A System Dynamics Study of an Emergency Department Impact on the Management of Hospital's Surgery Activities

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Abstract: In Italian hospitals equipped with an Emergency Department (ED), it is possible that patients coming from such a structure occupy beds that had previously been scheduled for other patients. This happens because of some law regulations that give these kind of patients preferential access to hospitalization, and it may cause reduction in, or even stop, scheduled surgery activities. For such a reason operating theaters, surgery teams, sterilization structure, etc., are often unable to operate in an efficient way. Regarding costs and hospital management, this issue become considerable, and maybe even more unpleasant for patients on the waiting list since their scheduled surgery date generally is delayed by a long time. Studying an ED, the authors decided to build a System Dynamics model to analyze the impact of the admission from ED on other hospital structures, and thus identify the critical threshold. Some "non trivial" corrective actions have been evaluated in order to suggest how to address the problem which is currently causing internal conflicts and, if not managed, is destined to grow over time.

1 INTRODUCTION

The persistence of economic turmoil, which was originated in the U.S. due to subprime mortgages and the collapse of Lehman Brothers in 2008, has forced many sovereign states in Europe to take drastic policies to limit their debt.

Among all the financial measures adopted by Italian government, also the Healthcare system, with a level of annual costs out of control, became the subject of increasingly frequent budget cuts aiming to contain the amount of Healthcare spending which in 2010 reached 9,6% of the Gross Domestic Product.

As a direct consequence, managers of individual cost centers (Local Healthcare public utilities - ASL, hospitals, research laboratories) had to make a choice between two alternatives: on one side the so-called "linear cuts" to performances, on the other, the pursuit and elimination of systemic inefficiencies, usually quite spread in those systems. This second way of act is certainly more difficult but could allow to recoup the amount of money corresponding to lower state transfers, without negatively affect the capacity of healthcare assistance.

Thanks to the experience gained in recent years by the DIME research group in the healthcare management field, working jointly with some hospital managers particularly sensitive to choice the second route mentioned above, it has been shown how wide the scope for action for engineers trained in the management of complex systems (Cassettari et al., 2011); (Frigato et al., 1999); (Mosca et al., 2002); (Mosca et al., 2005); (Mosca et al., 2009); (Mosca et al., 2010); (Revetria et al., 2011). In fact, with this kind of background culture, based on the use of ideas and models from the world of production and services, it is widely possible to reduce systemic costs through significant improvements in management efficiency. This paper arises from a collaboration between DIME research

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group and Prof. J. B. Morrison from Boston's Brandeis University. It aims to show how, through the combined use of quantitative analysis and modeling tools (Briano et al., 2010); (Cassettari et al., 2010); (Cassettari et al., 2011); (Mosca and Giribone, 1982); (Mosca et al., 2005); (Mosca et al., 2010), it is possible both analyze and understand the reasons that underlie certain inefficiencies, and the consequences of any corrective actions, before they are adopted.

The subject of this paper is a classic theme, namely an analysis of the impact of an Hospital's Emergency Department (ED) on the beds management of the hospital itself. With specific reference to the examined case, it should be stated that there are two different kind of access to the hospital:

- Ordinary admissions: made through booking and then scheduled in the ordinary surgery activity ;
- Urgent admissions: admissions from the ED, affected by statistical randomness and with strict priority on ordinary admissions according to Regional laws;

This second type of access implies a possible negative impact on the planning of hospital departments operating on appointment (ordinary surgery). In particular, especially in conjunction with epidemic events, the hospitalization of these patients in surgical wards reduces availability of beds to those who are waiting for surgical operation, reducing, consequently, the activity of whole divisions. The obvious consequence is the negative impact on the operators' utilization indexes and the reduction in efficiency with the related increase in costs due to inactivity. In order to better understand the extent of the problem, it could be highlighted that the 54% of overall 2011 hospital admissions (9361 on 17305) came from ED (Table 2).

