activities; these times were implicitly calculated in the total time of the single activities.

In the tests which followed, we used a simulation period of 6 days, preceded by a month's warm-up period, at the end of which the model reaches its standard use. The warm-up period was included to ensure that the analyses of the model were carried out while the department was fully operational.

(The warm up period is not critical, it could range between 15 days up to 30 days and more, given that it is only necessary in order to complete the simulation for all the start-up work items.)

As is customary in DES models, the tokens,(it is the unitary elements of the simulation, which coincides with the work items of SIMUL8 model) originate at the "Start Point" on the left of the diagram. The amount of work items produced by the start point which then feed the system is fixed by the number of discharged patients per day. At the beginning of the model, we see the block of activities which precede the assignment of a bed to the patient:

- Check-in;
- Taking on responsibility for the patient;
- Visits before the assignment of a bed.

Subsequently, we see the activities carried out at the patient's bedside and which come one after the other during the day, afternoon and night.

To simulate these direct activities we used a peculiarity of the SIMUL8 software i.e. the sub-processes. These allow the creation of a sub-model within the model. As can be seen in Figure 4, the morning shift has two sub-processes, one for nurses and one for support personnel and it is the same for the afternoon shift. The night shift, on the other hand, only has nursing activities since the ward in question does not consider support personnel during the night.

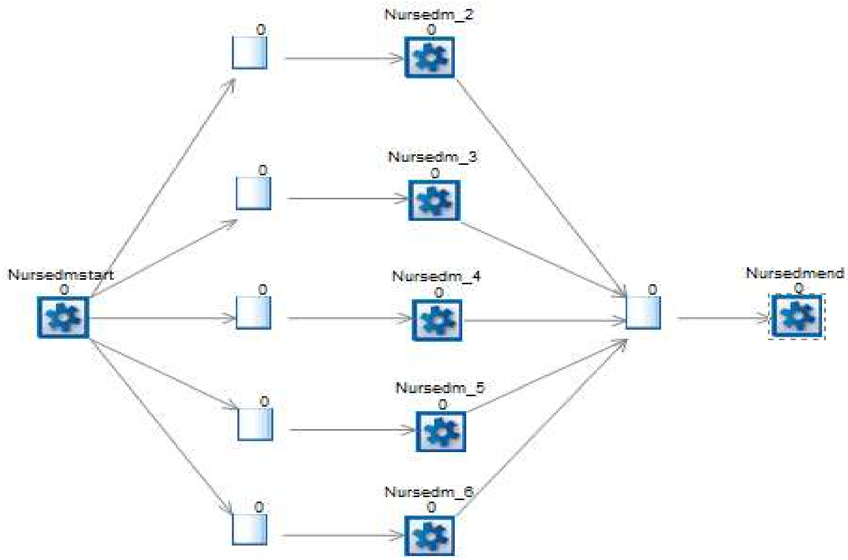

Figure 3: Sub-process of direct morning nursing activities.

As can be seen in the Figure 3, the nursing or support activities are further divided into activities taking into consideration the different types of nursing activities on the basis of the RAFAELA method (Rauhala and Fagerstrom 2003):

- Classification and planning of nursing assistance;
- Breathing, blood circulation and symptoms due to pathologies;
- Nutrition and medication;
- Personal hygiene and secretion;
- Movement, sleep and rest;
- Cure training and guide, emotional support.

According to the RAFAELA method, the patient can be classified by assigning a grade, A to D, for each aspect concerning the patient's level of autonomy.

A. mostly autonomous;
B. sometimes requires assistance;
C. repeatedly requires assistance;
D. totally dependent.

The duration of the activities in fig. 4 is related to the autonomy parameter patient by patient

Apart from the abovementioned nursing activities carried out at bedside and directly related to the patient, in the department there are many other jobs regarding the organization of the department the duration of which depends on the number of patients admitted and the management policies of the department. These activities have been represented in a separate workflow, although they coexist with the main one, and are reported in Figure 3.

- Pharmacy management: all the activities concerned with the preparation of drugs and trolley assembly;
- Maintenance activities: all the activities concerned with the medical plant and the maintenance of equipment;

- Instrument management: all the activities concerned with the preparation cleaning and maintenance of surgical instruments,;
- Collection of medical reports: all the activities concerned with the collection of medical reports (especially in the case of them not being delivered via an IT information system

