A SIMULATION TOOL TO PLAN DAILY NURSE REQUIREMENTS

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ABSTRACT
The economic cost crisis and the need for reducing costs while assuring a high service level to patients are the drivers of the introduction of operations management tools in the hospital environment. With the premise of flexible shifts schedules, the assessment of the actual nursing time can enable a wise resource planning, balancing the efficiency in resource usage (avoiding overstaffing) with the quality of care (assuring the presence of an adequate number of nurses to care patients). This paper proposes an innovative simulation method to plan daily nurse requirements in which the best number of nurses for each shift according to a desired service level is defined taking into account real requirements of hospitalized patients. In particular, patient dependence from nurses has been correlated to the time needed to perform nurse tasks deduced from the clinical pathway of patients. The validation and verification of the proposal have been assessed in a stroke unit.

Keywords: nurse requirements planning; patient dependency; healthcare operations management; patient flow simulation.

1. INTRODUCTION AND LITERATURE REVIEW

The economic cost crisis and the need for reducing costs and assuring a high service level to patients are the drivers of the introduction of operations management tools in the hospital environment (Iannone et al., 2011-2015; Guida et al., 2012). The huge impact of personnel (mainly nurses) cost on budgets and the relevance of the nurse involvement in the process of care of patients, make the nurse staff an interesting test-bed for such innovative tools. The adoption of flexible shifts schedules and the assessment of the actual nursing time can enable a wise resource planning, balancing the efficiency in resource usage with the quality of care.
The Nurse Requirements Planning (NRP) issue can be contextualized in the wider framework of "Nurse capacity planning and scheduling" (Punnakitikashem & Rosenberger, 2008) and (Siferd & Benton, 1994), ranging from the staffing in the long time horizon (Villarreal & Keskinocak, 2014) to the scheduling in the medium time horizon (Constantino et al., 2014), till the daily rescheduling and assignation of patients to specific nurses (Naidu, Sullivan, Wang, & Yang, 2000).
Methods to determine the nurse requirements (from staffing to rescheduling) have been developed since the eighties' and range from consensus approaches to top-down management approaches (Naidu, Sullivan, Wang, & Yang, 2000). They can be grouped into 5 categories ordered from the simplest to the complex one (Keith, 2003) and, in particular:

- *Expert judgment*, in which the number of nurses per shit is subjectively defined by nurses;
- *Number of nurse per occupied bed*, taking into account the statistics about the number of nurses attributed to beds of a certain ward;
- *Acuity-quality methods*, in which the time needed to give assistance to patients is proportional to their dependency on nurses (expressed by a patient dependency category) or patient acuity (Ernst, Krishnamoorthy, & Sier 2004), and changes from ward to ward. An interesting example of day-to-day nurse scheduling based on patient acuity has been reported by (Siferd & Benton, 1994) who, given a mean patient acuity for all patients, expressed in terms of number of nurses required, considered a mean rate of change in patient condition over the shift, assuming that new patients have higher acuity than the hospitalized ones. Then, they carried out a number of simulations to assess the impact of size of unit, acuity and number of admits and discharges on the number of nurses needed. Another case comes from (Liang & Turkcan, 2015), who presented a multi-objective optimization model for determining the number of nurses and the schedule of patients (minimizing waiting time) in an outpatient oncology clinic. The sum of patient acuities was matched with the maximum acuity manageable by a nurse to make assignments.

Nurse direct workload, instead, was concentrated in the first 30 minutes after each patient treatment start time (later, the nurse has to monitor contemporary patients' infusions). Both acuities and nurse workload for the treatment (excluding the other activities of the patient pathway) were assumed deterministic;

- *Time-task activity methods*, based on the concept that the type and frequency of nursing interventions on patients are good predictors of nursing time. To apply the models it is required to define a duration for each possible activity and then constructing the care plan for each patient. The ward overhead time has to be added to the total direct care time.
- *Statistics-based methods*, regression methods relying on the specific ward under analysis.

Methodological approaches to implement these methods range from subjective deduction to heuristic algorithms, simulation models or operational research.

This paper proposes an innovative daily NRP method which summarizes the best features of both acuity-quality and time-task activity techniques in a easy-to-use solution that is based on the concepts of:

- tasks of the patient clinical pathway (Bhattacharjee & Ray, 2014), that is the "standard" sequence of diagnostic, therapeutic and care activities a patient, with certain pathology and according to medical guidelines and resources availability, should undertake in a hospital;
- patient dependence on nurses in the activities of day living (Kaliszer, 1976), which is correlated to the time needed to perform each nurse' task.

Because of both concepts involve probabilistic evaluations related to task occurrence and task durations for each patient, and considering that patients number and characteristics change also over a day due to new accesses, discharges and status variance, the nursing time and, consequently, the number of nurses required to meet patient's demand, have a stochastic behaviour. Then, the service level offered to patient (that is the probability to meet the total patient's demand) is stochastically dependent on the number of planned nurses.
A simulation tool has been used to simulate each patient flow and find the cumulated probability distribution function of the number of nurses required for each shift. This distribution can be finally used by management to choose the right number of nurses for the real patient requirements according to the desired service level, avoiding of time consuming data entry for NRP calculation, thanks to the automatic retrieval of data from Electronic Medical Records and database of clinical pathways belonging to hospital's Information Systems.
The paper is structured as follows: Section 2 deals with the description of the proposed method and Section 3 regards with the case study chosen to assess the usability of the proposal (a stroke unit). Data collection and analysis, simulation, validation and verification are provided. The conclusions follow.