It may be interesting to observe how from the 80s up to now the proposed topic has been considered of primary importance by healthcare management scholars (especially in North America and Great Britain) and, consequently, is currently available an extensive bibliography on such a subject. For example it may be noted as in the U.S., between 1995 and 2005, while the ED visits increased of 20% (up to 115 million in 2005), the number of beds dropped by 134.000 units (Nawar et al., 2007), increasing the ED crowding (Asplin et al., 2003), and thus forcing many American ED to operate at peak capacity a day-to-day basis (O'Shea, 2007). In those circumstances it should be considered that usually the greatest part of hospital admissions from ED are ascribable to patients with a yellow code assigned them in the "triage" phase. The "triage" phase is carried out by specialized nurses and it consists into the assignment of a color code to each incoming patient depending on the seriousness of his conditions:

- Green/white code: non urgent patient, no risks in worsening his conditions, postponable visit
- Yellow code: medium critical level, possible evolving risks, possible life danger
- Red code: very critical conditions, danger of life, extreme priority

(*Italian Ministry of Healthcare, government ordinance, year 1992*)

Facing a specific request made by the hospital management, a System Dynamics (SD) model has been built in order to evaluate the impact of yellow codes on the hospital's beds capacity.

2 DATA COLLECTION PHASE

In a first phase an analysis on data extracted from the hospital database (related to year 2011) has been carried out.

ED inflows and outflows, and ordinary admissions data have been collected and then examined. This has been done in order to accurately assess the impact of the sum of these two contributions (ED + Ordinary admissions) on the hospital wards.

First step was the evaluation of different "color-coded" patients incoming to the ED and their destination after the ED physician visit (Table 1).

Table 1: Emergency Department admissions (2011).

Patient type	Entries	%Dismissed	%OBI	%Short staying	% Hospital admissions	% abandons & other
Red	1330	4.1%	5.5%	8.9%	78.9%	2.6%
Yellow	10879	39.1%	12.9%	8.6%	34.4%	4.9%
Green & White	41931	76.2%	2.5%	1.7%	7.0%	12.6%
From OBI	-	77.0%	-	4.9%	18.1%	0.0%
From SS	-	74.9%	0.0%	-	25.1%	0.0%
TOT. ENTRIES:	54140					

As previously stated in the introduction, each patient, arriving to the ED, is assigned a color depending on the seriousness of his condition. After the triage, the patient should wait in the queue or be urgently visited (depending on his code). The visit result could be:

- Discharge
- Admission to the Brief Intensive Observation (OBI) structure
- Admission to Short Stay (SS) structure
- Admission to ordinary beds (in hospital wards)

- Abandons and others (i.e. transfer to other structures)

The OBI is a ward inside the ED where patients could be monitored up to 24 hours. Patients coming out from OBI could be discharged, admitted to SS or admitted to ordinary beds. The SS is an hospital ward in which patients could be hospitalized in order to be monitored up to 72 hours. Patients outcoming from this structure are discharged or admitted to ordinary beds according to percentages shown in Table 1.

In the following modeling phase the authors decided to consider only the yellow-coded patients' flow because such a category is supposed to be the one which is most affecting hospital occupancy in terms of admissions per year.

Arrivals of yellow-coded patients have been sampled, grouping data by time slot (24 one-hour slots) in order to take into consideration the real arrival distribution of ED patients (Fig.1).

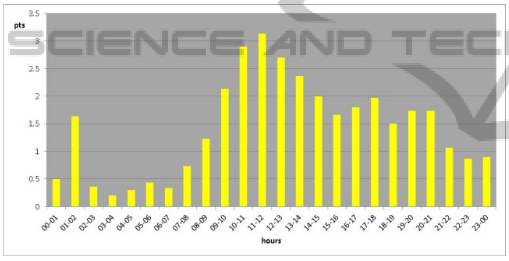

Figure 1: Hourly patients arrivals to ED.

Then, average Length Of Stay (LOS) both in the ED and in OBI/SS structures has been calculated.

Table 2: Hospital admissions (2011).

Admission sources	Hospital admissions (2011)	Average LOS (days)
From E.D.	9361	9.8
Ordinary admissions	7944	8.5
TOTAL	**17305**	**9.1**

Table 2 shows the average LOS in hospital wards calculated through data extracted from the hospital information system. This quantity will prove to be crucial as it will be explained later.

