Healthcare Lean Thinking: Simulation of an Intensive Care Unit (ICU)

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Abstract:- Hospital is an efficient company. To hack it, all hospitals are successfully implementing Lean Methods for benefits of patients, employees, physicians and hospital organizations in order to provide both better care, better quality and lower costs. This study’s purpose is to construct a simulation model of an Intensive Care Department; with the aim not only to simulate the behaviour but also to use it’s an optimal sizing tool. After a careful and heavy study about the Department’s functioning (from the perspective of the patient), we have built the model, using Powersim Studio software. Finally, we have validated the model, and to do it, we have required a hospital the opportunity to collect data in order to verify the goodness.

Key-words:- Healthcare, Lean Thinking, Quality, Pathways, Services, System Dynamics Simulation, Waste, Muda.

1. Introduction
Each production system uses resources to convert input in desired output. These transformation processes are carried out in different fields and what differentiates them is the nature of its output.

In the manufacturing system, goods distribution to customer follows physical good production process; in services case instead is just the opposite: at the beginning capacity to provide service has to be distributed, then service can be produced. Therefore “service industry” must consist of many activities to manipulate physical objects, human subjects and information that somehow affect each other, without, however, subjected a real physical transformation.

Main requirements of a service can be classified according to relationship between customer satisfaction and fulfilment degree of specific (figure 1). There are three types of requirements:

- Basic or implied requirements;
- Explicit or performance requirements;
- Exciting requirements

According to Kano model (figure 1) there are two kind of quality: Spoken Quality, which coincides with express requirements or performance (blue curve), Unspoken Quality, of which customer does not speak or because he is not aware (red curve is exciting conditions) or because he considered implicit in the product (green curve represents basic or implicit requirements).

Business future is all based on excitement quality.

In service organizations the backbone of activities is in the relationship consumer/producer because service production coincides with relationship with users, so it is important arise from the customer, understand what the needs and implement them in a more satisfactory.

2 Healthcare Lean Thinking
In the health sector, different actors conceive the Value concept differently. Often improving the value for a subject leads to degradation of a value by another actor. This means that quality is a concept at the individual level: doctor’s clinical value vs managers’ operational value.

According to Lean Thinking, Value isn’t an individual concept, but a system property, point of leverage of the system. When we speak about Lean, production is associated with it: being, however, a methodology that focuses on the customer and his
satisfaction, it is easy to associate it with health care world, where the spotlight is on patient and his health.

Hence the question at the centre of each Lean Organization: “What is the value?”. Toussaint and Gerard, in their “On the Mend” book, write in a hospital what is value is represented by patients health: patients want pain relief. Consequently, if an activity doesn’t help them to restore or to maintain good health, that activity isn’t an added value.

Hence the necessity of improving hospital processes. The Lean System’s goal is to eliminate waste.

According to “patient-in-process analyses”, Care Programme and Integrated Care Pathways can apply, in line with Lean Thinking.

In Care Programme all the activities are specified, coordinate and measured in order to provide health care services, focusing on an entire system of values, demonstrating their effectiveness in reducing symptoms and improving patient satisfaction.

Integrated Care Pathways is widespread and has many similarities with Value Stream Mapping tool and they are used to optimize Care Programme.

3 Delivery Process of Health Service in Intensive Care Unit

Intensive Care Unit is a structure within a hospital that is dedicated to the treatment of critically ill patients. Typical patients in intensive care unit could be those with multiple organ failures, respiratory arrest or any other problem that requires an intensive monitoring. Entering in the unit, it has the impression to access in a place, different from normal hospital departments: a high amount of equipments, absence of walls, high complexity care. For all these reasons, the Intensive Care Unit is required to overcome fragmentation of care pathways to promote the integration of facilities, services and resources, to implement an organizational procedure that encourages collaboration within and outside the department. In figure 3, many carried out activities in Intensive Care Unit (that involving patient) are shown.
4 Simulation Model

PowerSim Studio is the chosen software for construction and representation of model, able to graph any complex system to be analysed by SD method, translating into a transparent way to user the information into mathematical equations needed to model formulation.

First, we have constructed a physical flow, able to represent in brief way, the entire process that involves the patient from the access to the exit, as show in figure 4.

