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A Queueing Theory Based Model for Business Continuity in Hospitals

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Abstract— **Clinical activities can be seen as results of precise and defined events' succession where every single phase is characterized by a waiting time which includes working duration and possible delay. Technology makes part of this process.**

For a proper business continuity management, planning the minimum number of devices according to the working load only is not enough. A risk analysis on the whole process should be carried out in order to define which interventions and extra-purchase have to be made. Markov models and reliability engineering approaches can be used for evaluating the possible interventions and to protect the whole system from technology failures.

The following paper reports a case study on the application of the proposed integrated model, including risk analysis approach and queuing theory model, for defining the proper number of device which are essential to guarantee medical activity and comply the business continuity management requirements in hospitals.

I. INTRODUCTION

Appropriate technology management is essential for the continuity of medical care activities especially in critical phases (holidays and nights) [1]. During this period, in order to maintain business operations at an acceptable pre-defined level [2], special technical assistance is essential. Although most of the healthcare services meet only emergency and most of hospital areas are not available, the technology recover can be longer and affecting the regular day working time. Moreover, when a device fails, it should be possible to find a "twin device" within the hospital area and, at this point, the matter should be where it is better getting the twin device for avoiding activity problems on the lender ward [3]. Especially during the working-daytime scenario, as the device substitution procedure may not be applied since the twin devices could be in use, individuating the minimum number of devices for the clinical activity continuity is essential.

According to the Business Continuity Management (BCM), the definition of a specific BCM plan [4] is requested in order to recover, in case of technology failure, the clinical activities as soon as possible. This consists of few important steps: building a precise database listing all the hospital devices with the precise identification of their hospital location and carrying out a risk analysis which takes into consideration the technology failures event.

The development of a quantitative methodology to estimate the right threshold (minimum number of devices for satisfying the working load) is the principal aim of this paper. The methodology was applied to the endoscopic department at the teaching hospital in Florence [5], which included the plan development and the model validation carried out with the medical staff.

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II. METHODS

The endoscopic department at the Florence Teaching Hospital Careggi attends gastroenterology and hepatic diseases, it is located in three different hospital areas (one for emergency and two for regular activities) and treats over 12.000 exams per year. The methodology consisted of four steps as follows:

a. Special assistance definition;
b. Minimum equipment estimation and continuity plan;
c. Clinical Validation.

A. Special Assistance Levels

Guaranteeing business continuity during the working-day time is not simple since more physicians, according to the clinical practice, may employ specific devices simultaneously. As the failure of a device interrupts not only the specific activity but delays the whole process where the device is involved by interrupting more related activities, it is important characterize the medical equipment according to the availability within the medical facility and the estimation of clinical activity loss.

The special assistance levels are technical/organizational measures to be taken in order to reduce the unavailability of the broken device and include ordinary maintenance, purchase and alternative device availability. These level estimation depends on two indices: Continuity Index (CI) and Priority Index (PI). The first one is based on local

availability [0-1] where CI=0 means no availability and CI=1 define a continuity level of 100%. PI combines both the availability and the performance loss due to the device's failure.

Ordinary maintenance is suggested for devices where special continuity is not contextually requested [6] and shows a PI=0 and CI≥0.99. Purchase is suggested when 0.95<CI<0.99 and PI>X_p, where X_p is defined as the corresponding "PI threshold" which defines a HIGH severity clinical risk deriving by the device failure. Finally, the choice of alternative device is given by the following criteria: CI<0.95 and PI≥X_p, see figure 1.