As previously mentioned, this data collection phase was just the necessary prelude to the modeling phase, phase that will be described in the next section of this paper. The model was developed both with a thorough analysis of the real operation of the Emergency Department, conducted through observation on site, and as a result of discussions and interviews with hospital staff.

3 THE SIMULATION MODEL

The authors decided to adopt a continuous modeling technique, the System Dynamics (SD), in order to analyze the behavior of the studied system. In literature some SD studies over emergency departments can be found: Lattimer et al. (2004) built a SD model to investigate ways in which patients flow through EDs and system capacity could be improved, Morrison and Wears (2011) evaluated the crowding phenomenon affecting emergency rooms, Morrison and Rudolph (2011) studied how the accumulation of small interruptions on ED's ongoing activities could lead the dynamics of such a system into a fragile, crisis-prone one. This methodology has often been chosen because of its dynamic complexity, and the delayed feedback loops imbedded in it, thus it was proved to be particularly suitable to study the reality under consideration (Homer and Hirsch 2006).

Fig.2 shows Author's model in a conceptual form.

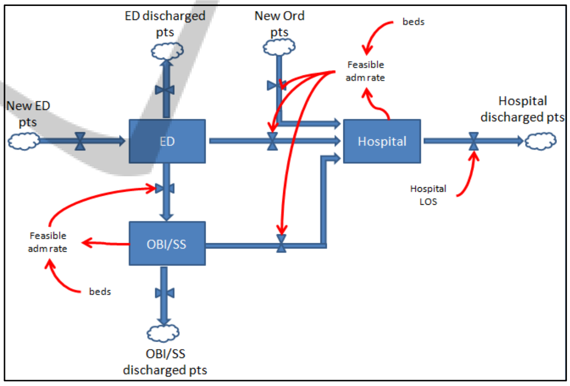

Figure 2: A conceptual scheme of the model.

Patients enter the ED and then, after a visit, could be sent home, or retained for a certain period in the hospital structures. In case of hospital admissions, this flow goes to overlap with the ordinary admissions flow (patients of pre-scheduled surgical operations). The admission decision, in both cases, is a critical point, strictly related to beds availability and Hospital Length Of Stay as it will be discussed later.

The simulation model, developed with ISEE's *iThink 9.1.4*, resulted to be a very complex model because of numerous variables and equations embedded in it (see Fig.3). Thus some conceptual schemes, with simplified illustrations, will be presented in the paper in order to allow the reader to understand the logical connections between main stocks.

Fig. 3 shows the Emergency Department block. Patient's flow enters to the ED block where it stays

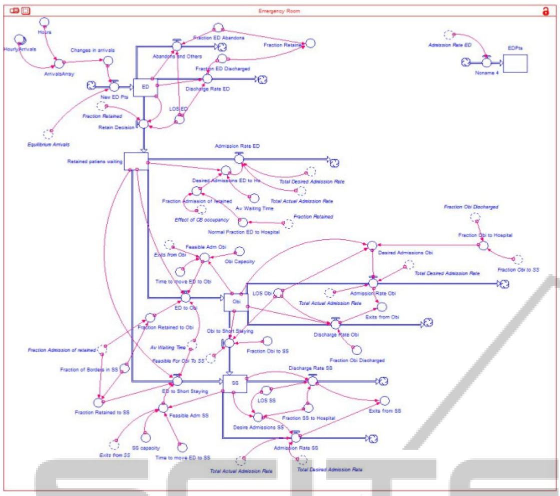

Figure 3: SD model – Emergency Department block.

Fig. 3 shows the Emergency Department block. Patient's flow enters to the ED block where it stays for an average time of 3,2 hours (ED LOS, calculated from hospital database), then a part of it goes out from the system, and another one is retained in order to be routed, at a later stage, toward Hospital, OBI, or SS. Patients are routed to these different destinations according to Table 1 percentages.

Both OBI and SS structures, and their related flows, work with the same behavior.

Patients flow addressed to ordinary admissions is routed to the *Pts in Real Beds* stock until its capacity has run out. When there is no more space in real beds, the flow goes to *Pts in Crisis Beds* stock and eventually, when even this stock is full, it goes to the *Pts in overflow* stock (Fig.4).