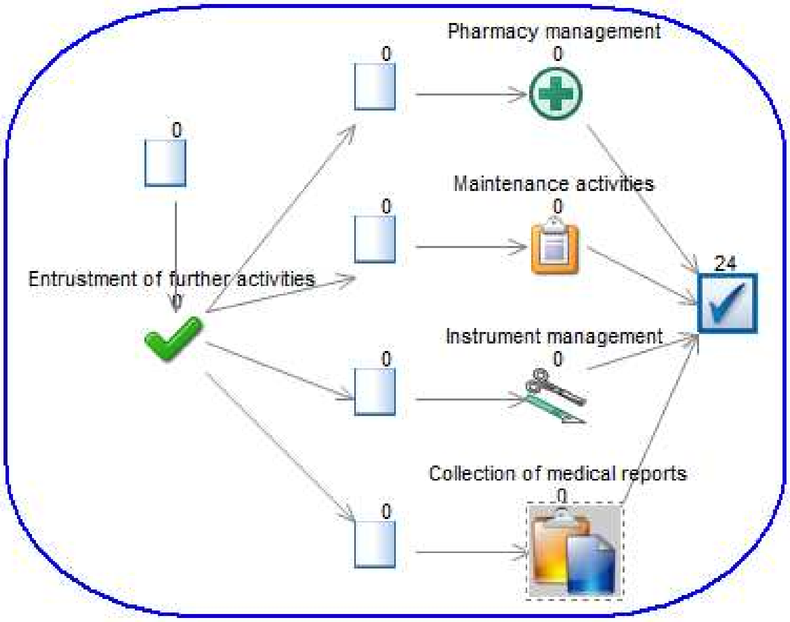

Figure 4: Workflow of further activities.

For this completely general model, the duration of the activities was determined on the basis of the experience. These activities are much important because they determine the resource availability for direct activities, therefore one of the possible use of the simulation model is to study how to rearrange the indirect activities nurses participating in order to maximize the direct time spent over the patient the work group.

Once all the required data have been set, it is possible to carry out the simulation at different speeds by means of a dedicated cursor. It is also possible to obtain indications regarding the tendency in time (?) of the model variables by means of a series of graphics selected by the user.

During the implementation, icons and animations facilitate the understanding of the operative workflow by all stakeholders with whom the organizational model analysis is shared.

The model may also be available for simulation without the development system SIMUL8, thanks to a dedicated module (viewer) to be downloaded from the producer's website which allows the visualization of the model's structure and the results.

At the end of the simulation the model reports:

- % nurse use;
- % support personnel use;
- Assistance in minutes to patient per day.

3. CASE STUDY: THE SIMULATION MODEL OF AN INTERNAL MEDICINE DPT

As previously stated, in order to trial the adaptability of the model in a generic ward, we decided to analyze an internal medicine ward specializing in clinical immunology cardiology and allergology (University Hospital "Federico II" – Naples). This is not a surgical ward but rather a medical one, therefore all the pre-surgery activities were removed.

The nursing staff were questioned regarding the workload related to the various activities and differing levels of autonomy.

Two questionnaires were prepared and given to the nursing and support staff on the ward respectively.

They were asked to indicate a minimum, medium and maximum time necessary to perform each activity associated with their specific roles,

The questionnaires, which were coherent with the simulation model, concerned X activities were relevant to three categories: morning activities, the afternoon ones and the night ones. Moreover, two different questionnaires were given out, one concerning the direct activities (i.e. those performed at the patient's bedside) and the other concerning indirect activities which are more related to organizational matters.

Once the staff had filled in the questionnaires, all the information was written into a spreadsheet that was uploaded into the simulation model at start-run time.

Once all the time parameters are uploaded, the DES model generates sufficient triangular distributions to define the work duration for each activity in each sub-process.

(The triangular distribution is used in the analysis process to represent the values of a distribution, when there is little information regarding the real performance of a distribution but you have, following interviews, direct observation of activities, or other type of investigation, minimum value, the maximum and it is possible to derive the mean value)

A correct functioning of the model depends on the possibility X of performing all the direct activities on schedule for all patients admitted. In the event that resources are not sufficient it is possible to create a queue containing the work items still pending.

The model provides the appropriate controls to track "residual activities ' without interrupting the flow of the model.

The number of residual activities and the bedside time spent with the patient depends, therefore, on the number of patients with a low level of autonomy.

4. MODEL VALIDATION

As regards the model validation, a "two step" approach was adopted:

- formal validation;
- structural validation.

The formal validation consists of evaluating the correctness of the model and therefore the technical issues concerning the modelling.

As regards the structural validation, a comparison between the behaviour of the simulation model and real systems is carried out in order to evaluate whether and how the simulation model may be considered a good approximation of the real system by means of two subsequent steps:

- Open-box validation: the model was shown to the nurse coordinator who took part in the working group so as to verify the functioning of the model and the organization of the activities and workflow.
- Black-box validation: the results of the simulation model are compared to the data obtained from the real system, i.e.:
  - Number of discharges/day;
  - Mean hospitalization time;
  - Patient's grade of autonomy;
  - Average bedside time spent by nurse and support personnel.