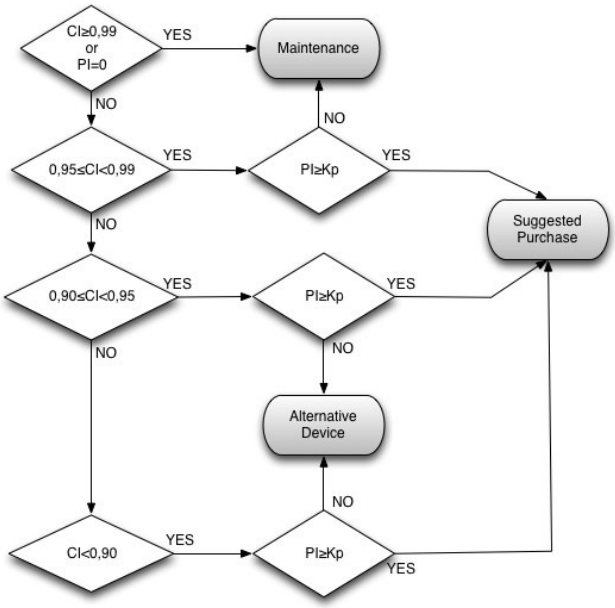

Figure 1. *Special Level according to the devices in the Hospital Area.*

B. *Minimum equipment estimation and continuity plan*

The minimum equipment level is estimated as the minimum number of all devices essential for carrying out endoscopic activity according to the process organization reported in Figure 2.

Devices can be classified in two categories: (1) devices with reprocessing need and; (2) devices without reprocessing need. Only the endoscope belongs to the first category as equipment with High-Level disinfection requirement [7]. The second group includes all the accessories such as endoscopic columns and the regular basic equipment in the room, e.g. defibrillator, pulse-oximeter or electrosurgical.

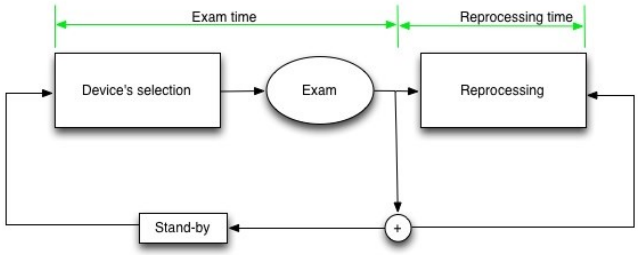

Figure 2. *Visual workflow of each exam request.*

The assessment for those devices that don't need reprocessing is estimated according to the importance of the specific device within the medical process (process role and process effect) and taking into consideration the number of operative medical rooms. For those devices needing reprocessing phase, besides the compliance with national accreditation law and guidelines, specific models should be implemented (queuing theory).

Once the minimum number of devices for guaranteeing ordinary activities is defined, business continuity management needs an extra step including a risk analysis, which in the specific case, consists of individuating how many back-up devices are necessary for building a "safety area." This area permits to protect the medical activities from technological failures and depends on the hospital availability [8], the failure and repair rates. The safety area is quantified by a device availability of at least 90%. In figure 3 we can see the model application to the endoscopic area. For each technology, the figure shows how the current number is never lower than the one foreseen for the ordinary activity while for the BCM seven technologies should require the acquisition of more equipment.

By considering the whole hospital working time and the interval for carrying out each exam and the reprocessing phase, it is possible to estimate the number of devices for maintaining the ordinary workload and obtaining the number of device in queue for serving all the planned patients. This

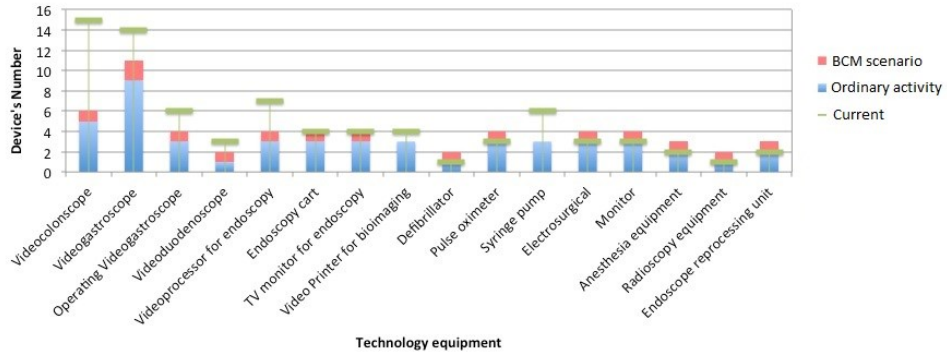

Figure 3. *Evaluation technology for ordinary activities and business continuity in the Hospital Area*