2. MODEL DESCRIPTION

As recognized by many authors, due the patient pathway complexity, simulation is the best modelling solution to take into account task time, routing probabilities, and facilities integration (Bhattacharjee & Ray, 2014); (Cardoen & Demeulemeester, 2008). The proposed NRP method is based on a Monte Carlo Simulation (MSC), a very common numeric simulation used to randomly generate a set of events of a stochastic variable according to its Probability Distribution Function (PDF). By means of MCS, the stochastic behaviour of patient accesses, characteristics, clinical activities of the pathway and the related duration are reproduced over the shifts to estimate the total nursing time in different scenarios and determine the nurse service level in dependence on the number of nurses.

Some medical unit data are needed:

- database of the pathway activities with the maximum and minimum duration;
- expected duration of the indirect activities for each shifts;
- duration and time schedule of the shifts;
- maximum availability of the nurse staff;
- PDFs of patient inter-arrival time, duration of the emergency activities, Barthel values assigned;
- probabilities of occurrence and assignation to a nurse for each activity.

In the daily operations, the following data should be collected for each hospitalized patient:

- day of the clinical pathway;
- possible modification in the pathway (patient flow routing definition);
- dependence from nurses, Barthel scale value, An extensive survey on English stroke units (Rudd, 2009.) demonstrated that patient dependency, expressed by the Barthel scale value, has a correlation with nurse direct workload (Spearman's correlation coefficient being -0.5); with nurse direct workload (Spearman's correlation coefficient being -0.5);
- planned discharge or transfer;
- time of the access to the medical unit.

The simulation steps are the following:

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1. Simulation of incoming patients'. Patients inter-arrival is simulated based on the related PDF. This time is added to the last accesses in order to find the next entries of new patients.
2. Simulation of patients' requirements. While for the hospitalized patients the Barthel scale is attributed by nurses, for incoming patient this value is simulated according to the occurred PDF. The nursing time (duration) of each caring activity is assumed to be a linear function of the Barthel scale) (Fig. 1) that can range from 0 (complete dependency of patient from nurses) to 20 (the opposite).

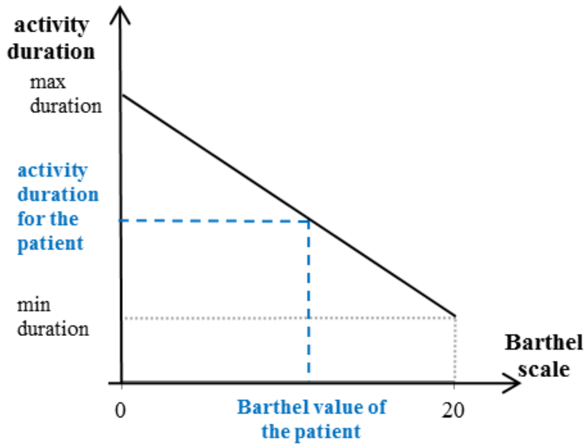

Figure 1: Activity duration for a patient in dependence on the Barthel value assigned to the patient.

The occurrence of each activity for the patient and the task assignation to nurses are taken into account based on its probability and, finally, the total duration of the nurses' activities for each shift is found.
3. Calculation of nurse requirement. The number of nurses required for each shift is found dividing the total duration of nurse activities by the time available by a single nurse during the shift and rounding this value to the highest integer.
4. Definition of the nurse requirement planning. The simulation from step 1 to 3 is repeated many times to reproduce the stochasticity of the variables involved. Finally, the cumulated probability distribution function of the number of nurses required for each shift is calculated, in which each number of nurses corresponds to a service level that can be probabilistically offered to patients. With this information the nurse manager or another decision maker are enabled to choose the best nurse sizing for the following day taking into account resource cost and service level to patients.

3. CASE STUDY: THE STROKE UNIT

3.1. Data collection

In order to validate and verify the proposed model, it has been implemented in a real environment. The case study under analysis is a stroke unit, a particular segment of the neurology medical unit dealing with stroke patients. Stroke is the second leading cause of disability in Europe and the reason of 10% of death worldwide (Wittenauer & Smit, 2013) and its clinical pathway is very expensive for healthcare systems (it is responsible for 7% of the UK NHS budget (Gillespie, McClean, Scotney, Garg, & Fullerton, 2011).

In the hospital environment, due to the high number of stroke cases and the relevant hospital cost, such patient pathway is well known: clinical process flow chart and task durations are standardized and shared among actors (emergency department, medical units' physicians and nurses) in order to efficiently manage patient care.