As regards the Open Box validation, the interviews with the staff coordinator reported a general conformance of the model with the real world.

As regards the Black-Box validation, the information concerning the present situation in the hospital department was collected and, following the running of the simulation, the average bedside time spent for different levels of autonomy was reported to the nurse coordinator in order to check how far these data are from the real case.

The coordinator agreed that, with differences of less than about 20%, the times obtained from the model were broadly consistent with the real times. It was also found that the total number of days spent in hospital per patient as revealed by the model coincided with the real number of days, and that the behavior of the model is similar to the real system at least as regards the workloads of the personnel.

5. RESULTS AND DISCUSSION

For example, in Tables 1 and 2 the results obtained are reported for the case study of the " Immunology Dept." at University " Federico II"

The amount of resources varies depending on the working shifts; three shifts were identified:

- I shift from 7.30 to 13.50;
- II shift from 13.30 to 19.50;
- III shift from 19.30 to 07.50.

The amount of resources actually available are

Table 1: Amount of resources per shift.

Working shift	*Resource*	*Number of resources*
Day	Nurse	3
Afternoon	Nurse	2
Night	Nurse	2
Day	Support personnel	1
Afternoon	Support personnel	1
Night	Support personnel	0

At validation time the Autonomy distribution was:

Table 2: Autonomy distribution.

A	40 %
B	10 %
C	30 %
D	20 %

The Occupation index 90 % and 3 patients/day were admitted and the average hospitalization time was 8 days. The model reported the following outputs:

Table 3: Output of the model.

Parameter	*Model Output*	*Comment*
Residual Nursing Activities	3	The nursing staff is within the limit and the result conforms to the real case
Residual Support Personnel Activities	83	The support staff are not sufficient and the result conforms to the real case

% Nurse Utilization	57%	A high utilization score because many incidences of lost time are not yet counted – the result conforms to the real case
% Support staff Utilization	70 %	A high utilization score because many voices (??) of lost time are not yet counted - the result conforms to the real case
Average Days of Hospitalization	8 days	The result conforms to the real case

Average Bedside Time (min.) versus autonomy grade:

Table 4: Results of the simulation.

Nurse			*Sup. Staff*		*Autonomy*
Morning	Aft	Night	Morn	Aft	
21,18	13,37	20,11	10,07	8,53	A
26,06	14,71	22,09	14,38	12,44	B
52,29	17,82	25,93	21,98	18,69	C
74,44	18,68	25,14	31,05	26,53	D

The result conforms to the real case.

Of course, more accurate validation could be done and, in fact, in the coming months an evaluation of patient time perception will be carried out.

If we consider the practical use of the model and the present availability of quantitative data related to the nursing workload, the model X may be considered a reasonable estimate of the present state (“As-is” model). Starting from this assumption, it is therefore possible to intervene on the model with contingent modifications as regards timing and/or the structure in order to foresee the consequences of organizational-managing changes before to do that (“What-if” model).

For example, if we want to evaluate the impact of a different distribution of tasks during the working shifts or for a different number of beds or complexity index on the system, it is possible to insert the appropriate data into the initial dialogue window and estimate the corresponding result.

In the model the admittance rate and the autonomy distribution is pre-determined, but it can be easily changed versus a time varying distribution in order to represent different scenario: this feature overcame the main limitation of the present nurse workload model that provide results at one specific instant of time.

6. CONCLUSIONS

By adopting the DES technique, this paper proposes a model which permits the study of typical clinical workflows as well as a series of any organizational modifications, generally too complex to analyze otherwise. After a preliminary validation carried out jointly with a team of expert ward nurses, the simulation model seems to produce quantitative indications quite near to reality.

In order to verify the real applicability in a real situation, the developed architecture was further analyzed by a different group of nurses and support operators employed in a specific internal medicine ward specializing in immunology so as to evaluate the transferability of the adopted methodology both qualitatively and quantitatively.

This model responds to the requirements of the personnel involved in a (according to “black box” logic) even though it will need further validations regarding the observational data, the input data workflow analyses and the measurement of the KPIs (Key Performance Index).

An interesting point is that the response of the nursing personnel involved in the various working phases; at all times the staff involved, and especially the nursing coordinator, showed great interest and a high level of participation despite the lengthy working meetings.

The functioning mechanisms of a hospital ward are certainly very complex and therefore the authors are far from considering a DES integrally capable of reproducing the many working dynamics here present, nevertheless the proposed model could be a useful start point and a valuable management and planning instrument for introducing new methodologies and different management culture into Health Management and nursing which, at the moment, does not exist.

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