The "Hospital" block (Fig.4), which has a limited beds capacity, receives patients from both others model blocks ("ED" and "Ordinary Admissions"). Patients stay into the Hospital for an average hospitalization time (Hospital LOS), as shown in Table 2, and they are then discharged.

Ordinary admissions and discharges usually take place from 7:00 am to 5:00 pm, while admissions from ED occur continually during the 24 hours since they are emergency admissions.

Overall real beds among all Hospital's wards are 397, plus more 13 "crisis" beds addressed to face possible emergency situations.

In actual practice, since it is not uncommon for the capacity to run out, the medical staff is able to set up a number of additional beds in order to ensure medical assistance even in the case of capacity limit reached. In the modeling phase the authors deal with this practice creating the *Pts in Overflow* stock destined to receive patients not able to be hospitalized neither in *Pts in Real Beds* nor in *Pts in Crisis Beds.*

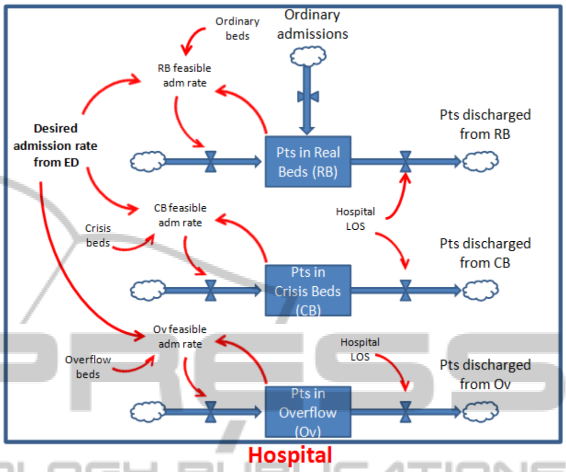

Figure 4: SD model, Hospital block – a conceptual scheme.

Third and last block is representing ordinary admissions dynamics (Fig.5).

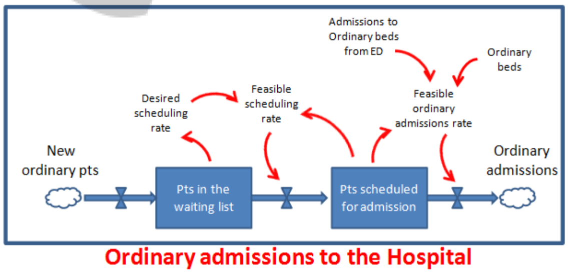

Figure 5: SD model, Ordinary admission block - a conceptual scheme.

New patients requiring surgical intervention are inserted on a waiting list, and then comparing the availability of beds with demand from PS, scheduled to be hospitalized. The model has been built by implementing a logic of "strict priority" which focuses on access from ED. This has been made in order to simulate the real behavior of the Hospital which must act this way because of regional laws' requirements.

Model has been validated through the Dynamic Equilibrium technique (Sterman, 2000) which states that the model reaches the equilibrium when all incoming flows equal the total of outcoming flows. In this specific case the equation is:

Hospital Exits = New OrdinaryPts + New EDPts (1)

Once the equilibrium condition has been identified, the model has been fed with real functioning ED data in order to evaluate its real behavior. In particular, yellow-coded patients' arrival distribution, daily ordinary admissions (from the Hospital database), and each structure LOS have been set.

4 SIMULATION RESULTS

Analyzing the simulations results it can be immediately put in evidence, as expected, the importance of the impact of hospitalization time on the Hospital's beds availability.

Fig. 6 shows the results of 4 simulation runs, each one with a different value of AvgLOS. Different colors have been used to draw each scenario's line:

- Green line: LOS = 10 d
- Blue line: LOS = 9.6 d (today)
- Red line: LOS = 9 d
- Purple line: LOS = 8.5 d

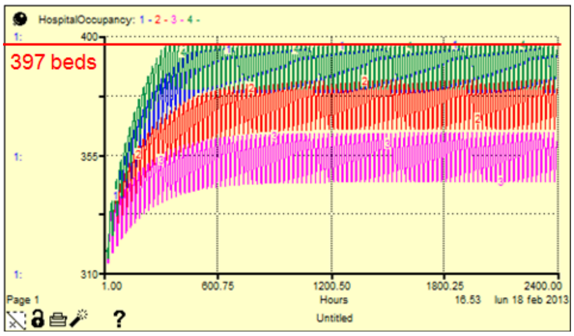

Figure 6: Hospital Occupancy during time vs AvgLOS

Oscillations in each individual curves are obviously due to the daily trend of simulation inputs (ED admissions and ordinary admissions) and outputs (discharges). All curves reach the stability condition after 600 simulated hours (as it can be seen in Fig.6); this could be considered as the model's warm up time, and so results could be reliable only after this period of time.

For a thorough analysis of the Fig.6 graph, the trend of crisis beds during simulation has to be considered (Fig.7).

Same line colors of Fig.6 have been used for all the simulation graphs presented in this paper.

Analyzing Fig.6 and Fig.7 graphs at the same time, the great impact of the hospitalization time on the Hospital's level of occupancy can be put in evidence.

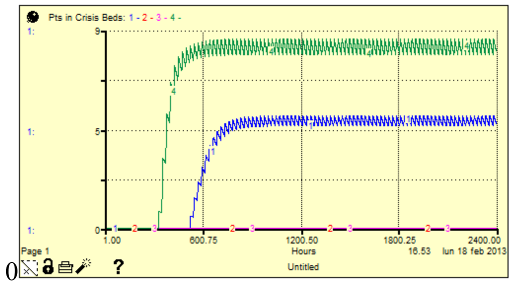

Figure 7: Crisis Beds Occupancy during time vs AvgLOS.

According to simulation results, currently (Average Hospital LOS of 9,6 days) Hospital is almost always working in bed capacity saturation conditions, and 5 additional crisis beds are necessary to face the admission demand. It can be observed that if the Avg.LOS grows up to 10 days, the demand for crisis beds would rise up to 9 (on 13 available crisis beds).

Both these results are worrying because it has to be noted that in this work the authors consider just the ED admission flow related to yellow-coded patients, and this doesn't obviously represent the total admission demand coming from such structure.

Other Fig.6's curves (red and purple) show the expected benefit from a possible decrease in the average hospitalization time.

If the Hospital management could achieve a 6,25% decrease in the avgLOS (from 9,6 to 9 days), the Hospital occupancy would stabilize around 380 beds (96% of total available beds) and thus no crisis beds would be occupied.

The expected benefit in the fourth scenario (purple line, 11,5% decrease in avgLOS) is even greater, with an occupancy level of about 90,6% of total capacity (360 occupied beds).

In order to complete the analysis, SS (Fig.7) and OBI (Fig.8) behavior in the four scenarios has been evaluated.

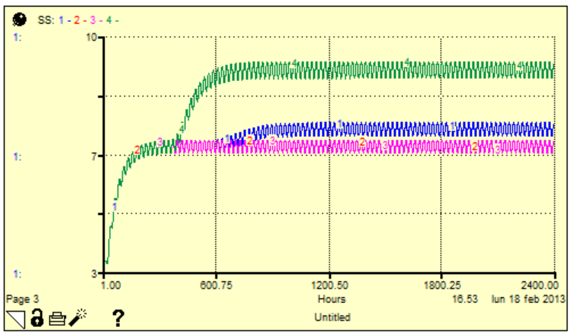

Figure 8: SS Occupancy during time vs HospitalLOS.

By looking at both graphs it is possible to observe how the demand for ordinary beds impact on OBI and SS occupancy.

When the Hospital is not completely full (red and purple lines), 7 Short Stay's beds and 3 OBI's beds are required, respectively on 12 and 8 total available beds.

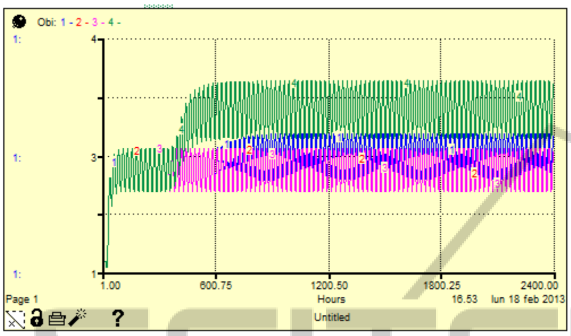

Figure 9: OBI Occupancy during time vs Hospital LOS.

On the contrary, by looking at the blue and green lines, when the Hospital's capacity reaches the limit, these two structures are affected by an increased demand for beds. In current case (blue line) the demand for SS beds increases of one unit, while the OBI occupancy remains unchanged. In the worst scenario (green line) the SS occupancy rises up to 9 beds, and the OBI demand increases by one unit.

Such a simulated behavior reproduces the reality in a very accurate way; the ED decision makers, in fact, use these two structures as a kind of "shock absorber" for the Hospital in order to drain the admission demand from ED. This practice could be considered as a "bad behavior" of the system because OBI and SS for their own nature should be destined to a different kind of patients. They should allow ED physicians to keep a certain percentage of patients monitored for a limited period of time (24 or 72 hours) whether their conditions are not completely clear.

Eventually, since only yellow-coded patients have been considered in this study, it should be noted once again that graphs shown in Fig.7 and Fig.8 are not representative for the real occupancy level of the structures. By completing the analysis with other patients' flows, is reasonable to expect a saturation of capacity for both structures

5 CONCLUSIONS

This study points out the criticality of the impact of yellow-coded patients on the ordinary surgery structures.

In order to avoid such critical situations, two strategies have been identified through the simulation analysis:

- Increase the number of available beds without change the LOS
- Decrease the avgLOS of 6,25%, passing from 9,6 to 9 days

However, the first strategy does not match with the current Italian trend of Healthcare costs reduction in which the decrease of beds is one of key points. This could be true not only for Italy, but also for other countries such as USA or England as well.

The second alternative, even if feasible from a management point of view, would need a non trivial change in some medical habits and it could be even seen like an interference of engineers in the physicians' decisions. The pressure on Hospital physicians to discharge patient in a shorter time, in order to increase the assistance capacity, could bring patients to revisit the ED and thus to increase the demand for hospitalization (Baer et al., 2001); (Jack et al., 2009).

Acting on their own capability in handling complex systems, the DIME-MIT group suggested a third strategy to slow down the problem at its source: this approach consists into contain the number of yellow-coded patients coming to the ED.

While the decentralization of some ED activities to 24 hours clinics is taking place, as advanced by actual government, it can be put in evidence that a great number of yellow-coded patients are originated by chronic ills (i.e. diabetic, heart patients) which do not comply elementary healthcare rules. This phenomenon in 2011 caused an overall LOS estimated in about 5000 days (considering all the hospitalization structures in the studied Hospital). A strategy to contain this problem could be the creation of dedicated outpatient clinics in order to monitor such kind of patients in scheduled visits such as happens for the precautionary screening of other diseases (i.e. colon tumors, breast cancers).

By adopting this strategy, hospitals would incur in almost negligible costs because these outpatient clinics would have to be open just a few hours a week, with scheduled visits carried out by ward's physicians in low workload moments. On the other hand, the advantages in terms of social costs and patients satisfaction would be significant.

The management of the Hospital appreciated such a proposal and then declared that they will seriously take into consideration the proposed solution.

6 FUTURE DEVELOPMENTS

To face the problem discussed in this work, the authors became aware of some problems affecting the operational functioning of the Emergency Department.

In particular it has come to light that the triage phase is not carried out with an adequate accuracy. In fact, a considerable percentage of hospital admissions (37%) is ascribable to patients previously identified with green code, while the greatest part of such category is supposed to be discharged, or in the worst cases, sent to OBI or SS.

On another hand, it has been pointed out that the great pressure on ED physicians, caused by white and green codes that usually represent the majority of ED accesses, has no reasons to exist. It is a non sense to wear out and divert such kind of emergency specialists with high frequency visits forced by the significant number of patients affected by low critical diseases. This kind of patients could be easily visited by young specializing doctors as already happens in the US. For such a reason, the authors are currently building a discrete event simulator in order to evaluate a possible ED re-organization. This re-organization will have to take into consideration the creation of a different path for white and green-coded patients among the hospital, in order to allow emergency specialists to take care of real urgent cases in a better way.

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