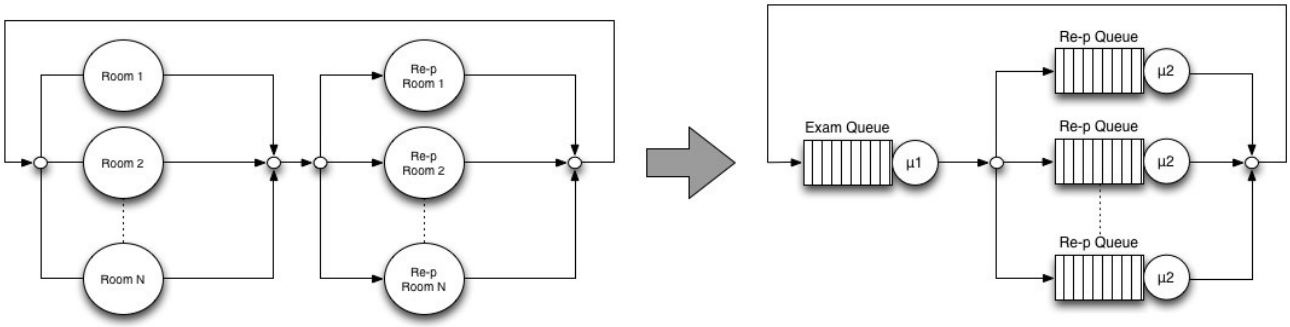

Figure 4. *Hospital application of the Gordon-Newell model.*

process can be seen as a close loop, solved by Gordon – Newell theorem [9], as we seen in Figure 4.

Finally is the BCM planning related to the hospital area 1. Table I reports which devices must be purchased (how many), ordinary maintained or included as hospital alternative.

TABLE I. Special Action Level suggested for the hospital area HA1. In bracket we show number of device we suggest to buy.

Device	***Special assistance levels***
Videocolonscope	Regular maintenance
Videogastroscope	Regular maintenance
Operating Videogastroscope	Regular maintenance
Videoduodenoscope	Regular maintenance
Videoprocessor for endoscopy	Regular maintenance
Endoscopy cart	Regular maintenance
TV monitor for endoscopy	Regular maintenance
Video Printer for bioimaging	Regular maintenance
Defibrillator	Suggested Purchase (1)
Pulse oximeter	Suggested Purchase (1)
Syringe pump	Regular maintenance
Electrosurgical	Suggested Purchase (1)
Monitor	Suggested Purchase (1)
Anesthesia equipment	Suggested Purchase (1)
Radioscopy equipment	Alternative Device
Endoscope reprocessing unit	Suggested Purchase (1)

C. Clinical Validation

The final step of the methodology consisted of the clinical validation of the plan, through the organization of specific panel of experts according to the medical area, which discussed the suggested solutions and validate the final version of the plan.

III. RESULTS

As reported in table I, the suggested special levels refer to a three endoscopic rooms activity, two for regular activity (HA1 e HA2) and one for emergency (HA3).

The more numerous purchases in HA1, according to the high workload coming from regular activity, depends on the fact that this equipment can be used for back-up (or alternative) technology for the area HA2 as well while HA3 define its own specific scenario with all the device 24/7 available but not necessarily used.

Moreover, the suggested levels were confirmed by the medical staff, almost the 50% of devices under "suggested purchase" had been already included in the hospital purchasing plan as back-up (defibrillator, electrosurgical and pulsoximeter).

IV. DISCUSSION AND CONCLUSION

Proper planning and specific procedures including recovery strategy [10] and BCM are essential for medical activity since although it is unknown when and where the failure will happen it will be very risky for the patients.

This study showed how, especially in medical facilities, the availability of an identical (or similar) device is the best and fastest strategy to recover the clinical activity. In order to do so, the proposed methodology provided with a quantitative reliable model, as showed by the clinical validation, which was able to quantify the minimum devices' number for guaranteeing both ordinary activity and business continuity.

Further validation on real life conditions is currently in progress as the model needs a reliable sample of failure scenarios.

Finally, future implementation regards the development of a metropolitan business continuity plan where each hospital makes part of a bigger health system. This would allow to reduce risk for patients and, at the same time, to optimize available resources for a sustainable solution.

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