The level variables are three:
- Paz_in_ingresso: it represents the patients’ number who need to enter the ward, and the nit identifies patients’ number outside waiting to enter the ward;
- Paz_terapy: patients’ number actually used in the ward;
- Paz_uscita: those who leave the ICU

The flow variables are:
- Paz_generati;
- Ev_letto_libero: it is the flow that fills the second level, or rather that of hospitalized patients actually; this flow is constrained by the resource letti_disp, because ward hasn’t got infinite capacity, but limited. This means the patient comes only when there is an available bed to accommodate it.
- Ev_in_uscita: it allows the patient exit outside the ICU, regardless of exit type. There are five different exits: ordinary exit to patient’s residence, died, voluntary exit, exit to transfer to another department and exit to transfer to another institution. In all cases, expect for died, the exit depends on Ev_consulto, ie on the outcome of the consultation between anaesthetist and the head physician of the Department.

SnapShot variables are added, used as an alias origin variable: they are useful for connection of located variables in different parts of the model.

Physical Flow is activated by events, when they happen; they enable the level variables and ensure that patient can advance to the exit. Once bed has been released and patient goes to ward and is hospitalized, he is subjected to a series of activities.

Paz_terapy level is simulated by events chain that simulates the events sequence, characterizing each operational phase of process (figure 5).

Events chain is built considering flow chart of patient process. The levels represent different activities to which the patient is subjected within ward; from the moment bed is released, when he exits. The flows, however, represent pulses that generate state changes and allow to switch from an operation to the next, allowing the advancement of the flow. To activate the events, it must satisfy constraints, which are individuated graphically by SnapShot, seen as resources management (in which the passing time is the resource) connected by an arrow to the events themselves.

It begins with “paz_in_terapy”, initialized with a value of 1. Then, there is “ev_access” event, influenced by “ev_letto_libero” SnapShot and “letti Disp” SnapShot. This event is blocked only when in “paz_terapy” levelthe is at least one patient.

This event indicates the first activity to which patient has: once the bed is available, patient accesses to the care unit by a dedicated corridor, nurses ward are already prepared to receive it within an area at the end of that corridor defined “filter zone”. Furthermore, the patient is brought on a stretcher and is moved on the bed. It has therefore “spostament_letto” as a result of which there is “ev_collegamento” event.

When patient is moved on the bed, he is connected to machines above, in order to be constantly monitored and hold under control all vital parameters. The event is “ev_collegamento”, influenced by SnapShot “tempo_spostamento_sul_letto”. When “ev_collegamento” is activated, monitoring begins, after which it passes to the next event, the “ev_controllo”. This event influenced by SnapShot “tempo_macchine_collegate”. Then, it passes to “aesgn_terapy”, at the end of this there is “ev_cure” event. This last event is influenced by “tempo_di_cura” SnapShot.

With reference to events chain, after “tempo_di_cura” event, “ev_analisi” event is enabled, where patient, after therapy, has to take blood samples, in order to assess whether he
responds positive or negative to therapy. “Ev_analisi” event is enabled when the “tempo_di_prelievo” resource is spent.

Once “ev_analisi” is enabled, it passes to next event “ev_test”: it is enabled after “tempo_test” is run out. When “ev_analisi” is 1, “tempo_test” is enables and it empties like an hourglass.

After “tempo_test” event, “ev_test” event enables, that is set up when “tempo_consultazione” event is passed. Then, when “ev_consulto” is enabled, “spostamento_sulla_barella” event is activated and let’s move on “ev_trasporto” event, that is enabled when “tempo_barella” event is finished. At the end of this, “ev_trasporto” event is enabled, “lavaggio_bonifica” is present and then “ev_lavaggio” event will be after “tempo_lavaggio” is passed. At the end of “tempo_lavaggio”, “ev_lavaggio” is enabled and cycle ends and it begins from “paz_in_terapia” event.

After explaining construction model, we return to physical flow: a patient is hospitalized if and only is there is a bed. So bed resource represents constraints that must be satisfied, as all temporal resources. This resource is show in figure 6:

![Fig. 6: Management of available bed resources](image)

There are two levels: one represents “letti Disp” such as available resource and the other represents busy resource “letti Occup”. It starts from layer that represents available resource; once “ev_letto_libero” is activated, “letti Disp” scales of one unit and next “letti Occup” level increases of one entity. This happens each time “ev_letto_libero” is activated and until “letti Disp” resource doesn’t exauste. From the moment “letti Disp” level is zero, resource isn’t available and then patients don’t fit within the department. This resource will be available again, from the time in which “letti Occup” is decreased (“ev_in_uscita” event is activated and patient is out and a bed is delivered); a bed is now available and then another patient can be hospitalized.

The model evaluation is achieved by the consideration of some parameters of our interest. In this case:

- Patient that are on hold;
- Patient that are served (admitted in ward).