The stroke unit under study belongs to a medium-sized Italian acute university hospital of 1500 beds. It is devoted to the care of ischemic stroke (classified as DRG 014) and it is provided with 8 beds for inpatients and 1 room for incoming cases transferred from the Emergency Department.

The values of the model inputs have been collected in the stroke unit by means of semi-structured interviews, time measurements and data retrieval from hospital information systems. In order to share the pathway model with physician and nurses and enable them to make suggestions to improve its design, a 3D simulation was developed by using the software FlexSim Healthcare (Fig. 2).

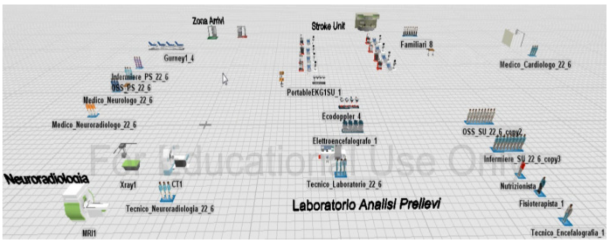

Figure 2: Stoke patient pathway simulation with FlexSim Healthcare software.

3.2. Model validation and simulation

Validation. The first validation of the model was carried out comparing the total nursing direct care time calculated by the model to the one experienced by nurses over a week and recorded by them in provided forms. The proposed model resulted to be a good predictor of reality (the error, with a confidence level of 95%, was 15%).

Case study simulation. Using the daily patient characteristics of Table 1 and implementing the model in a simple Microsoft Excel Spreadsheet, the resulting cumulated distribution function of the number of nurses required for a shift over 500 simulation replications is shown in Table 2. By this, the decision maker is enabled to make decisions about the number of nurses

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to possibly re-schedule for the day. For example, for the first shift, 6 nurses are required to assure 99,9% service level to patients, while with 5 nurses, the probability of satisfying the patient needs is equal to 87,1%. In the second shift, instead, given the hospitalized patients and their needs that are evaluated by the simulation, the assignation of 4 nurses or more would be a waste.

Table 1: Patient data of 1 day of the case study

Patient	Barthel scale	Day of the pathway	Time of patient entry	Presence of patient for shift		
				1	2	3
1	0	1	01/01/2015 16:00	1	1	1
2	2	2		1	1	1
3	5	2		1	1	1
4	7	3		1	1	1
5	8	3		1	1	1
6	13	5		1	1	1
7	10	8		1	1	1
8	20	9		1	1	1

Table 2: Patient service level in dependence on the number of nurses required per shift

	Service level achievable with number of nurses for each shift		
Number of nurses	Shift 1	Shift 2	Shift 3
1	0,0%	0,0%	96,6%
2	0,0%	39,0%	100,0%
3	0,0%	99,1%	100,0%
4	12,1%	100,0%	100,0%
5	87,1%	100,0%	100,0%
6	99,9%	100,0%	100,0%
7	100,0%	100,0%	100,0%

Moreover, for each number of nurses per shift, the probability of the nurse saturation can be calculated (Figure 3), providing the decision maker with information about possible negative effect on stress. In the example, choosing 4 nurses for the first shift will imply a significant saturation (always more that 70% of nurse time will be used).

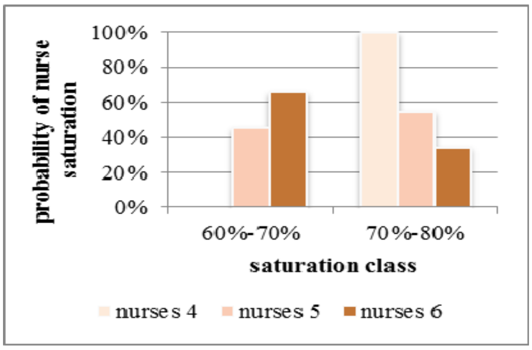

Figure 3: Nurse saturation probability in the shift 1

4. CONCLUSIONS

This study copes with the proposal of a daily Nurse Requirements Planning (NRP) method based on simulation of patient flow, which takes into account real patient needs considering both the variability of clinical pathways and of the duration of care activities. The method summarizes the best features of both time-task activity methods (because single tasks of the clinical pathway and the related occurrence probability are taken into account) and acuity-quality methods (because patient dependency from nurses is used to estimate single task duration). For the sake of simplicity, the model has been formalized considering the activities of one clinical pathway carried out in one medical unit. Anyway, it can be easily extended to many pathways, many medical units and many resources. Given the probabilistic dimension of the results, both in terms of service level and personnel saturation, it can be a valid support for management in nurse rescheduling decisions, being a daily support system in finding the trade-off between costs (dependent on the number of nurses) and service level offered to patient. The approach is based on patient clinical data collected in Electronic Medical Records and hospital information systems and it is suitable to work without any human intervention. The first results of the proposal have been assessed in a stroke unit of a medium-sized acute university hospital. The ongoing activities are aimed at refining the relation between activity duration and patient dependency on nurses by means of an extensive time and methods study on the field. Moreover, a cost analysis will be performed in order to quantitatively assess the impact of the NRP decisions on the medical unit budget.

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