Before moving to simulation, let’s summarize input data:

- Tempo_spostamento_sul_letto, equal to 2 minutes;
- Tempo_macch_collegate, equal to 3 minutes;
- Tempo_di_cura, i.e. mean time spent in the unit (it has an exponentially decreasing);
- Tempo_di_prelievi equal to 3 minutes;
- Tempo_test equal to 3 hours;
- Tempo_consultazione equal to 15 minutes;
- Tempo_trasporto_in_barella equal to 2 minutes;
- Tempo_lavaggio equal to 20 minutes.

4.1 Vectored Model

This step allows having a better view about flow development. Vectors of 20 components are considered, corresponding precisely to material resources number. This means when patient enters, he takes up bed and begins all activities, and then a second patient enters and goes to occupy the second bed and begins the activities later then the first.

A third patient will enter, which will go to occupy the third resource. He will be in a time difference with the second equal to half compared to that with the first entered patient, and so on.

At the end of the events chain, the first patient will come out, releasing the first resource, but in the meantime, other patients will continue to enter and they will occupy the fourth, fifth resource and so on.

Switching from scalars to vectors have involved changes also in the used logic: instead if…then logic, loop for is used, that represents an iterative control structure.

Figure 7 shows the new physical vectored flow: vectors utilization is evident from the concentric symbols. In figure 8 the new-vectored chain is represented: the “controllo_pazienti” variable is introduced, which is influenced by the “ev_letto_libero” event, which in turn is influenced by “letti Disp” resource. Really, this variable controls, i.e. whether “ev_letto_libero” event is activated then patient passes and enables, together “paz_in_terapia”, “ev_accesso” event so as to turn whole chain.
5 Model Application

To confirm the goodness of model, we have considered a real case of a Neapolitan Hospital: Reanimation and Intensive Therapy Department data have been developed, implemented and structured. The collected data concern the trend of admissions, discharges and crossing times of each patient within the ward. We have found an input function of time between arrivals (of patient into the ward) approximated to a Gaussian with following parameters:

\[ \mu = 0.013889 \text{ paziente/hr} ; \sigma = 0.005322 \]

High variability of crossing times is present within the ward. Considering frequencies for each crossing time and representing them on a graph, where times are on abscissa axis while frequencies are on ordinate axis, we obtain figure 9. From this, one can infer that mean residence time of a patient within the ward is 293 hours, to about 12 days. Considering data input, simulation has started: some possible scenarios/iterations were analysed, whereas 20 beds, that represents the real actual number of beds. Results are shown in figure 10.

Three possible scenarios were considered, and it’s evident that the performance curves are more or less always the same. With regard “letti_disp” and “letti_occup” curves, they are one a complementary of other: this is already a first demonstration that model works.

With regard to “paz_terapia” curve, is evident that it has an increasing trend and it’s around an average equal to half of available resources. Really, it is clear that a sufficient number of patients in the year is not served and queues can be formed, risking to go in supersaturating. Really, from the model analysis, in particular from the hits number during last year, the existence of such queues has found, so we tend to waste minimization. For this reason, the first scenario considered a Dynamic Filter presence, where physicians of operative unit move themselves from this section to evaluate previously the accessibility of patient to the ward, according to actual degree of benefits that he could be learned. Considering a residence time with an exponential average equal to 120 hours, we have obtained the results, shown in figure 11. In the second model, long chronic patients were not considered, because they don’t take advantages of an intensive therapy, because of chronicity of their condition. We believe that an intensive care, which is beneficial of this solution, obtains a Gaussian as input function:

\[ \mu = 0.013889 \text{ paziente/hr} ; \sigma = 0.005322 \]

Fig. 7: Vectored physical flow

Fig. 8: Vectored events chain

Fig. 9: Patient Crossing Time

Fig. 10: performance curves in input and in therapy with a 293 hours mean time

Fig. 11: trend of a mean permanence time with exponential average of 120 hours
With a mean residence time, which results in an exponential average of 80 hours, it is possible to notice an increasing hospitalized patients number and a greater exploitation of resources.

Finally a third scenario is considered: it includes the Filter presence, doesn’t consider long chronic patients and even patients with respiratory problems that may still be treated at the first admission ward. For this purpose, a mean residence time is provided, with an exponential average of 60 hours, as shown in figure 13.

Here we have an optimization of available resources and served patients increase significantly: it’s possible to think to manage the hits with 14 beds instead of 20.

6 Conclusions
The presented model shows a significant diversity in the answers, in function of adopted policy management. Progressively, moving towards solutions that contain more leaness, we note that the ward assumes a greater correspondence to those is strict external stresses, represented by annual accesses in the same department.

These solutions present economic savings, optimizations of healthcare and provide, in most cases, absence of queues.

References:


