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Master of Science in Management Engineering

Analysing hospital resilience capacities to cope with maxi emergencies: a simulation approach

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Abstract (Italian version)

Scopo di questa tesi è dare un contributo al miglioramento delle strategie e pratiche di resilienza e di continuità operativa nelle strutture ospedaliere. I risultati raggiunti si ritiene possano offrire utili raccomandazioni ai manager ospedalieri che devono preparare le loro organizzazioni a far fronte a un evento di maxi emergenza. All'interno di questa tesi viene valutata la risposta del sistema ospedaliero applicando le indicazioni proposte dal PEMAF (Piano di Emergenza per il Massiccio Afflusso di Feriti). La presenza di un PEMAF è un requisito di accreditamento per ogni ospedale italiano dotato di un Dipartimento di Emergenza e Urgenza. Una simulazione *multi-method* in condizioni di routine e di emergenza, basata sul caso dell'Ospedale San Raffaele, è la base della metodologia applicata per l'analisi. Sono state condotte due campagne di simulazione per analizzare due diversi scenari, quello diurno e quello notturno. Nel primo scenario, la risposta del sistema ospedaliero, applicando le indicazioni contenute nel PEMAF, viene confrontata con due diverse strategie sviluppate per promuovere la resilienza del sistema ospedale e per preservare i processi di cura sia urgenti che ordinari. Nello scenario notturno viene valutata la robustezza del Pronto Soccorso, simulando diversi scenari di aumento delle risorse per individuare quello più efficiente ed efficace. Per valutare e comparare le prestazioni misurate in diverse campagne di simulazione è stato sviluppato uno specifico set di indicatori (KPIs). I risultati indicano chiaramente che, in caso di allarme di maxi emergenza, è ragionevole destinare immediatamente tutte le risorse disponibili al Pronto Soccorso, al fine di garantire la massima capacità di erogazione dei servizi medici. Viceversa, la riallocazione graduale delle risorse dal Pronto Soccorso alle attività ordinarie, anticipando in questo modo la loro parziale ripresa (*recovery*), consente un miglioramento delle prestazioni complessive del sistema ospedaliero, in termini di servizio ai pazienti, sia urgenti che elettivi. Per quanto riguarda lo scenario notturno, è emersa la convenienza di aumentare il personale disponibile in termini di chirurghi generali e anestesisti. La metodologia proposta supera alcuni dei limiti dell'attuale approccio presente in letteratura verso l'applicazione di tecniche di simulazione alla valutazione delle prestazioni del sistema ospedaliero in condizioni di emergenza. Questa ricerca mostra inoltre come ulteriori indagini potrebbero essere svolte approfondendo la rappresentazione dei processi effettuati in Pronto Soccorso o modificando la natura e l'entità dell'emergenza.

Abstract (English version)

The aim of this thesis is to contribute to the research and practice advancements on Resilience and Business Continuity Management in hospitals. The results achieved offer useful insights to hospital managers for orchestrating hospital resources to cope with a maxi emergency event. Specifically, the response of the hospital system to a maxi emergency event applying the indications proposed by the PEMAF (Piano di Emergenza per il Massiccio Afflusso di Feriti) is evaluated. PEMAF is a set of organizational and procedural provisions that allows a hospital to cope with maxi emergencies, and it is an accreditation requirement for Italian hospitals with Accident and Emergency Department (A&E). Multi-method simulation under routine and emergency conditions, based on a case study to support the likelihood of the simulated-performances evaluation, is the basis of the research methodology applied in the study. All the parameters quantified to develop the simulator are related to Ospedale San Raffaele in Milan. Two simulation campaigns were carried out to analyze two different scenarios: the daytime and the night one. In the first scenario, the hospital system response is compared with two different strategies developed to foster the resilience of the overall system and to integrate and preserve urgent and ordinary care processes. In the night scenario the ED robustness is evaluated, simulating different scenarios of resource release escalation to identify the most efficient and effective one. In both the simulation campaigns a specific set of KPIs was developed. The results clearly point out that, in case of a maxi emergency alarm, it is reasonable to immediately allocate all the available resources to the ED, in order to guarantee the maximum emergency services delivery capacity. Conversely, shifting resources gradually from ED to ordinary activities, anticipating this way the recovery to normal operating conditions, enables the improvement of the overall hospital system's performance, considering both urgent and elective patients. For what concerns the night scenario, it emerged the suitability of improving the available staff in terms of general surgeons and anesthesiologists. The proposed methodology overcomes the limitations of the current approaches towards the application of simulation techniques to the evaluation of hospital system performance in emergency conditions. This research shows also how further investigations could be carried out deepening the representation of the processes carried out in ED or modifying the nature and the magnitude of the emergency.

Executive summary

i. Introduction

In modern societies, infrastructures are becoming more and more relevant and human activities rely on their functioning (Ouyang, 2014) in day by day routines as well as in critical contexts: transportation, communication, health are just some of the areas of the network our society is based on and which strongly depend on the availability of infrastructures. As a result it raised along the years the necessity to designate critical infrastructure (Ci) to be protected in order to serve the population in case of emergency. In the most advanced countries, such as United States and Europe, but also Japan, Healthcare is considered as Ci. Indeed, Hospitals, clinics and public health systems have a critical position in the overall network of Cis for its role in delivering primary services to the population in the event of a crisis and in daily routines. Healthcare system criticality in case of disasters and high-stress events such as earthquake or terroristic attack is even more significant since, by one side, physical damage to these facilities or disruption of their operations could deteriorate the outcome of an emergency situation and, on the other side, demand of services and patients to be treated increases significantly with respect to day by day activities. This means that criticality does not emerge just from the necessity of protection, but also from the required flexibility to increase capacity. Towards the objective of a structured approach to guarantee the continuity of medical services in any circumstance, the concept of resilience is surely that with the highest momentum.

ii. Literature research and thesis proposition

The first step of the thesis development process was a review of the already existing contributions, with the aim of understanding the state of the art and identifying knowledge gaps to be filled. In particular the research has been conducted around the concepts of Resilience, Business Continuity Management (BCM) and Critical Infrastructure concerning healthcare. A common logic has been identified laying behind the majority of the contributions retrieved and along its main building blocks a cross sectional analysis has been conducted focusing therefore on the scope of work, the threat considered and the KPIs analyzed in the literature basis.

The literature review revealed gaps in the areas related to the development of business continuity plans and resilience capabilities to deal with maxi emergencies. In particular when it comes to compare different allocation of resources strategies to reconfigure processes in case of maxi emergency. Indeed, the interruption of ordinary activities is currently the most diffused decision to guarantee the maximum medical services delivery capability to Emergency Department (ED) in serving urgent patients. In addition, no particular attention is dedicated in literature to the analysis of the transient from normal operations configuration of resources to the emergency one and reverse. It arises therefore room for improvement in the comparison of different approaches towards the management of transients, with the purpose of fostering resilience at an hospital system level. The focus of the thesis was thus set on assessing the suitability of different resources allocation strategies oriented to maximize the continuity of ordinary medical services without worsening ED capability to serve the demand arising from emergency. In addition, from the interaction with the Ospedale San Raffaele (OSR), it emerged the necessity of analyzing different scenarios, in particular to distinguish the one characterized by an emergency occurring in working hours from the one during the night. The study methodology was a quantitative assessment based on numerical and multi-method simulation. In particular the analysis has been based on the information derived from the Ospedale San Raffaele (OSR) case. The main idea was to set up a systematic comparison of the resilience level of the hospital system facing a maxi emergency under different strategies of resources allocation. In the scenarios simulating an emergency triggered during working hours, the logic driving the work was to determine a potential improvement with respect to the current procedures to manage transients from normal operations resources configuration to the emergency one and reverse. Current strategies have been derived from the so called PEMAF (Piano di Emergenza per il Massiccio Afflusso di Feriti). On the other side, in the scenario simulating an emergency triggered during the night, it has been conducted an analysis with the purpose of identifying the critical resource determining ED medical services delivery capability to red patients in the temporal development of the emergency, and the most efficient way to improve it.

iii. Design of the simulation system and definition of the simulation campaigns

To sustain the research objective a simulator was developed through Anylogic, a multimethod simulation modeling tool. The simulation system design process was developed starting from a deep analysis of the processes carried out in OSR and on the available resources. The system was presented first in its normal operations conditions, so in its day by day routine. The overall scope of work has been split in sub-processes: for each of them it has been described activities, procedures and the rules that govern it. In particular it has been dedicated specific attention to the care processes undertaken in ED, in the Operating Block (ORs), in Intensive Care Units (ICU) and to those of hospitalization in wards. Each of these areas was analyzed independently and according to the way it interacts with the others in order to propose a schematization of the different processes. Thanks to this rationalization, all the resources consumed by the system are identified. Afterwards it was described the representation of the system in the software environment. The last phase corresponds to the description of the reconfiguration of resources to deal with maxi-emergencies.

The overall simulation system design relied on different sources of information, first of all a direct observation of the ED system and the interaction with the OSR ED SAD dr. Faccincani. In addition it was analyzed in depth the plan produced by OSR to accomplish with the legal requirement for all hospitals to have both external and internal emergency plans to cope with a Maxi-emergency maintaining a standard of treatment of patients comparable to that granted to the single patient. In particular it was considered the logic proposed by the so called PEMAF *(Piano di Emergenza per il Massiccio Afflusso di Feriti)* and its application in OSR.

Two different streams of analysis were identified along the simulation system design process and they represent the main topics assessed through the simulator coherently with the objectives set for the thesis. They can be summarized as follows:

1. PEMAF rigidity in activation and deactivation;
2. Night scenario medical services delivery capability;

The first one refers to the on/off approach stated in the plan that consists in activating and deactivating resources reconfiguration in one single step. The main consequence of this approach is the ordinary activities interruption as soon as the plan is activated and resumption when it is stopped. This approach is the one suggested by the PEMAF, it is summarized in figure0A and along the thesis it has been named "As-is" strategy.

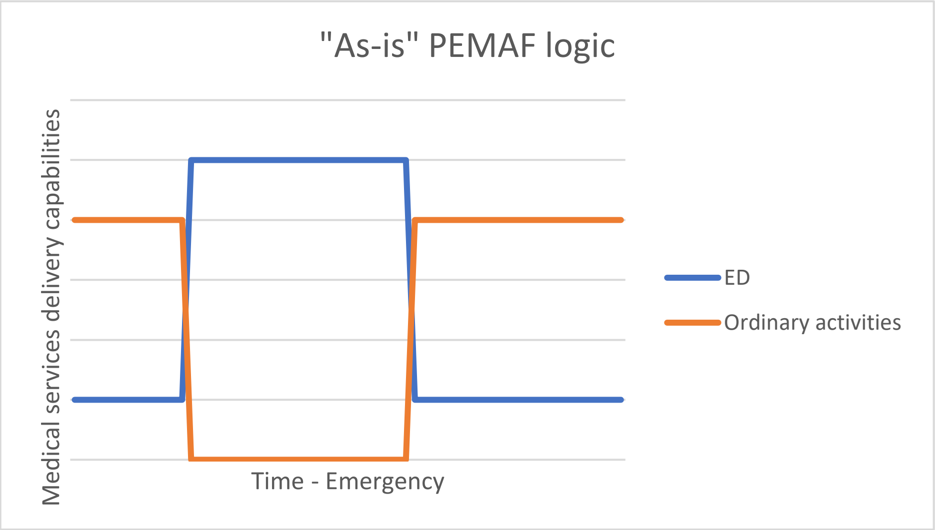

Figure0A Current medical services delivery capability distribution logic

Given these two premises, the simulator will be exploited to compare hospital system performance in responding to a maxi emergency applying the current strategy suggested by PEMAF and two more "flexible" strategies summarized in Figure0B and Figure0C. In particular, for this work thesis, ordinary medical services delivery capability is assumed as represented by the resources dedicated to ordinary patients in the operating block and wards. According to the logic proposed by the strategy named "StepsOnOff" ORs and beds scheduled to be assigned to ordinary patients are, conversely, allocated to demand arising from emergency progressively in time, as well as they are reallocated to ordinary patients gradually once the peak of patients arrival is over.

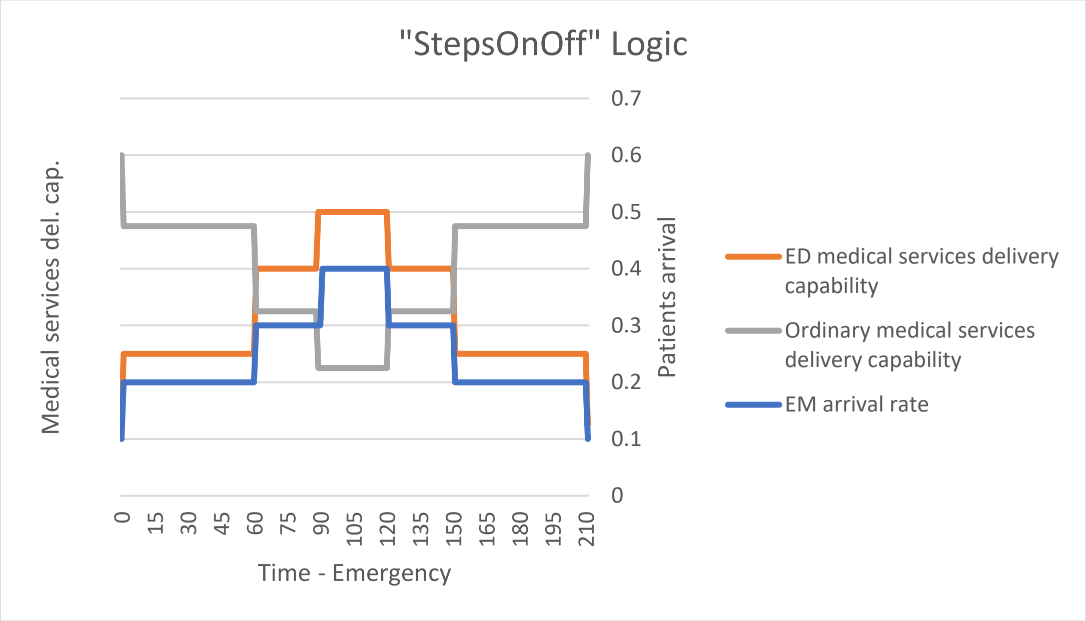

Figure0B, "StepsOnOff" strategy

The so called "StepsOff" strategy consists in an immediate allocation of all the available resources to the ED as in the "As-is" strategy, but a gradual reallocation of resources to ordinary activities in the transients from emergency configuration of resources to normal operations.

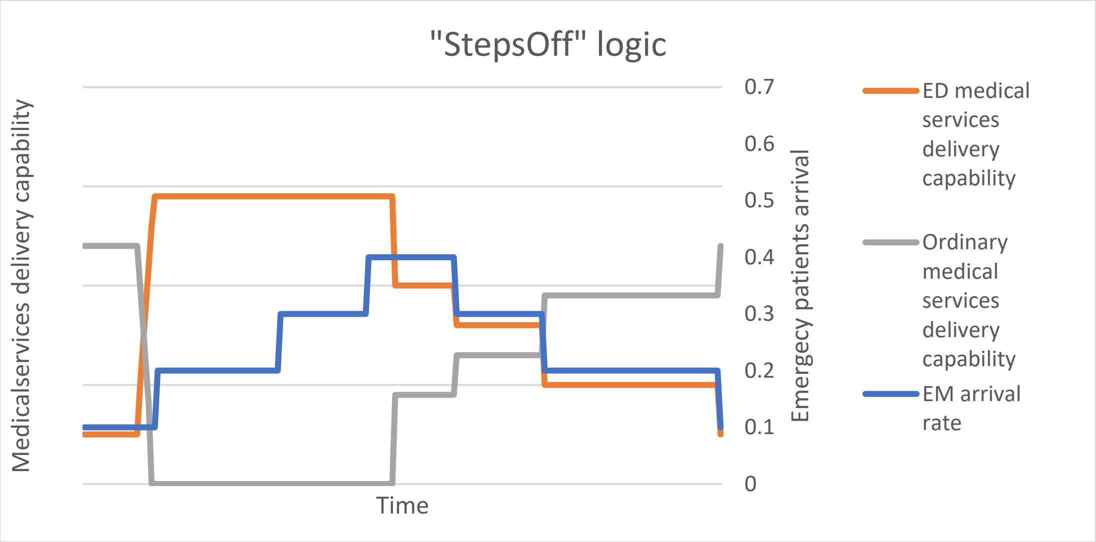

Figure0C, "StepsOff" strategy

All the strategies were analyzed both in a scenario simulating an emergency triggered during the morning and during the afternoon.

The second simulation campaign was focused on the scenario simulating an emergency triggered during the night. It was analyzed the current procedures and strategies to deal with maxi emergency in this scenario. It was proposed a time based analysis, in order to evaluate ED capacity of response to the sudden influx of patients *in time*, and not just according to the available staff, which is the current approach in OSR. Subsequently it was proposed an analysis on different scenarios proposing an increase in the availability of a different resource (staff or spaces) per scenario, in order to identify the one determining the highest improvement in ED medical services delivery capability.

To structure the simulation campaigns to be undertaken, it was assessed each of the three variables characterizing the cross sectional analysis on the literature basis: threat, scope of work and KPIs. In particular it was established stochastically a stressful event to be replicated deterministically in each simulation. In Figure0D it is depicted the temporal development (morning scenario) of patients arrival in the emergency event simulated. Red patients are 18 while the remaining 27 patients are yellow. A traumatological external event is considered. It is important to notice that this is extremely realistic scenario since numbers and percentages of patients are similar to real recent events, such as terroristic attacks.

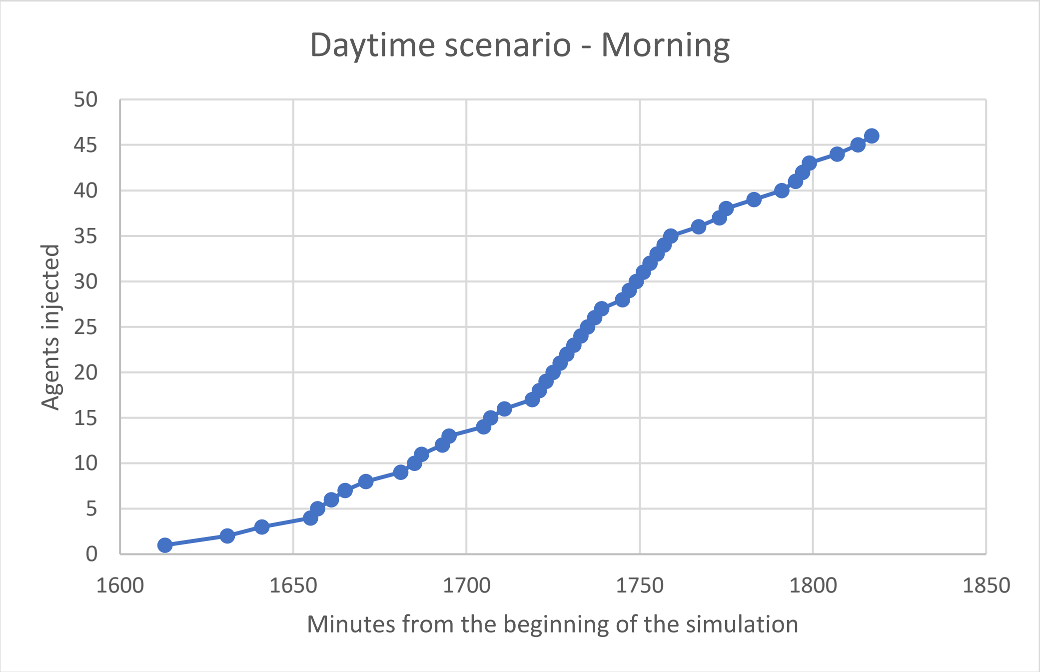

Figure0D,Temporal development of the emergency

Particular attention was dedicated to the structuration of a proper set of KPIs, considered as a lever to achieve the results set for the thesis. For what concerns the first simulation campaign, patients waiting time was selected as the parameter to base the analysis on. The AHP method was applied to assign weights to patients waiting time in different steps and phases of their care processes. The results of the AHP are reported in table0A. They have been applied to create the indicator "I" as the weighted average of the different *classes* of patients' (reported in the first column of table0A) waiting time for each minute of the simulation. It is assumed as waiting time representative of the 6 different categories of patients, the one of the last patient terminating its period of awaiting. In this way "I" is expected to give a representation of the overall hospital system performance (in terms of waiting time) along the simulation. 9 simulations have been run for each scenario, in order to compute the average trend of "I".

Yellow - ED	0.132
Yellow - OR	0.088
Green - ED	0.036
Red - OR	0.555
Ordinary - OR	0.153
Ward	0.036

Table0A, "I" weights

Starting from "I" it was determined the indicators "R' " and "R" as described below.

$$R' = \int_{First\ ME\ patient}^{Return\ to\ normal\ operations} "I"$$

$$R = \frac{R'_{Baseline}}{R'_{Strategy}}$$

To complete the analysis of the first simulation campaign, beside "R" it was considered the number of red patients at risk (PAR) in ED, so those patients not starting the care process in a sufficiently rapid manner.

For what concerns the second simulation campaign the KPIs selected are PAR and the number of patients treated at level of care lower than the standard (LLC), evaluated as the number of patients assigned to a team not composed by the expected staff.

iv. *Results summary*

Summarizing the results, the simulations run for assessing the hospital system performances in facing a maxi emergency through the PEMAF in OSR highlighted potential room for improvement. For what concerns the first simulation campaign, results are summarized in table0B.

	Morning scenario		Afternoon scenario	
	"R"	PAR [pt/sim]	"R"	PAR
"As-Is"	0.60	0.11	0.87	0
"Steps On-Off"	0.72	1.7	0.89	2.1
"Steps Off"	0.66	0.11	0.91	0.11

Table0B, Simulation campaign1, final synoptic

An additional parameter evaluated for each scenario is the time necessary for the system to return to the average performance level characterizing normal operations.

The results suggest that in the transient from normal operations to the emergency configuration of resources, the most appropriate strategy is that allowing to allocate all the available resources in ED, to deal with the sudden influx of patients. In this case it has been found confirmation on the validity of the strategy currently applied in OSR.

The second finding regards the transient from the emergency configuration of resource to normal operations. In this case the simulator suggested a potential improvement with respect to the PEMAF produced by OSR. In facts there are evidences highlighting the suitability of a gradual resources shifting from ED to ordinary activities. The main advantages are realized in a reduction of the disservice to elective patients and of unwanted effects on the system. Particularly relevant is the possibility to reallocate ORs to the most urgent scheduled surgeries. Last, the analysis carried out on the first simulation campaign consisted in comparing two different scenarios, one in which the emergency is triggered during the morning and one during the afternoon. The results suggest a higher improvement in hospital system performance due to resilient strategies when the pression over the system is higher. Referring to the two scenarios, it seems reasonable to claim that the afternoon scenario is less critical than the morning one.

For what concerns the second simulation campaign, results are reported in table0C which refers to the entire emergency lapse of time and proposes the comparison of ED performances in responding to the emergency in the "As-is" scenario and in scenarios in which the availability of one resource per simulation (first column) is increased (last column). 10 simulations have been run for each scenarios and

Resource increased	Avg PAR [#pat/sim]	Avg Max WT [min]	Avg Lower LOC [#pat/si]	Units added
As-is	8.2	37.7	5.4	
ShockRoom	8.40	35.80	4.90	+1
	6.67	35.35	5.26	+2
Anesthesiologist and general gurgeon	3.90	28.10	3.00	+1
	3.63	29.10	1.09	+2
Nurse and Oss	7.20	38.30	3.20	+1
	7.20	44.90	3.70	+2
Trauma Team	3.50	33.60	3.20	+1
	2.20	30.40	3.70	+2

Table0C, Simulation campaign2, final synoptic

Comparing the results with the ones characterizing the "As-is" scenario, it seems evident how increasing simply the number of shock rooms, so in general spaces, instruments and technology, does not improve the capability of the ED to receive red patients. Results are clear enough to affirm that, very likely, adding 1 anesthesiologist and 1 general surgeon is sufficient to reduce significantly the number of patients at risk as well as the number of patients treated at a level of care lower than the standard. The lapse of time in which the ED is able to serve the patients arising from the emergency passes from 95 minutes to 120, as a symptom of the higher robustness of the system.

v. Conclusions: implications, limitations and avenues for development

Beside the findings described in the previous paragraphs, it is worth to highlight the relevance of the methodology applied and the tool selected to sustain the analysis. In facts, the method developed for this work thesis is an evidence of the suitability of *events based* simulation integrated with *system dynamics* to obtain a quantitative assessment of the impact of an emergency on the overall hospital system processes. The methodology presented in this work study overcomes some limitations of the existing approaches towards the application of quantitative methods to evaluate the response of hospitals facing maxi emergency. In particular it suggests the possibility to maintain a systemic approach towards the overall hospital system keeping into considerations the most relevant processes and activities determining the performance of it. This is obtained both through a proper conceptualization and translation into the software of the care processes but also through a rational definition of KPIs able to integrate different dimensions of the hospital performance in serving patients in case of maxi emergency (Indexes named “I” and “R”). In particular, this work thesis proposed the application of this methodology towards the evaluation of different resources allocation strategies, highlighting the way resilient enabling strategies permit to improve the performance of the hospital system. This represents a contribution to fulfill the gap highlighted in literature, in the development of resilience capabilities in hospital, in particular to support the definition of business continuity plans. It is important to notice that the findings highlighted in the previous paragraphs can be viewed from two different perspectives, both helpful to fuel a more conscious resilient approach towards the resource management in hospital in case of maxi emergency. First of all, understanding and experimenting ways to reconfigure existing assets in order to determine the most appropriate one to face disruptive events is a resilience enabling practice. The second interpretation that could be given to the findings mentioned above, is the creation of a set of explicit knowledges that can sustain the HDM in the decision processes in case of emergency. In addition, the simulator developed can be considered as an useful decision support tool for hospital managers both at a strategic and tactical level.

At the end of the thesis some questions and several ideas concerning the obtained results raised, starting from the limitations and the assumptions made in this work which can be the starting point for further improvement. First of all, it is possible to see a weakness of the model in the representation of the medical area of the ED (green and yellow patients). Along the simulation system design process, in facts, a lower level of detail has been achieved in describing this area with respect to the one achieved in representing the flow of red patients. A deeper analysis on this area could open a further stream of analysis which is the one related to the best practices to be put in place to favor the process of ED immediate emptying in case of emergency. One of the most interesting aspects of the simulator produced is, in general, the possibility to consider it as a platform, as the core of a wider model potentially developable by expanding the modules considered. In the present work the ordinary activity of the hospital is represented mainly by ORs and wards, but it could be, of course, included many other areas of the hospital, or disentangled the ones considered in sub-areas according to the different specialties. One last remark refers to the possibility, even considering the same structure of the simulator presented in this model, to expand the analysis modifying the event simulated, both in terms of intensity and nature.

L’emergenza è come una scatola di cioccolatini,

non sai mai quello che ti capita

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CHAPTER1

INTRODUCTION

In modern societies, infrastructures are becoming more and more relevant and human activities rely on their functioning (Ouyang, 2014) in day by day routines as well as in critical contexts: transportation, communication, health are just some of the areas of the network our society is based on and which strongly depend on the availability of infrastructures.

However, recent catastrophic events threaten the functioning of infrastructures: natural disasters such as the hurricane Katrina (August 2015) and the Fukushima earthquake (11th march 2011), or terroristic attacks, like, of course, New York 11/09, but also the ones that hit Madrid (11th march 2004) or London (7th July 2005) and black outs like the one that occurred in Italy on 28th September 2003 are example of events showing the vulnerability of our society. Reasons for critical infrastructures becoming more vulnerable are generally recognized as the higher complexity and (Perrow, 1999), interconnectedness (Kröger, 2008) of our systems.

As a result it raised along the years the necessity to designate critical infrastructure (Ci) to be protected in order to serve the population. With this purpose, schemes, criteria and quantitative models are available, at a European level in an homogenous way, but also in the United States and in all the advanced countries of the world. Conversely, instruments to identify the necessity of protection of Ci, how to satisfy it, and to enhance its capacity to serve the population in disruptive events are still generic: of course Telecommunication, Transportations or Energy sectors acted as a tow in the process of definition of such instruments and a consistent body of knowledge was developed; the same cannot be applied to all the domains presenting Cis, such as the Healthcare one. Consequences of this delay in some sectors are many, from a Ci protection culture growing slowly and unevenly in different areas of our societies to the inefficacy of instruments.

Despite the relevance of the topic, there is not yet an unanimous agreement on the criteria that make critical an infrastructure, and they differ from country to country. None of the definitions of what constitutes a CI, given over the years, could be considered rigorous. They bound the issue somewhat, but leave plenty of room for interpreting which infrastructures fit the definition (Moteff, Copeland & Fischer, 2003). In 2008 the European commission defined Cis as “asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions"” (EC, 2008; art. 2a). As we can get from the definition, the understanding of critical infrastructure is necessarily negative, so understanding what may be the result of the critical infrastructure being lost or damaged. Therefore, according to the European commission, general areas of critical infrastructures are many, energy installations and networks, communications and information technology systems, banking facilities, health care facilities such as hospitals and research facilities, pharmaceutical production, means of food production and distribution, water storage and delivery, transport facilities, production, storage and transport of hazardous goods, and government services (European Commission, 2005). Similarly the latest PPD-21 (White House, 2013) identified 16 CI sectors in the US, namely: Chemical; Commercial Facilities; Communications; Critical Manufacturing; Dams; Defense Industrial Base; Emergency Services; Energy; Financial Services; Food and Agriculture; Government Facilities; Healthcare and Public Health; Information Technology; Nuclear Reactors, Materials and Waste; Transportation Systems; Water and Wastewater Systems. Even if lists and results are similar, we can say that CIs are of different importance in each individual country and each has defined its own CI sectors

1.1 Hospitals as critical infrastructures

In the most advanced countries, such as United States and Europe, but also Japan, Healthcare is considered as CI. Hospitals, clinics and public health systems, in particular, have a critical position in the overall network of Cis for its role in delivering primary services to the population in the event of a crisis and in daily routines. Healthcare system criticality in case of disasters and high-stress events such as earthquake or terroristic attack is even more significant since, by one side, physical damage to these facilities or disruption of their operations could deteriorate the outcome of an emergency situation and, on the other side, demand of services and patient to be treated increases significantly with respect to day by day activities. In addition, usually, hospitals are recognized as a point of reference to look for information or repair in chaotical situations. This means that criticality does not emerge just from the necessity of protection, but also from the required flexibility to increase capacity.

Despite the relevance of healthcare infrastructures, traditionally medical preparation for mass casualty and potentially disruptive events management have focused more on the scene and all the pre-hospital sectors, so more on what occurs out of the hospital, rather than on guaranteeing continuity of medical services *in-hospital*. A turning point in the approach towards this issue can be identified in the twin tower attack, 09/11, since it showed the vulnerability of the healthcare system and infrastructures. As a result, the homeland department of the US government produced the Medical and Health Incident Management System (MaHIM), (Barbera and Macintyre, 2002) which is a comprehensive and highly detailed functional system description for mass casualty medical and Health Incident Management. This document is particularly relevant because, beside practical and technical indications, it highlighted the necessity to start approaching hospitals as a critical infrastructure, determining major functional areas, activities and services that are essential for providing care to the patients reaching the facility.

1.2 Moving from security to Resilience

Towards the objective of a structured approach to guarantee the continuity of medical services in any circumstance, the concept of Resilience is surely that with the highest momentum. Traditional approaches towards business continuity and security in general, that are common in healthcare, have always been considered to offer efficiency under normal conditions but they may create gaps in care continuity and hide hazards that become evident when operations shift outside of normal conditions (C.Nemeth, 2010). However, during the 2005 World Conference on Disaster Reduction (Kobe, Japan) the model of 'safe and resilient hospitals' was promoted as a key component of disaster risk reduction planning in the healthcare sector and in October 2009, the National Infrastructure Advisory Council (NIAC or Council) issued "Critical Infrastructure resilience" a study that examined how critical infrastructures could become more resilient. These documents represent strong endorsements towards policies that "ensure that all new hospitals are built with a level of resilience that strengthens their capacity to remain functional in disaster situations" (World Conference on Disaster Reduction: 2005). In addition the NIAC introduced an interesting specification considering resilience not only to be a fundamental strategy that makes our communities better prepared, and our nation more secure but also to be often the most flexible and cost-effective strategy to ensure continuity of services and functions and to minimize the impact of disruptions

Despite its relevance, compared with some of the concepts developed along the years to define hospital capacity to cope with disasters, such as hospital preparedness, hospital security, hospital safety, surge capacity etc. resilience results to be the object of a smaller amount of studies and researches, despite these disaster concepts occur in isolation and therefore provide limited perspectives of disaster response capacity, in particular for highly uncertain, interdependent and dynamic environment, resulting in gaps, and, duplication (Zhong, 2013). On the other side resilience represents a property of the entire system and, if properly measured, can provide significant insights on hospitals capacity to ensure continuity of medical services in the event of crisis.

1.3 Room for improvement and research value

At the state of the art, hospital resilience is the new emerging trend, proposed and incentivized by international and local governments to ensure continuity. Different frameworks and tools have been proposed by international organizations such as World Health Organization or the Pan American Health Organization to assess safety and resilience of hospitals. A very wide range of concepts has been actually developed within the resilience framework, and some recurrent domains can be identified: hospital disaster preparedness and resources (disaster planning and procedure, crisis communications, community connectedness, available resources and logistics management), continuity of essential medical services (emergency medicine, medical continuity and surge capacity), recovery and adaptation (recovery, evaluation and adaptation) (Zhong, 2013). In particular, the assessment of continuity of essential medical services reveals the necessity of procedures to identify, prioritize and maintain essential functions. Despite a significant body of knowledge is already available on the identification of essential functions, the analysis on the possible strategies to maintain them is still lacking. In fact, some studies present the topic of hospital disaster preparedness or crisis management, but a systematic and comprehensive analysis to evaluate possible strategies to improve hospital resilience is still missing. In this context, this thesis overarching goal is to contribute to fulfill this gap, proposing a model and a method to assess and compare possible strategies to guarantee continuity of medical services; this model and the subsequent analysis are developed to improve and support the transition from security to resilience, evaluating different strategies for business continuity in terms of resilience, both from a strategic point of view, so in terms of resources dimensioning and allocation, and a tactical one so to determine effective strategies to improve resources management.

CHAPTER2

STATE-OF-THE-ART REVIEW

In this chapter it will be described the starting point of the thesis which is a systematic review of the literature. First, it has been carried out a research in order to gather all the relevant contributions within the domains of interest of the thesis, having this way a general picture of the state of the art. In particular the research has been conducted around the concepts of Resilience, Business Continuity Management (BCM) and Critical Infrastructure (Ci).

Then it has been performed an analysis on the collected knowledge, categorizing and classifying contributions with the purpose of identifying potential gaps in literature. From this analysis it will be then proposed the thesis proposition in detail trying to highlight its significance and value

2.1 Literature research

In this paragraph it will be described the different steps of the process applied to gather the contributions from the literature around the topic of the thesis, and how they have been evaluated in order to reduce the initial amount to a body of knowledge relevant for the scope of the thesis, and exclude those contributions out of it. Later on, it will be discussed the way the analysis has been organized in order to represent all the contents recognized as relevant.

Major electronic databases for publications, Scopus and WebOfScience, were searched to retrieve relevant publications, including articles, conferences reports and documents that may be applicable to study aims and objectives. The very first scan of the available literature has been run through 3 search terms, namely, (1) “Business Continuity”, (2) “Resilience” and (3) “Critical Infrastructure”. To limit the research at the healthcare context, a domain has been set, fixing “health* or hospital” as key words. For what concerns the Resilience topic, “hospital” and “healthcare” have been fixed as domains since, researching “Resilience” AND “health*”, a big portion of non-coherent contributions were included in the research. So basically the three sets of terms have been “Resilience” AND “healthcare” OR “hospitals”, “Business Continuity” AND “health*” OR “hospitals”, “Critical Infrastructures” and “health*” OR “hospitals”.

Topic	Domain
Critical Infrastructure	Health* Hospital
Resilience	Healthcare Hospital
Business Continuity	Health* Hospital

Table 1 Queries

All the types of documents have been included, so articles, conference paper, review and conference review. Subjects areas have been limited to health professions, engineering, business, management and accounting and decision strategies etc. so excluding all the medical disciplines, such as Oncology, Psychology etc. Results have been ordered according to the relevance score assigned by Scopus and WebOfScience. Results, in terms of numbers, of this first round are summarized in the table2

	Resilience	**CI**	**BCM**
Results of the queries (filtred per discipline)	1307	1410	251

Table 2 Queries filtered per discipline

The remaining items have been first filtered on the title of the source, in order to further exclude those topics out of the scope of the thesis. Results are summarized in table3, keeping the division into the three domains.

	Resilience	CI	BCM
Filtering on the source	701	952	251

Table 3 Queries filtered on the source

Further step of the analysis consisted in filtering according to the title. Results are summarized in table4

	Resilience	CI	BCM
Filtering on the title	115	67	62

Table 4 Queries filtered on the title

In order to define the final set of documents relevant for the scope of the thesis, a further step has been made analyzing the remaining items in terms of abstract and introduction in order to identify clearly the topic treated. Furthermore, from this analysis, it has also been possible to identify a structure to classify the knowledge gathered through this methodology. In order to be as complete as possible, relevant papers have been added snowballing from the publications already considered. Final results are described in table5

	Resilience	CI	BCM
Filtering on the abstract and introduction	58	30	35

Table 5 Queries filtered on the abstract

These have been examined at an higher level of detail and contents have been classified in the structure considered as the most suitable to represent the body of knowledge collected. Starting from this classification it has been possible to develop a deeper understanding of the main areas of interest.

2.1.1 Critical Infrastructure concerning healthcare domain

To present the characteristics of the literature collected revolving around the concept of CI applied to the healthcare sector, it is worth to notice that actually it’s just from the early years of the new millennium that hospitals, and the healthcare system in general, have been designated as a CI. Some authors identify 2003 as the first time. In that year

Homeland security department of the Unites States, in the National Strategy for the Physical Protection of Critical Infrastructures and Key Assets (2003) identified a set of essential infrastructure systems that cover a large number of sectors, including also the public health networks. As a result, the first relevant contributions in literature on the topic can be found at the beginning of the century, with an increasing development in the subsequent years.

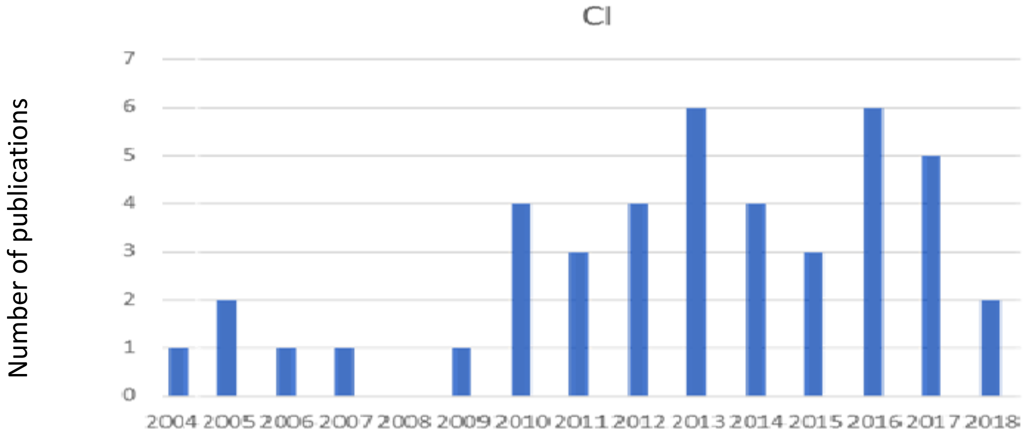


Figure 1 CI publications [2004-2018]

In addition, considering the time span within which the literature related to the subject developed, it results, reasonably, to be still "immature", since knowledge emerges to be still technical and practical, rather than theoretical. The level of maturity can be assessed looking at how the collection of documents and productions is structured. As a matter of fact, less than half of it comes from articles and academic papers. On the other side, a significant portion of the production regarding the concept of CI applied to the healthcare domain is still available as a conference paper or a book chapter. This can be considered as a clue of the low level of maturity of the knowledge around this topic.

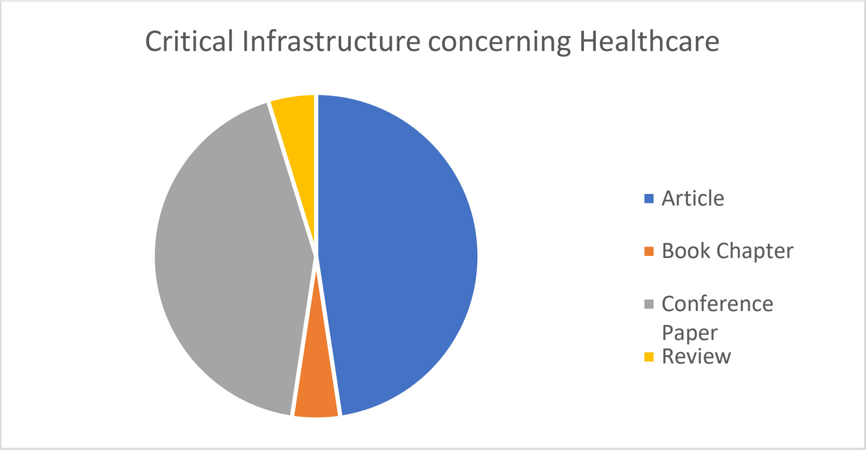


Figure 2 CI publications, source

Moving to the analysis, it is possible to affirm that the CI concerning Healthcare domain literature can be segmented into two streams, one focusing on the *internal vulnerability* of the hospital, and one on the *external interdependencies*. Of course it exists a certain degree of overlapping among the two: the factor considered to split the two segments lays in the approach towards the hospital. In the first case the focus is *within* the boundaries of the hospital, while in the second one the hospital is analyzed as a node of a network. It will be discussed also the intersection among these two approaches.

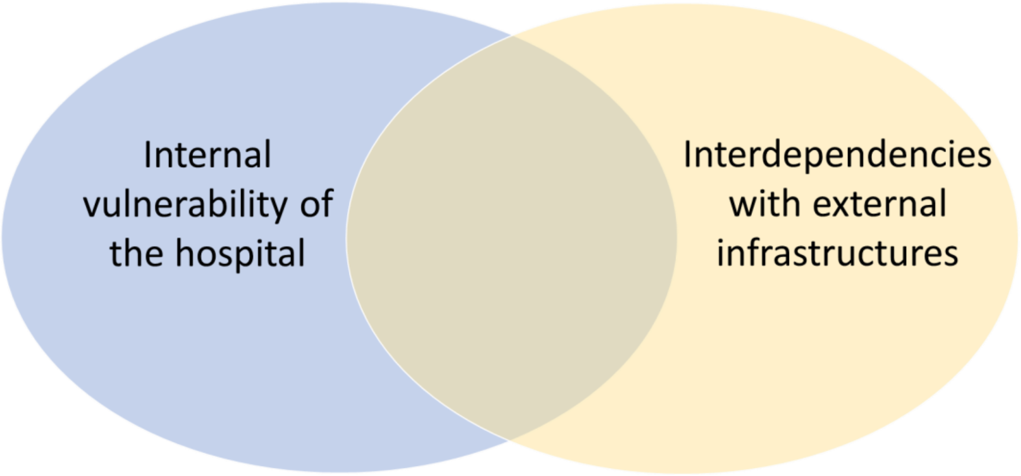


Figure 3 CI, representation logic

The first segment is about the assessment of the internal vulnerabilities of the hospitals as a facility. All the papers collected, in fact, propose tools and methods to assess hospital performances and the impact of hazards on them. Methods are mainly qualitative, such as surveys or semi structured interviews. These are developed assessing the impact of the considered hazard in past events, so mainly in terms of "lessons learnt". Approaches are rarely *all hazard*, more frequently they are strongly oriented towards a certain hazard such as terroristic attack or extreme weather events.

The first driver of analysis in this stream of literature is the identification of all the critical factors that may result in a source of vulnerability, in order to deal with the complexity of the hospital, where the performance levels depend on different factors. In Miniati, Iasio, Alexander, 2011, "the assessment […] includes the availability of staff, organizational procedures, developmental factors and physical and architectural elements" so, to synthetize, structural, nonstructural and organizational factors. This classification of factors will be shared also by other authors. In addition, According to Yavari, Chang, Elwood (2010) "Hospital functionality may be disrupted by structural damage to medical facilities, damage to non-structural elements or medical equipment, disruption of internal and external utilities and lifelines, or lack of key personnel due to fatalities, injuries or inability to access the hospital". This adds to the classification of factors mentioned before, also that of supplies. Structural, Non-structural, organizational and utilities are, to wrap up, the four major systems of hospitals treated in the body of knowledge revolving around the topic of Hospital as CI and that may induce its vulnerability. Non-structural factors represent a core topic for the majority of the papers and it is worth to detail how they are dealt. This is because, if on the one hand structural engineering has taken giant steps in making hospitals safe in its primary elements, it is not the same for what concerns non-structural factors. As an example, The California Seismic Safety Commission (CSSC 2000) found that the structural performance of hospitals in the Northridge earthquake (Los Angeles, 1994) was generally excellent. However, they also found that the nonstructural performance in these new facilities was often less than acceptable. The relevance of non-structural factors is the concern of many of the papers considered. Goulet in 2007 showed that as much as 80% percent of the earthquake damages to hospitals is due to nonstructural components (Goulet et al. 2007). A different degree of maturity in the readiness of structural factors compared with the one of non-structural factors is a common point to many of the papers considered. What differs is the *category* of non-structural factors representing the object of the research. In particular two different categories of factors are assessed: the vulnerability of non-structural physical elements, and the vulnerability of non-structural non-physical, so functions and processes. For what concerns the first category, in Reiser, Mahoney, 2012 it is proposed a list of non-structural elements that resulted to be a threat to life safety during the earthquake in the Bio-Bio province (Chile, May 2010). It considers elevators, Equipment scarce anchorage, Equipment on Wheels and others. For what concerns the second category, it is worth to have as a reference the priority definition of hospital functional areas during disasters proposed by the Word Health Organization in the Operational Framework for Building Climate-Resilient Health Systems (2015). An index representing the importance in emergencies is assigned to all the clinical and support services. A similar analysis is proposed in Myrtle, 2005, in which it is stated that “Trauma Unit, Surgical Suites, and Intensive Care areas form the critical core patient care areas in case of emergency”. As it will be described later, these kind of considerations are conceptually linked with the two remaining domains (Resilience and BCM)

The second stream refers to the assessment hospital external interdependencies as a source of risks in case of cascading effects, and the evaluation of proposals and solutions to improve the response towards emergencies. Both direct and indirect effects of other infrastructures failures on the performances of the hospital are considered. In this case methods are mainly quantitative with a large application of simulation techniques, from Petri Net modelling to System Dynamics. The relevance of the topic is agreed by all the contributions collected; according to Rinaldi, 2004, “omitting interdependencies will at best limit the validity of analysis and at worst lead to bad or inappropriate policies and decisions during crises or severe infrastructure disruptions”. Also in Prieto 2012 it is stated that “identifying […] infrastructure interdependencies is essential since healthcare systems do not operate in isolation”. A factor identified as critical in many papers, and enhancing the level of interconnectedness of hospital with other infrastructures, is the dependence on technology. The level of vulnerability induced by the interdependencies of the hospital with other CIs is found to grow steadily as the diffusion of technology and IT systems. In Setola, 2007 it is described the negative side of the technological dependence of hospitals. If by one side this improves the service towards patients, on the other side "unfortunately, this [dependence on technological infrastructures] introduces many dependencies and interdependencies links among the different components”. As a result “even if a network-based healthcare system is more robust than a model composed of many single ‘assets’ with respect to components’ failure, it appears to be more fragile to ‘catastrophic’ events". Also in Moon, Lee, 2013 it is possible to identify this concern, as it is recognized that “as infrastructures of a modern society have become increasingly interdependent, it is becoming more common to face unanticipated cascading failures, so-called rare disasters”. Similarly in Rejeb et. al, 2012, it is affirmed that “e-Health systems recognize the benefits of new Information and Communication Technology (ICT) in the delivery of healthcare services, but while these modern technologies have enhanced practices in the healthcare sector, the potential of failures to interrupt a process is still important”. On the other side, “the interconnectedness across scale and networks can encourage greater flexibility in planning and better coordinated response during disaster” and also "The key to the successful adaptation of an organization to a changing environment is to recognize and leverage the various sub-systems associated with that organization” (Barabasi and Crandall 2004). These last two contributions do not have a specific focus on healthcare, but resulted to be applicable to the healthcare sector as well.

Before going on it is necessary to specify that *dependencies* and *interdependencies* between infrastructures are treated as two different concepts. If by one side dependencies are univocal relationships, Rinaldi defines interdependency as a bidirectional relationship between infrastructures (Rinaldi 2004). One of the principal driver of analysis within this segment is exactly the identification of the interdependencies between the hospital and the overall network of infrastructures. Always in Setola 2007 the interdependencies with other networks are emphasized, focusing on three types of networks: In-hospital network, e-health services, National CIs (Setola 2007). Some complete frameworks for the identification of interdependencies and related risks are available. In Polinpapilinho F. Katina , 2014 six categories of interdependencies are proposed: Physical, Cyber, Geographical, Logical, Societal and Policy and Procedural healthcare interdependencies. It is worth to specify that the assessment of the impact of utilities failure represents an overlap between the first and the second stream, since, as utilities were a part of the analysis of the first one as a source of internal vulnerability of the hospital, in the second stream utilities are evaluated to highlight the potential cascading effects of the network failure on the hospital. To conclude the analysis of this stream it is necessary to mention also the topic related to the selection of performance parameters, so those parameters which are assessed to identify the effects of hazards in order to understand critical interdependencies. It is well accepted the necessity to consider time based parameters, in order to keep under consideration all the cascading scenarios arising from the failure of a node of the network in which the hospital is inserted in, but then parameters can vary significantly. In Abdullah Alsubaie 2015 the performance indicator considered is the number of patients treated per hour, while in Loosemore and Chow 2012 different key performance indicators which best represent the successful functionality of a hospital are proposed and described: access index, index of care, adverse non-admit events, adverse hospital events, time under care. These are computed at different time distances from the failure event. The topic of performance parameters will be deepened later.

As a final comment, it is interesting to notice that it exists a very limited portion of literature integrating the two approaches described up to now. As a matter of facts, just three items have been identified describing methods and approaches to keep into considerations both the assessment of the vulnerabilities of the hospital as a single entity and as a node of the network. In Brauner 2015 it is proposed a two-step framework: “the first step of the framework is micro-CI-orientated and focused on the vulnerability of the organizational units within a specific hospital, while the second step is macro-CI-orientated and addresses the different relevancies of CIs in a district”. Differently, in Arboleda, 2007 and then in Arboleda, 2009 it is developed a system dynamics simulation model which is the integration of two sub models: one to analyze the external infrastructure system and one to analyze the internal capabilities of the hospital. Both are divided into three steps, a normal operations model, a response to disruption model and a restoration model. This model is the unique attempt to integrate in a quantitative way both the internal capabilities of the hospital to face disruptive events, and the influence of external dependencies.

Segment	Papers
Internal vulnerability of the hospital	Mitrani-Reiser, Mahoney, et al. (2012), Guinet, (2015), R.ba, Masri, et al. (2005), Yavari, et al (2010), Chow, Loosemore, (2012), Chand, Loosemore (2013), Miniati Iasio Alexander (2011), Goulet (2007)
Interdependencies with external infrastructure	C Jacques, J Mitrani-Reiser (2014), C Balducelli, S Bologna (2005), C (2010), N.Nivedita, S.Durbha (2003), N.Nivedita, S.Durbha (2004), Achour (2014), Moon, lee (2013), M Loosemore, V Chow, (2013), Polinpapilinho F. Katina (2014), ED Vugrin et al (2015), Loosemore, Chow (2012), Ariel Prieto (2012), Alsubaie, Alutaibi, Marti (2015), Hiete, Merz, Schultmann, (2011), N Nukavarapu, S Durbha, (2016) Setola (2007), Rinaldi (2004), Rejeb et al (2012), Barabasi, Crandall (2004)
Internal vulnerability of the hospital And Interdependencies with external infrastructure	Brauner et. al (2015), Arboleda (2007), Arboleda (2009)

Table 6 CI publications

2.1.2 Resilience concerning healthcare domain

In this paragraph it is described the research done on the existing literature about the concept of Resilience, specifically concerning the hospital and healthcare context. As it was highlighted with regards to the literature revolving around the concept of CI, it possible to affirm that the attention towards the concept of Resilience applied to the healthcare sector started from the second half of the 2000's. Also in this case the profile of the curve describing the development of the production of papers is increasing until nowadays.

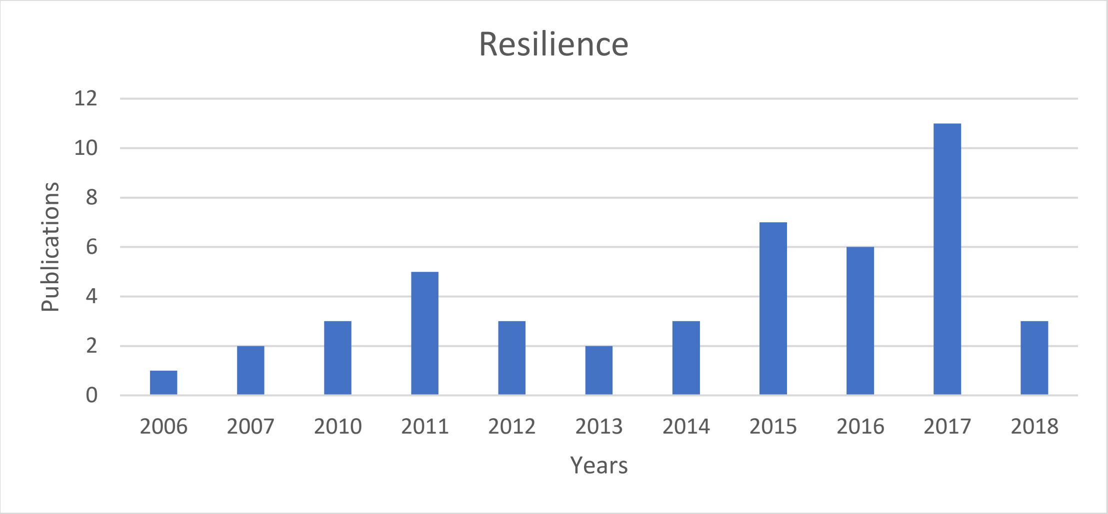


Figure 4 Resilience publications [2006-2018]

What differs from the previous stream of literature is the amount of contributions relevant for the research, much more consistent in this case, cumulating almost 60 relevant papers, showing the high level of attention and interest on the Resilience concept. This can provide a clue to explain the higher level of maturity, determined once more according to the types of documents collected. As it is possible to see in Figure5, the vast majority of the papers are articles, suggesting a strong theoretical basis.

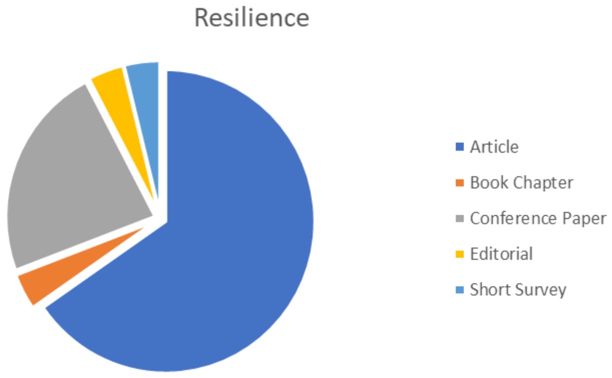
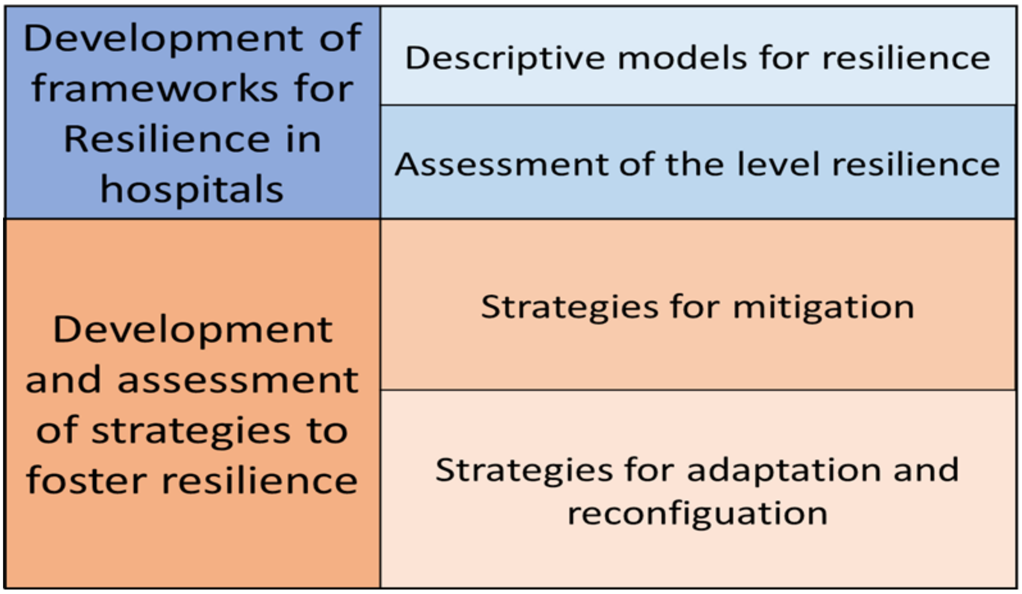


Figure 5 Resilience publications, source

Moving to the analysis, it is possible to affirm that the literature focused on the concept of Resilience concerning Healthcare could be segmented into two macro areas of analysis (streams). The first one regards the development of frameworks to shape Resilience in hospitals, while the second one regards the assessment or development of strategies to enhance the resilience of the hospital system.



Development of frameworks for Resilience in hospitals	Descriptive models for resilience
	Assessment of the level resilience
Development and assessment of strategies to foster resilience	Strategies for mitigation
	Strategies for adaptation and reconfiguation

Figure 6 Resilience, representation logic

The first sub-group of papers regarding the topic of Resilience in healthcare contains all of those publications with the aim of giving a general overview on the attributes and features related to the resilience property of the hospital system. In this case it is possible to identify two segments of analysis: the first one refers to the definition of descriptive frameworks, so models and schema to represent the attributes of a resilient Hospital; the second one, on the other hand, refers to the development of methods and tools to assess the *level* of resilience of an hospital, measuring it as a property of the system depending on its characteristics. For what concerns the first segment, many different frameworks are proposed. In this case methodologies are basically qualitative, such as Delphi methods or reviews of the available literature. The starting point for many of the papers collected is the so called "Safe and resilient hospitals' model, promoted as a key component of disaster risk reduction planning in the healthcare sector during the 2005 World Conference on Disaster Reduction, or the "Operational framework for building Climate-Resilient Health Systems", proposed by the World Health Organization. In the last one, six building blocks of a functioning health system are recognized to be strengthened in order to promote resilience: leadership and governance, health workforce, health information system, essential medical products and technologies, service delivery, and financing. The concept of Resilience is then declined in all the papers, providing different approaches towards it. First of all, in order to contextualize, it is worth to mention the different approaches towards the relation with Risk Management. In Labaka et. al 2015 Resilience is considered to "go well beyond traditional risk management methods by not only defining policies for facing expected events but also by taking into account unexpected events". According to Park et al., 2013 both approaches, risk management and resilience, must be combined to adequately cope with crises. In Simeone 2015, it is proposed a definition of Resilience as a best practice for risk management. Similarly in Devlen 2009, healthcare Resilience is considered at "the center of several integrated domains, including emergency management, risk management, safety/security, Business Continuity, disaster recovery and crisis communications". We can now move to the second driver of analysis of this segment: the definition of Resilience for hospitals. Since, basically, Resilience definition in the healthcare sector is just an adaptation of the concept developed in other domains, definitions do not differ significantly, despite different orientations can be highlighted. In Zhong 2013 hospital disaster Resilience is defined as "the capability to absorb the impact of disasters without loss of functions (termed resistance); maintain its most essential functions (called absorption and responsiveness); and 'bounce back' to the pre-event state (termed recovery) or to a new state of function (termed adaptation)". In Cimellaro 2010 Resilience is first defined in general terms and then applied to the healthcare sector. The definition provided views Resilience as a "function indicating the capability to sustain a level of functionality or performance for a given building, bridge, lifeline networks, hospital or community, over a period defined as the control time (TLC) that is usually decided by owners, or society”. To conclude, in Hollnagel et al., 2015 Resilience has been defined as ‘the ability of an organization to adapt to pressures and still produce good outcomes”. These definitions are coherent with the MCEER’s framework (Bruneau 2003) which is arguably one of the most used. This framework, which is not sector-specific, includes four criteria to describe resilience in a system: robustness, rapidity, resourcefulness and redundancy. Adapting the framework to the healthcare domain, it is possible to affirm that the extent to which the functionality of the hospital is maintained reflects the hospital’s robustness while the speed with which the recovery of function is achieved reflects the hospital’s rapidity. Robustness and rapidity can be improved by both preparedness and responsiveness activities (Bruneau et. al 2007), as it will be stated in the description of the second stream. In Zhong 2013 the four dimensions taken from the MCEER’s model are integrated with domains and management techniques typical of an hospital, creating a resilience framework tailored on the healthcare sector. In Labaka 2015 it is taken the approach proposed in Bruneau et al., 2003 and other papers, so to divide resilience in four dimensions (Technical Resilience, Organizational Resilience, Economic Resilience and Social Resilience) to create an holistic framework for CI, included hospitals. A different focus on the development of a descriptive framework is the one proposed in Kijihara et. al. 2016. It is developed a matrix of the functions and organizations that ensure continued healthcare services in a disaster, analyzing pre and post disaster phases.

The second segment of this stream refers to the development and assessment of tools and methods for measuring and quantifying the *level* of resilience of an hospital. As a property of the system, resilience is, in facts, function of the characteristics and attributes of the system. In this case qualitative, semi-quantitative and quantitative methods are proposed. First of all it is necessary to specify that, as highlighted in Zhong 2013, many instruments with associated measures for assessing *aspects* of hospital capacity in responding to disasters are available in literature. Dimensions considered may be hospital preparedness for disasters or hospitals’ response and recovery capability and surge capacity, but in all these cases dimensions are considered in isolation. A smaller amount of papers propose an holistic evaluation of Resilience. In Darrow 2017, it is described a tool named RAG (resilience analysis grid) targeted towards assessing the overall resilience of the healthcare system against disturbances.

It is done by gauging four capabilities (Monitor, Anticipation, Response and Learn capability) through a set of contextualized questions. In Cimellaro 2018 it is proposed a semi-quantitative method. Starting from extensive surveys and case studies, eight variables were selected as those most representative to describe the hospital's performance during an emergency. Then, through a factor analysis, three factors were found explaining more than 80% of variance of performances during emergencies. These include cooperation and training management, resources and equipment capability and structural and organizational operating procedures. A unique resilience function is then defined as a weighted average of the three factors. To conclude, in Cimellaro 2010 a framework for analytical quantification of disaster resilience is described, with an application to the healthcare sector. Functions to analytically quantify the four dimensions of resilience are described, as well as a Loss function, in order to achieve the definition of a unique disaster resilience function, combining information from technical and organizational fields such as engineering, social science and economics. In this last example, the focus is mainly on structural and physical components.

Moving to the second stream, it is possible to identify a segment of literature focusing on the assessment of the existing strategies to foster resilience or on the proposal of new ones. In both cases methods are mainly qualitative, such as the description of past experiences in crisis event and case studies, or extensive literature review. In particular, also in this case, two drivers can be identified: the first one is the evaluation of approaches and strategies to enhance the level of *preparadness* of hospitals, so in general proactive actions to build resilience in advance. The second one regards strategies to foster the *adaptation and the reconfiguration capabilities* of the system. This is coherent with the analysis on resilience proposed in the conceptual framework for health system resilience adapted by the World Health Organization (2015), in which resilience is viewed as function of two key components: vulnerability/preparedness and adaptive capacity. This means that hospital resilience depends on decreased vulnerability to the shocks brought by disasters and increased adaptive capacity brought by improved choices and opportunities. For what concerns the first driver of analysis, first of all it is worth to highlight the attempt in many papers to provide a definition to the concept of disaster preparedness. According to the International Federation of Red Cross and Red Crescent Societies (IFRC) (2000) "Disaster preparedness refers to measures taken to prepare for and reduce the effects of disasters. That is, to predict and, where possible, prevent disasters, mitigate their impact on vulnerable populations, and respond to and effectively cope with their consequences." Federal Emergency Management Agency (FEMA) defines preparedness as "a continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective actions in an effort to ensure effective coordination during incident response.". Specifically to the healthcare sector, many papers provide a complete framework for the definition of the necessary actions to improve the level of preparedness. In all of them, the starting point is the assessment of vulnerability elements. In Mulyasari et. al (2013) from the assessment of all the vulnerability elements, strategies for preparedness and preparedness classes of attributes are identified: structural, non-structural, functional and human resources are the identified elements. According to Bajow, Alkhalil (2014) "Structural preparedness attributes are essential in health facilities that determine the overall safety of the building, such as the foundations, the columns, the beams, the slabs, the load-bearing walls, the braces, and the trusses”. In Janius et al. 2017, it is stated that non-structural preparedness attributes include mechanical and electrical systems such as water utilities and power supplies, and referred to as critical engineering infrastructures. In addition, Bajow and Alkhalil (2014) add that architectural elements and equipment should be embedded into the non-structural preparedness attributes. To conclude Mulyasari et al. (2013) states that the functional preparedness attributes are stocks for hospital facilities in emergency, communication, and transportation while human resources preparedness can be evaluated as the disaster preparedness of medical and service staff. In Samsuddina et. al 2017, a similar framework, is proposed, distinguishing structural, non-structural and functional attributes, in order to assess the relationship between these classes of attributes and resilience indicators, so Rapidity, Robustness, Redundancy and Resourcefulness. This seems to be a good summarization of the contributions presented up to now, referring in an integrated manner, to structural, non-structural and functional attributes. A more dynamic framework describing the strategic process to *build* preparedness is described in McDaniels 2007, named as “ex-ante disaster management process for hospital infrastructures”. Also in this case the pre-disaster planning phase starts from the identification of hospital vulnerabilities, but differently from the frameworks mentioned above, the preparedness attributes are not considered in isolation, but as integrated and interrelated. In addition “the ex-ante and ex-post decision contexts are embedded within the overall activities of planning and mitigation for extreme events in specific infrastructure systems”. This introduces the contents treated in the second segment, so the assessment and improvement of the adaptive capacity of the hospital. As a general introduction, in McManus et. al, 2007 adaptive capacity is defined as the “ability of an organization to alter its strategy, operations, management systems, leadership structure and decision-support capacity to withstand disasters, generally by adopting adaptive qualities and proactive responses”. In this case it is more difficult to find papers or articles describing a comprehensive framework for emergency response. As stated in Smith et. Al 2010 “one reason a standard framework has not been proposed for, is that in most situations assessing emergency response capacity must be somewhat site and facility specific to be effective“. Nevertheless the importance of developing knowledge on the topic of proactive and reactive adaptive capabilities is recognized as maximum by all the papers collected. In Cimellaro 2016, the numerical results of a simulation model developed to evaluate the performances of an Emergency department illustrate that the waiting time of patients in case of emergency is significantly reduced when the emergency plan is active. Similarly, also in Kaushik et al., 2006 it is highlighted the importance for “all healthcare facilities to create, practice and implement efficient and effective disaster response planning to provide an adequate medical disaster response”. As a result, in order to fulfill the necessity to improve the knowledge in terms of adaptive capabilities without losing the specificity of the different contexts, a significant literature describing the lessons learnt from past events is available. In Aguirre, 2006 it is described the healthcare sector response to Hurricane Katrina, while in Ghanchi, 2016 some insights are proposed from the hospitals’ emergency response following the Paris Terrorist Attacks of Friday, November 13, 2015. In Labarda, 2017 the results of the analysis of two hospitals response to Typhoon Haiyan in the Philippines are described. As stated by the author, "factors identified as key in the recovery of the hospital to deliver health services were the following: commitment of staff and employees beyond the call of duty, readiness to serve even amid terrible circumstances and the presence of external support from the larger community and other health sector partners who helped in many ways". To conclude, as reported in Smith et. a,l 2010, it is possible to find categories used to evaluate a healthcare facility’s capacity to provide medical care services immediately following a disaster. These include: Current disaster planning strategy, Bed capacity, Surgical capacity, Blood transfusion resources, Supplies of medicines and equipment, Staff availability, Staff training, Communication facilities and clarity of message and Transport availability.

Segment	Paper
Development of frameworks for resilience in hospitals	Eric Toner et al (2018), Zhong et al. (2014), Cimellaro (2016), Malavisi and Cimellaro (2015), F Landegren, SM Sulaman et al (2016), Zhong (2013), Zhong (2014b), Darrow (2017), Cimellaro, Reinhorn (2016), Kajihara et. Al (2016), Cimellaro, Reinhorn (2011), B Aguirre, RR Dynes et al. (2015), Samah, Norazam (2017), Cimellaro (2018), F Kadri, S Chaabane et al (2015), Simeone (2015), Nebil Achour, Andrew D.F. Price, (2011), Devlen (2009), In Labaka et. Al (2015), Cimellaro, (2010), Bruneau et al. (2003), Park et al. (2013), Hollnagel et al (2015), Bruneau et al (2007).
Development and assessment of strategies to foster resilience	Chow, Loosemore (2011), Chand, Loosemore (2012), Loosemore, chow (2014), Farah Mulyasari, Satomi Inoue (2013), Ghanchi, (2016), Cook (2010), Labarda (2017), Aguirre (2006), Samsuddina, Takima , et al (2017), McDaniels, (2007), Miniati Iasio Alexander (2011), Chand, Loosemore (2016), Van Vactor (2011), Smith et al, (2010), J Rajamäki, R Pirinen (2017), Chand, Loosemore (2015), Albanese, Birnbaum et al(2012), MM Herrgard, APJ Rabe et al(2017), C Nemeth, R Cook (2007), M El Sayed, AF Chami, E Hitti (2018), Rejeb et al (2012), Achour (2010), Zehrouni, V Augusto (2017), C Cartwright, M Hall, ACK Lee (2017), BF Liu, BM Fowler et al (2017), MC Therrien, JM Normandin (2017), Cimellaro, Malavisi (2017), Y David, C Borrás, F Hosea (2015), Bruneau et al. (2003), Janius (2017), McManus et al (2007), Cimellaro (2016), Kaushik et al. (2006), Jafar, Taneja (2014)

Table 7 Resilience publications

2.1.3 Business Continuity Management concerning healthcare domain

Business Continuity Management (BCM) is evidently a very wide domain, characterized by a significant degree of heterogeneity in terms of methods, contents and objectives. These characteristics can be reconducted to two different factors: first of all the fact that terminology, concepts and techniques related to the topic of BCM in healthcare are derived from other sectors. Second, the strong interaction and intersection with other domains, such as Emergency Management or that of Resilience itself. Both these factors tend to determine a certain degree of heterogeneity in the production of papers, and, moreover, a low degree of specificity and detail, as it will be expressed later.

In order to be complete, also for what concerns this stream of literature, some figures are presented. First of all it is worth to notice that differently from the two other topics described before, that of BCM is an area explored by scholars and professionals since from the beginning of the 90's, and that the development of the discipline has an increase in the last decade.

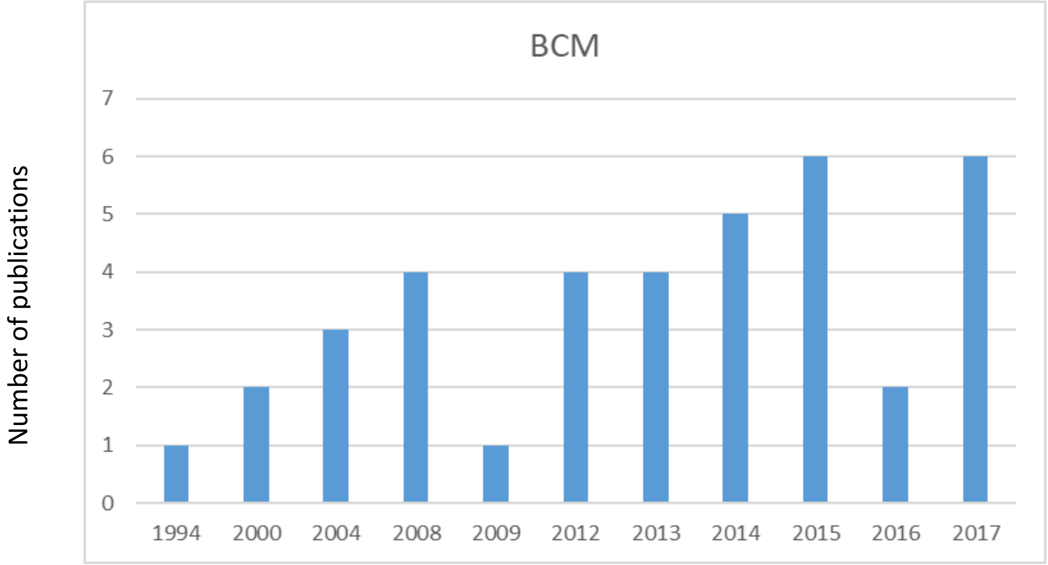


Figure 7 BCM publications, [1994, 2018]

Despite the time span in which the literature revolving around this topic develops, the amount of papers found to be coherent and relevant for the research aim, are quite few. As a matter of facts, few contributions focus specifically on the healthcare sector. Analyzing the sources and type of contributions collected, the result shows a significant portion coming from academic article.

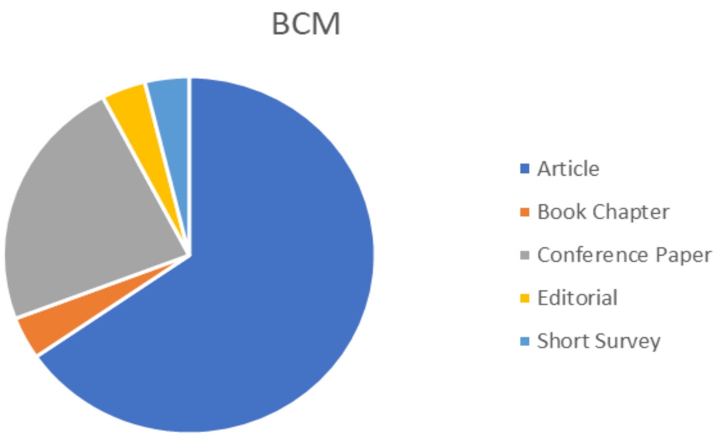


Figure 8 BCM publications, source

The result presented in Figure8 could suggest a mature and consistent literature focused on BCM concerning healthcare, but keeping into considerations also the scarce development, in terms of number, of the production of papers treating these issues, this conclusion has to be reviewed. As a matter of facts, the large majority of the knowledge in this field is actually contained in the technical documents produced directly by the single hospitals, governmental or non-governmental organizations and that are not available in the search engine that were searched for this research. This is one of the main reasons for the low level of homogeneity in terminology, processes etc. in this field. Along Chapter3 it will be proposed the analysis of one of these documents.

In order the represent the available literature it is possible to identify two different streams: the first one refers to the analysis and description of the BCM system overall. The second one contains all the papers discussing one single steps of a BCM system. This second segment has been subdivided into areas, related to the processes identified by the international organization for standardization (ISO) for business continuity management system (BCMS): business impact analysis (BIA), and business continuity plan (BCP). In addition also a third segment, named Incident response has been considered, in order to represent also a significant part of the literature revolving around this topic.

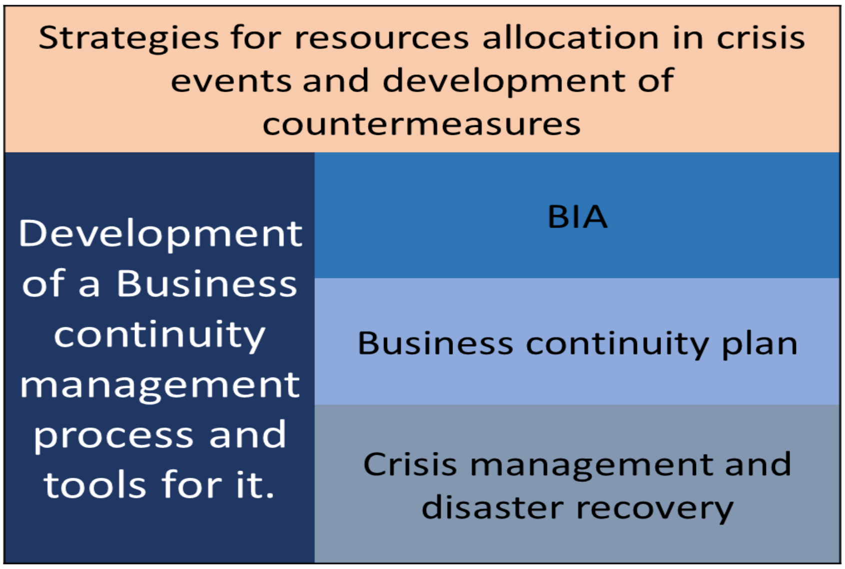


Figure 9 BCM representation logic

For what concerns the first stream of analysis, it is possible to identify two different drivers of analysis, the first one regarding the definition of the BCM system and its purpose in healthcare, while the second one focusing on the deployment and description of the different phases of the system, proposing a complete framework. As already introduced above, definitions and systems tend to be an application of the general frameworks to the healthcare domain. This is the reason why definitions partially lack in specificity. In the BS 25999 BCM (then withdrawn in 2012 (part 2) and 2013 (part 1) following the publication of the international standards ISO 22301) is defined as "an holistic management process that identifies potential threats to an organization and the impacts to business operations that those threats, if realized, may cause, and which provides a framework for building organizational resilience with the capability for an effective response that safeguards the interests of its key stakeholders, reputation, brand and value-creating activities". The vast majority of the papers collected rely on this definition. In Rejeb et. al 2012 this definition is considered in order to define BCM in health systems and it is assumed as a methodological framework "to ensure the ability to operate in spite of unforeseen events and recover from disruption in the shortest possible timeframe". In Geelen-Baass and Johnstone 2008 it is taken as starting point the definition proposed by Siutryk T. in 2000, in which it is stated that "BCM is a decision-making process aimed at maximizing business recovery and continuance following any disaster that may occur at any time". In addition the authors consider also the "whole business" approach to BCM provided by the Australian Prudential Regulation Authority (APRA) thought for the financial services. As recognized by

Cartland this standard is not confined to financial services but embodies best practice with application across many industries (Cartland 2004). This is representative of the approach towards the topic of BCM in healthcare, mainly based on the definitions borrowed from other sectors. Similarly, also those papers describing the entire sequence of steps mainly rely on the BCM lifecycle proposed by the British Standard Institute, or on other generalized definitions. In A. Zalewski, et. al 2008 it is actually pointed out that if by one side standards and guides provide a clear and consistent framework for BCM lifecycle, no standard format for the actual plan development and execution are available. This is probably the reason why, in order to have a satisfying degree of specificity to the healthcare sector, it is necessary to focus on the second segment of the stream literature in analysis, so on those papers describing uniquely one single step of the BCM system, rather than on those, few, describing the entire sequence. These are actually very generic. As an example, always in Geelen-Baass and Johnstone 2008 a general framework for the introduction of a BCM system in organizations is proposed; among these organizations also hospitals are considered. This is representative of the low level of specificity.

Moving to the second segment of the literature, the three different areas on BCM system we'll be now discussed separately. It is worth to notice that an uneven level of attention has been dedicated to them in literature. As a matter of fact, while many different papers and articles analyzed the topic of the application of Business Impact Analysis (BIA) in healthcare and that of Incident Response Management, it is not the same for what concerns the development of a Business Continuity Plan, as also anticipated above. In BS25999 BIA is defined as "the process of analyzing business functions and the effect that a business disruption may have upon them". In Jafar et. al, 2014 it is possible to find a relevant approach to the topic in the healthcare domain. It is affirmed that "to carry out an impact analysis for hospitals, there is a need to identify the core business sectors within a hospital, the core information required to treat patients in each area, core systems including equipment and facilities, the core skills likely to be required to do this, and also the people responsible for back up and restoration and key decisions". In particular, for what concerns the objectives of a BIA, it is reasonable to affirm that they are to identify the types of resources and duties that support business continuity; evaluate these resources quantitatively and qualitatively; determine how severe the results would be when each resource or duty is interrupted; classify resources according to their priority for business recovery; and confirm the important duties at individual level" (Okamoto et. al 2014) . Similarly, in Bandyopadhyay, 2000, BIA is explained as the process for "studying the effect that the unavailability of a system, activity or resource would have on different areas of the business". Some examples of applications in the healthcare sector are available in literature. In Masaki et. al, 2013 it is presented the application of a BIA in an Intensive Care Unit. According to the authors, "the information that must be managed in the BIA involves five aspects： critical activities, recovery time objectives, degree of emergency restoration, financial resources, and relevant department". In Bandyopadhyay, 2000 the focus is on the technology risk in the healthcare sector the importance of BIA is recognized as it leads to better understanding of "critical business functions which in turn makes the actual restoration more effective". In particular the gathering of data and documentation related to the various functional areas of an hospital phase is considered as the major component of this part of the BCM system. It is interesting to notice how the BIA represents, for many authors, the intersection with the Risk Management framework, as Risk Assessment and BIA are presented as complementary and the two major tools of understanding the organization in the context of BCM (Torabi et al., 2016). To conclude the representation of the literature about the BIA in healthcare, it is necessary to mention how, beside many other tools, it is widely accepted the relevance of the Hospital Safety Index as a tool for BIA, with slight modifications (Jafar, 2014) (Taneja et. al, 2017). This index was developed by a group of experts within a the Pan American Regional Office of the World Health Organization (PAHO/WHO). The purpose of this tool was to provide an affordable model for rapid appraisal of hospitals for estimating their probability of to cope with and remain functional in the event of a potential disaster. Despite it was not directly thought as a tool for BIA, some authors sustain that with slight modifications it can result in good basis for it.

For what concerns the BCP phase, in the BS2599, BCP is defined as "documented collection of procedures and information that is developed, compiled and maintained in readiness for use in an incident to enable an organization to continue to deliver its critical activities at an acceptable pre-defined level". In this case, the state of the art is much different from the one related to the BIA in healthcare. As a matter of fact it is very hard to find a relevant assessment of the topic providing meaningful techniques or processes for the development of a Business Continuity Plan in hospitals, as also already stated in A. Zalewski, et. al 2008. BCP are developed by several companies as a technique for crisis control, and several articles have described the importance of developing BCP for medical Institutions. However, there has been little mention of practical methodologies for BCP development in hospitals (Masaaki takemoto et al, 2013). In facts, different papers discussing the importance and the objective of a BCP can be found, few proposing a practical methodology for its development. In Kerr, 2008, it is recognized how an health care organization has a "significant number of critical business systems and therefore it is required to develop an all-inclusive plan that addressed the risk to patient care services". In Epich and Persson, 1994 the objective of BCP is defined as that of "ensuring the methodical re-establishment of business functions halted by a disaster". Finally in Bandyopadhyay, 2000, it is affirmed that "all the available strategies for recovery and resumption of an Healthcare Organization functions and processes must be evaluated and a cost-effectiveness analysis performed prior to the selection of appropriate strategies." For what concerns the small collection of papers discussing the approach towards the development of a BCP in healthcare, the common point is the necessity of a multi-level approach. In Rejeb et. al, 2012 it is proposed methodology which integrates two levels: a Strategic Level, represented by the continuity strategies, and an Operational Level composed by a set of procedures to be applied at the operations level. Similarly in Geelen-Baass and Johnstone 2008 levels are defined as Process Level and Corporate Level.

To conclude, the last sub-domain identified within the context of the BCM applied to the healthcare sector, is the one referring to Incident Response. Actually, all the papers dealing with the contingent management of the emergency have been made converging in this segment. Different standards for the contingent management of incidents in hospitals are available country by country. In the US, since from the 1980, it is widespread the so called Hospital Incident Command System (HICS). It is a standardized management system with clearly delineated and functionally based operating procedures for hospital disaster management and it is applied in the United States and also in other countries such as Japan. Differently, the Regional Office for Europe of the World Health Organization, developed the Hospital Emergency Response Checklist which is suggested as a guideline in Europe. In addition different terms can be found to describe the approach towards the management of disasters and incidents: Crisis Management, Disaster Management, Emergency Management, Incident response. All of them refer to specific approaches differing in terms of moment of implementation, only during the event or also before and after, and to the features of the process, and this, of course, introduces a certain degree of heterogeneity. In this section all the knowledge related to the reactive management of an incident in order to guarantee the continuity of medical services in an hospital are considered and reported. In Hendrickx et. al, 2016 it is described how the HICS should be integrated within a wider disaster response framework. The HICS represents the hierarchy to be rapidly structured in case of emergencies, while from a functional point of view, according to the author, three separate types of department can be identified, each of which is responsible for carrying out different tasks and have different requirements in case of an incident. These are "medical departments with hospitalized patients; medical support departments that are involved in diagnostic and/or therapeutic processes; and general support departments such as technical services, the information technology (IT) department, cleaning department and pharmacy". In addition, four response plans are considered as necessary to be ready for implementation: reception evacuation, relocation and isolation plans. Always in Kendrix 2016, and also in Sabbe 2013, it is suggested a particular focus on the classification of patients during an incident. Classification involves categorizing patients on the basis of mobility and duration of intervention if a diagnostic or therapeutic intervention is in progress. In Yu Wang, 2012 the same concern is showed describing the process, named Triage, usually performed by the first arriving emergency medical technicians, of assessing a group of patients' situations and assigning appropriate medical resources for treatment. based on their severity levels. In Moore 2017 it is proposed to extend the Triage methodology not just for the prioritization of patients, but also, more in general as a support "decision-makers in times of crisis by providing a simplified framework for decision-making based on objective, evidence-based criteria, which is universally accepted and understood". In Bongiovanni, 2017, the Emergency Management paradigm is assumed as best practice for fire emergency. The American Society for Healthcare Risk Management (ASHRM) identifies four steps that are involved in emergency management in healthcare facilities: prevention, planning and preparation, implementation and response and recovery, which are then deployed in detail. Specific emergency management components have been indicated to align to the BCM phases (Devlen, 2009), in particular "plan activation, emergency response and operations, incident command and emergency operations centers". To conclude, it is worth to mention the two seminal works by

Kento (2015, 2017) in which it is proposed a model to represent disasters in Hospitals and a subsequent system of countermeasures to face them, both proactive and reactive. The model contemplates, as it done also in Kendrixx at. al, the simultaneous presence of internal and external incidents, creating a “the gap between medical needs and the capability of delivering medical services”. According to this model a system of countermeasures is developed, comprising categories of countermeasures to “suppressing an increase in medical”, “Reducing to decline in capability”, and “Capability improvement when a disaster occurs”.

Segment	Paper
Description of an entire Business Continuity Planning process	Rejeb et. Al (2012), Hendrickx et. Al (2016) Briana NL Geelen-Baass and Jade MK Johnstone (2008), Raja K. Iyer, Kakoli Bandyopadhyay, (2000), Acosta J et al (2015), Kaneko, Takagi (2017), Kento et al (2015), Zhong (2013), Hirsch, (2004), Siurtryk (2000), Zalewsky et. al (2008), Cartland (2004), Kadri et al (2014)
Description of one single step of the Business Continuity Process	Eilia Jafar, Udita Taneja (2014), Torabi, Giahi, Sahebjamnia (2016), Masaaki takemoto et al (2013), Okamoto et al (2014), Moore, Bethany, Bone, Eric A. (2017), Yu Wang (2012), Hosseinijenab V (2015), Yu Wang, Louis Luangkesorn, Larry Shuman (2012), Eilia Jafar, Udita Taneja (2017), Bongiovanni (2017), Kerr (2008), Namoglu et al (2014), R Miniati, G Cecconi et al (2013), Parise et al (2015), R Gomes, LV Lapão (2008), Avisoa, A.P. Mayolb, et al (2016), Acosta J et al (2015), Kaneko, Takagi (2017), Kento et al (2015), Hirsch, (2004), D Smith, J Paturas, A Tomassoni (2014), Sabbe (2013), Epich and Person (1994), Devlen (2009).

Table 8 BCM publications

2.1.4 Analysis of Synergies and Intersections between segments

Figure 10 Intersections analysis

From the analysis described in previous paragraphs, it results evident the very high degree of interconnectedness between the three macro areas considered for the thesis. As a matter of facts, there are ambits of interest discussed within a specific area which are very close to the contents contained in sub-domains belonging to a different segment. To make an example, those works, results and contributions contained in papers described in the section related to the identification of vulnerability elements of Ci, intuitively, seems to be very interlaced and complementary to the analysis reported in the section related to the development of preparedness and mitigation strategies to enhance the level of resilience of the hospital. Similarly, the topic of adaptation strategies has been found out to be treated both by papers discussing the development of BCM practices in the healthcare sector, and in those regarding the enhancement of hospital resilience. Of course approaches and theoretical background may be different.

Given these premises it was expected to find papers retrieved through two or three different queries, so the subsequent paragraphs report the analysis made on that portion of literature falling within the intersection between two or three of the areas considered, so those contributions showing the explicit purpose to integrate at least two different areas of analysis. As previously done for the Resilience domain, the BCM domain and the Ci one, the literary contents are classified for understanding the domain's composition and for assessing the state of the art knowledge in this literature portion. Differently from the previous analysis regarding the three domains separately, the accounted contents are fewer. Indeed, even if a lot of papers embed elements slightly dealing with topics which could be shared with a different segment, they are not focused enough for accounting them in the intersection; in addition, in many cases, the potential intersection emerges just implicitly, and not as a clear purpose of the author. In order to make the analysis as objective as possible, just those papers retrieved from search engines through the queries described above and present in more than one segment have been considered.

2.1.4.1 Resilience And Business Continuity Management Concerning Healthcare

In this paragraph it is deepened the analysis of the existing contents in literature about the Resilience topics and the BCM ones, specifically concerning the healthcare domain. In the table below those papers referring explicitly to both the areas are reported. The identification and description of the relation between BCM and Resilience is the common driver of analysis that has been identified.

Driver	Paper
Identification and description of the relation between BCM and Resilience	Rejeb (2013), Zhong (2013), Jafar, Taneja (2014), Kadri et al (2013), Devlen (2009).

Table 9 Resilience AND BCM publications

Despite just those contents explicitly referring to Resilience and BCM are considered, it is fair to say that, in all the papers taken into considerations, the starting point and the core of the work is always just one of the two areas, with, in addition, a particular view on the other one. This is to say that the driver mentioned above, and that represents the touch point between the contributions considered, emerges mainly as a corollary to the core of the work, which is Resilience in some cases and BCM in some others. Nevertheless, all the authors agree in considering the continuity of the business as an element determining a resilient system, and so BCM as a lever to enhance the resilience of the system. In Rejeb, 2013 it is proposed an "approach based on BCM to ensure the ability to operate in spite of unforeseen events and to quickly recover from any type of business interruption”. As a conclusion of the work, which is mainly based on the ICT infrastructure of a so called “e-health system”, the author affirms that “BCM provides a framework to ensure the resilience of business processes, the ability to operate following a disruptive event and to quickly recover.” (Rejeb 2013). Similarly in Devlen 2009, it is discussed one approach to build a comprehensive business continuity program for healthcare organizations. According to the author this program will be a “roadmap towards Resilience in the face of the many risks faced by hospitals today” (Devlen, 2009). To conclude, in Zhong 2013 it results evident the way the continuity of the business, so the continuity of essential medical services, is a brick of the wall of Resilience, so just one of the necessary components to establish a Resilient system.

2.1.4.2 Resilience and Critical Infrastructure Concerning Healthcare

It is discussed in this paragraph the existing contents in literature about the topic of Resilience, specifically concerning and applied to the concept of Ci in the Healthcare domain. In table10 those papers referring explicitly to both the areas are reported.

Segment	Paper
Identification of hospital vulnerabilities	Chand, Loosemore (2012), Chand, Loosemore (2013), Miniati, Lasio, (2011), Achour (2014)

Table 10 Resilience AND CI publications

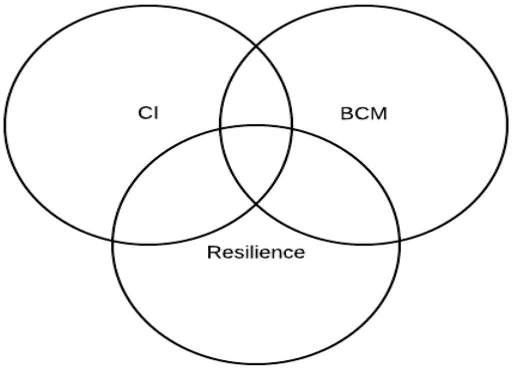
The most significant driver of analysis common to the papers considered in this section is the identification of vulnerabilities, so those areas of the system determining a lower level of preparedness of the system. These have to be determined in order to design mitigation strategies. In Miniati, Lasio ,2010 it is proposed a work with the purpose of assessing the elements of vulnerability of an hospital when facing the threat of a flood. The assessment includes the “evaluation of susceptibility and fragility” of nodes, as the hospital is a complex system where performance levels depend on different factors that require a multi-dimensional analysis. Susceptibility and fragility are defined by the author as indicators of a “lack of resilience of the system”. Similarly Achour, in Achour, 2014 proposes an analysis focused on the exploration of major and potential challenges facing healthcare facilities operation and specifically those related to utility supplies. The result of the work is the same as the one proposed by Miniati and Lasio, since "improving the resilience of utility infrastructure to natural hazards" is identified as one of the most appropriate strategy to mitigate the effects on the Hospital coming from the disruption of supplies. So to conclude we can say that according to the authors considered the relation between the vulnerability of Ci and its resilience in the healthcare domain is two way: by one side vulnerabilities reduce the level of robustness of the system, and so its resilience, while on the other side fostering the resilience of the components of the Hospital-system reduce the effect of its vulnerabilities. It results evident how scarce it is the deepness of analysis in this segment, since very few papers have been found out suitable to be considered in this intersection.

2.1.4.3 Triple Intersection

Lastly it is pointed out the triple intersection of the scouted domains, highlighting the very few presences of academic contents. In this case both the considered papers refer to healthcare network, in Brauner (2015) the integration of a micro (single Hospital) and a macro (Healthcare network) perspective, while in Loosemore (2013) it is treated the topic of the Inter-agency governance risk in managing hospital responses to extreme weather events.

Segment	Papers
	Brauner (2015), Loosemore (2013)

Table 11 Triple intersection publications



2.1.5 Literature cross sectional analysis

Reviewing the literature it raised the necessity to analyze it not just “vertically” but also “horizontally”, so not just deepening the three selected streams of literature (Critical Infrastructure, Resilience, and BCM concerning Healthcare), but also analyzing them transversely, in order to highlight common approaches or dissimilarities among the three streams. This approach differs from the analysis on the intersections presented in the previous section since it is not based on the contents and the results, but mainly on the methodology. In particular, the purpose is to *unearth* the *logic* behind the different papers; this was done to define the variables characterizing the majority of the works and that are able to discriminate one paper from the other according to the way these variables are considered.

The results suggest a common logic behind the papers considered, which is reported in Figure11 below. The majority of the works considered analyzes the way different *threats* affect the *performances* of the hospital taken into consideration.

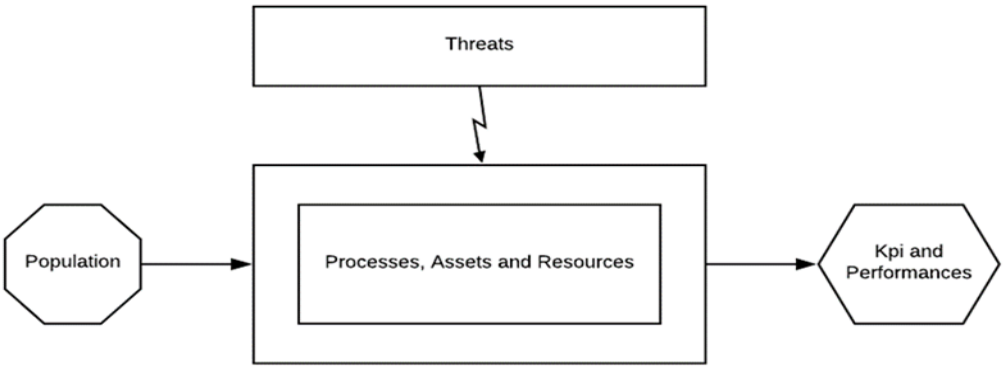


Figure 11 Cross sectional logic

Actually, the *scope of work* may differ from one work to the other since in some cases the entire Healthcare network is considered, while in some others, just a portion of the processes characterizing the activities of an hospital are taken into considerations, such as, for example, the Emergency department. Methods and tools applied have already been described in the previous sections respectively for each of the three streams therefore in the following paragraphs it will be presented the results of the revision on three elements: Threats, Scope of work and KPIs selected to measure performances. Of course the literature base taken into considerations is the same as the one described in the previous paragraphs.

Figure 12 Cross sectional literature research logic

2.1.5.1 Threats

In this first paragraph it will be described the way the literature is distributed according to the threat taken into consideration. As it was already stated, the purpose of the majority of the papers is, of course, to describe or measure the effects of the threat on system. From a theoretical point of view it is well accepted the double nature of threats on hospitals: by one side the increased amount of essential medical services due to the sum of medical needs that are newly generated by the disaster to ordinary medical needs. On the other side the potential damages to the hospital reducing medical service delivery capabilities. Both these aspects threaten the balance between demand of medical services and medical service delivery capabilities. Despite many papers include this element in the theoretical background, it’s very rare to find papers analyzing both the threats in an integrated manner. Kento 2015 and Kento 2017 are two of the few examples.

Among the 123 items retrieved from the queries described at the beginning of the revision, 30% of them takes an all-hazard approach. In this category it has been included that portion of papers referring to a generic threat, not specifying the nature of that. An interesting distinction that is present in some of the contributions considered in this segment is that between a shock event and an event that manifests itself as a continuous pressure over time.

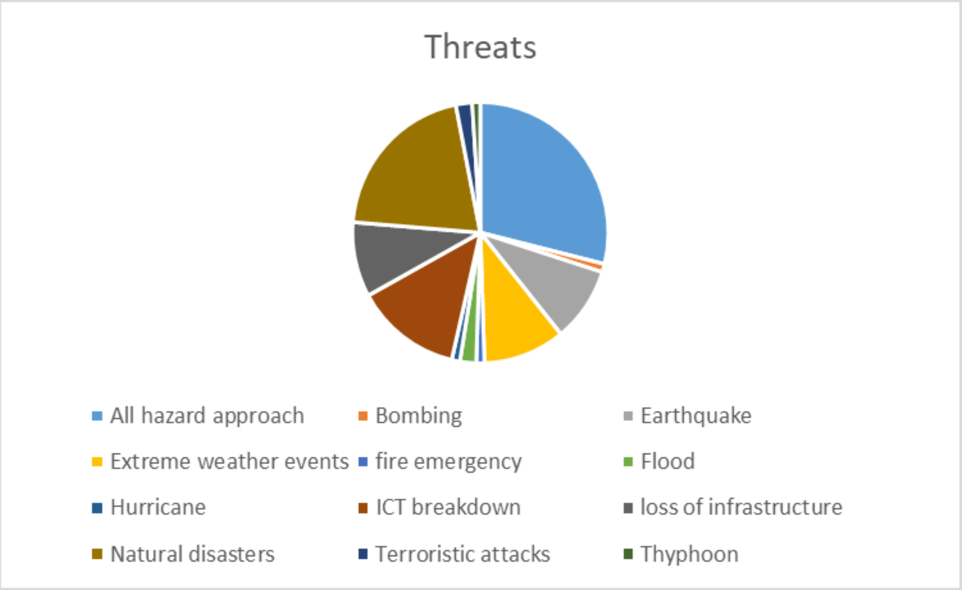


Figure 13 Sources of threats

In the remaining 70% of the cases, a specific threat is considered. This means that also effects and consequences are not generic. By one side this poses, of course, a limitation to the generalizability of the considerations but permits to go more in deep the nature of the event. In particular 43% of the papers are related to extreme natural events. This makes the topic of extreme natural events the most treated one, despite, as already mentioned, more in terms of damages to the physical infrastructure rather than in terms of sudden inflow of patients. Within this sub-group, earthquakes, hurricanes and extreme weather events are the threats more frequently discussed. Among the residual 27% of the papers, those focused on non-natural threats, the loss of ICT infrastructure is a very significant topic, since in almost 25% of the cases it is the object of the analysis. To conclude, what is interesting and surprising to notice, is that just very few works are centered on terroristic attacks.

2.1.5.2 Scope of the study

In this paragraph it will be presented the results of the research on the second variable of the *logic* previously described: the scope of work. This analysis has been conducted with the general purpose of understanding where the authors put the borders of their work, what is inserted and what is left out.

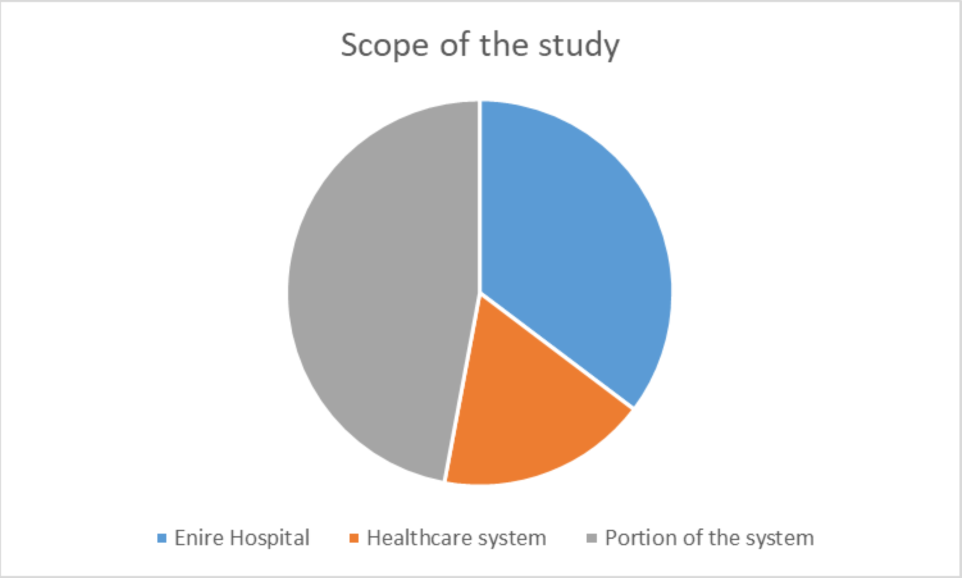


Figure 14 Scope of the study

In a very first step papers have been classified into three categories according to the extension to which they considered the healthcare domain: Healthcare system, Entire Hospital and a reduced portion of the System. In the first category it has been inserted each work considering the Hospital as a node of a wider network composed by other Hospitals, but also general practitioners, clinics etc. Almost 15% of the papers have been inserted within this category. Drivers of analysis within this domain are mainly two: the importance of Hospital coalitions in the response to disasters, and the role of hospital in the community resilience to disasters. In the first one it is discussed the way interconnectedness with other hospitals may play a role in enhancing the capability of managing and responding to extreme events. In the second one the hospital is presented not just as a node for the supply of medical services, but as a point of reference of the community in case of disaster.

Moving to the second category, that named Entire Hospital, it has been considered within this domain each work focused just on the single hospital. The hospital, in this case, is analyzed in isolation with respect to the rest of the network, but in its entirety, so as a complete and finite entity. This category represents 35% of the cases and works are focused on the hospital-system response to a crisis condition. Generally these are mainly qualitative studies, based on the description of the consequences of a specific event.

In the remaining half of the literature base considered, the scope of work is reduced just to a subset of the hospital processes which are deepened more in detail. In these cases the main purpose is that of identifying the way a single process may be affected by an emergency and its performance being enhanced. Two different sub-groups of works can be identified within this category accounting each one accounting for almost half of the papers: by one side there are researches focused on cross processes, so shared by many different operative units, such as logistics, the management of technology or the governance of the hospital. On the other side, the remaining half moves along a more *vertical* differentiation of activities, so based on the different departments and operative units of the hospital.

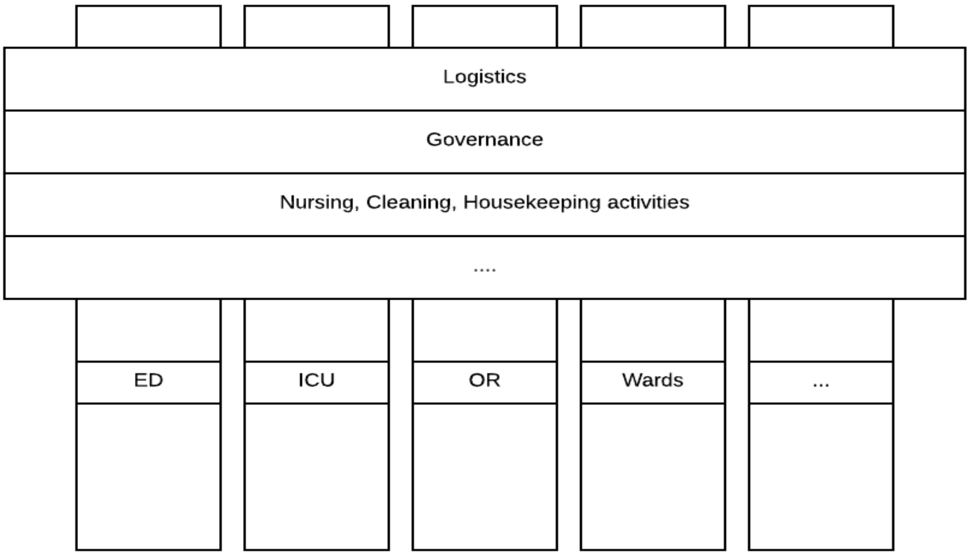


Figure 15 Vertical and Horizontal differentiation of activities

In this second case it is almost impossible to find papers distinguishing the activities in terms of specialties (Neurology, Oncology etc.) while it is more frequent to find processes separated for intensity of care. This second sub-group is more structured with respect to the first one (cross processes), since the majority of the papers can be reconducted to a similar structure: tools and methods are mainly quantitative and the subset of processes is selected in order to simplify the analysis maintaining the highest possible level of representativeness of the entire hospital performance in responding to a specific threat. In table12 it is reported, for each of the papers inserted within this section and that follow this kind of logic, the portion of processes taken into considerations.

Paper	Services considered
A Dynamic Model to Support Surge Capacity Planning in a Rural Hospital, William Manley et al.	ED, Wards
Modeling the Consequences of Major Incidents for Health Care Systems, Gary B. Hirsch	ED, operating rooms, Wards
Simulation As a Tool to Assess the Vulnerability of the Operation of a Health Care Facility, Arboleda	ED, wards
Medical and Health Incident Management (MaHIM) System, Barbera, Macintyre.	Pre hospital care, ED, Medical care
Modeling Hospitals’ Adaptive Capacity during a Loss of Infrastructure Services, Eric D. Vugrin et. al	ICU, operating rooms, laboratory, pharmacy.
A System Dynamics Model of Health Care Surge Capacity, Alexander Lubyansky	Hospital staff and Home care staff
Vulnerbility Assessment of Healthcare Facilities During Disaster Events, Arboleda	ED, Intensive Care Units, wards, Operating rooms.
Using Discrete Event Simulation Models to Evaluate Resilience of an Emergency Department, Cimellaro	ED
Vulnerability to Earthquakes and Floods of the Healthcare System in Florence, Italy, Miniati	ICU, ED, Diagnostic surgery, Urology, Pharmacy, Sterilization, In-patient, Blood
Modeling emergency medical response to a mass casualty incident using agent based simulation, Yu Wang et al	Incident site, Pre-hospital sub system, In hospital sub-system (ED, ICU, general wards, operating rooms)

Classification and Prioritization of Essential Systems in Hospitals under Extreme Events, Robert C. Myrtle	Emergency and trauma room, Blookd Bank
Hospital’s Vulnerability Assessment, Alan Guinet and Roberto Faccincani	Emergency Department, the Operating Theatre, the Intensive Care Unit and many other
A Bottom-Up Approach to Understanding the Efficacy of Event-Analysis in Healthcare: Paradigm Shift from Safety to Resilience Engineering, Sudeep Hegde et al.	general inpatient medicine, ICU, operating room, Interventional radiology, post-anesthesia care, transport
A Queueing Theory Based Model for Business Continuity in Hospitals, Miniati	Endoscopic department
Resilience-based performance assessment of strain situations in emergency departments, Fahrid Kadri	ED’s subsystems of a pediatric emergency dept (administrative registration, medical consultation, short-term inpatient unit etc.)

Table 12 Publications and services considered

As it is possible to notice, Emergency Department is for sure the most addressed department of the hospital, as a confirmation of its high degree of criticality in responding to emergencies.

2.1.5.3 KPIs and Performances

The last topic that will be dealt in this section is that related to the KPIs and indicators selected to measure or describe the performances of the hospital. As already stated in previous paragraphs, just a portion of the literature base considered assumes a quantitative approach, determining a strictly quantitative parameter to measure objectively one or more dimensions of performance. In all the other cases the approach is qualitative. In this paragraph it is reported the analysis just on the first category, so that characterized by measurable and quantifiable parameters. These are mainly referring to two different dimensions of analysis: quality of care and time. Quality of care is a wide concept and of course many of the KPIs that aim at evaluating it are time based, but not only. In Loosemore, 2012 two different indicators are proposed: Adverse Non-Admit events and Adverse Hospital events; the first one is the number of patients who will suffer an adverse impact due to the inability to access hospital treatments in time while the second one refers to the number of patients who will suffer an adverse impact while inside the hospital. Evaluations on the "backlog" of patients are present in many other cases, such as Hirsh 2004, Manley et al 2005, Yu Wang et al 2012 and many others. The General Accounting Office, (GAO) in a report published in 2003 proposes some indicators for evaluating ED performances in case of overcrowding event. Among these indicators it is relevant to mention the proportion of patients (the so-called "walkouts") who voluntarily leave the ED because of the delay in receiving a medical evaluation. In Bayram, Zuabi, 2012 it is described an indicator called Injury to Hospital Interval (IHI) which is the time interval from the occurrence of injury to the completion of care to critical patients.

For what concerns time based parameters, KPIs are mainly two: number of patients treated per time unit (Alsubaie 2015, Lubyansky 2005 and others), and waiting time. Of course waiting time can be considered an useful indicator also to evaluate to performance of the hospital in terms of quality of care. In Cimellaro 2016 it is available a revision of the literature working on the reduction of patients waiting time and the conclusion of the work is that "different parameters can be used to evaluate the performances, among these indicators, but the most representative one is the waiting time. Patient waiting time plays an increasingly important role to measure hospitals' ability to provide emergency care to all the injured in an extreme situation [Cimellaro et al., 2011]. The time patients wait to receive assistance is considered a visible and significant indicator of ED resilience". Linked to the last statement, to conclude, it is worth to mention a specific stream of literature focused on the definition of parameters and function to evaluate the level of resilience of an Hospital. Cimellaro 2010 is a seminal work for this topic, despite it is mainly based on physical structural resilience.

2.1.6 Gap Identification And Thesis Objective

Reviewing the literature, it is possible to notice that some topics have already been largely treated in literature. In particular the concept of Resilience, despite the development time span of the related literature is the shortest one compared with the two other areas of research, it results to be the one dealt more in depth in some of its subdomains. This is probably because of the high interest around this concept in many different sectors, with positive spillovers and effects on the improvement of the knowledge also in the healthcare one. As largely described in the section dedicated to Resilience, features and properties recognized as necessary to make resilient a system are many. Some of these have been already deepened in literature, also for what concerns the healthcare sector. More in detail, considerable work has been undertaken aimed at defining hospital capacity to cope with disasters according to the level of hospital preparedness, robustness and reduction of vulnerabilities. However, contributions revolving around these topics are mainly qualitative. Coherently, also for what concerns the literature regarding the BCM process, the portion related to the Business Impact Analysis is evidently the most developed one. A very wide range of contributions is available discussing the importance of a proper identification of the core functions sustaining the provision of essential medical services and the effect that a disruption may have upon them. On the other side, no examples are available on the application of the BS ISO 22301 in the healthcare sector, for the definition of a proper Business Continuity Plan.

Particular attention has been dedicated to the role of supplies and the interconnection of the hospital with external infrastructure. In this field, quantitative methods, in particular simulation, have been applied more frequently and with the most satisfying results. A similar consideration can be done on the application of quantitative techniques to evaluate assets, resources, processes and configurations of them in order to deal with a peak of demand or with the necessity to face a disruptive event. To clarify this topic, it could be useful to make reference to the adaptation of the MCCER's framework to hospitals proposed by Zhong, 2013 to represent the trend of a system's relevant performance over time when facing a disruptive event. (Table13)

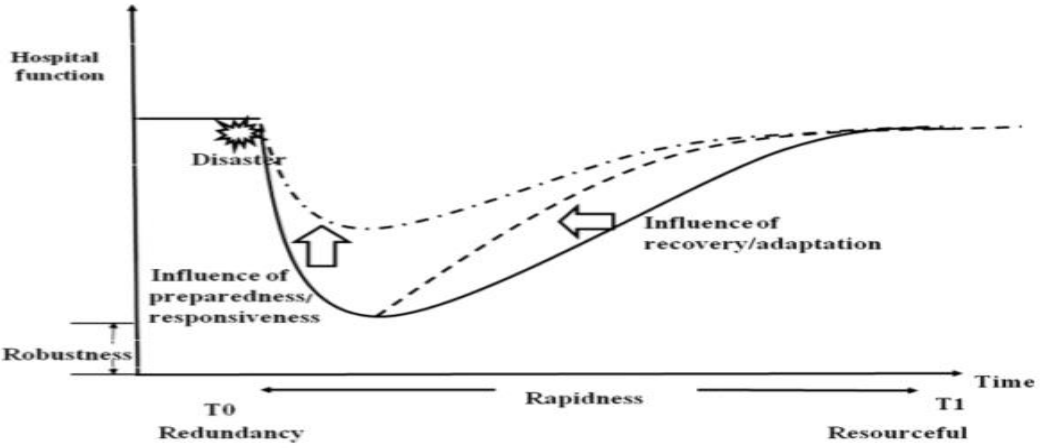


Table 13 Understanding hospital disaster resilience criteria (adapted in Zhong 2013, from Bruneau et al 2003).

The horizontal line showing full hospital operation is fixed. The occurrence of a disaster leads to a rapid decrease in the balance between the demand and the capability to provide medical services (may it be because of an increase in the demand, or a decrease in the capacity). As already mentioned, a *reconfiguration* of the resources permits to regain some level of equilibrium. The time necessary to achieve the new configuration of resources largely determines the capability of the hospital to maintain the continuity of medical services. If by one the topic of the optimal allocation of resources and the identification of critical assets is a topic present in literature, it is probably to be deepened the analysis on the transitory from the normal hospital operation state to the emergency one, and also the reverse. As it is possible to notice from the section related to the literature lying in the intersection between BCM and Resilience, it seems to be still to be enriched the knowledge revolving around the evaluation of strategies to guarantee the continuity of medical services within the framework of Resilience. In particular it emerged clearly the necessity of improving the knowledge revolving around the development of a proper business continuity plan to foster the level of resilience of the hospital-system. In this context it is important to distinguish the continuity of emergency medical services, so the capability to serve the demand arising from an emergency, and the continuity of ordinary medical services, so the capability to keep on providing medical services to elective patients. This distinction is rarely considered in literature, despite in case of disruptive events, emergency and elective patients compete for the same resources. In addition, interrupting ordinary activities is one of the most diffused strategies to deal with emergencies but no papers are available on the calibration of these strategies and on the management of the trade-off between ordinary activities and emergency requirements.

The thesis objectives concern thus the development of a Simulation environment for simulating the performances of an ED and the way its activity interferes/is in synergy with the ordinary activities of the hospital in case of disruptive event. Referring to the three variables mentioned in the previous section (Threat, Scope of work and KPIs) the ED has been selected as the core process of the simulation. This choice has been done considering the criticality of the process highlighted by the high volume of papers focused on this department. ED will not be considered in isolation, but also analyzing to the way it interacts with Operating Rooms and wards. In particular it will be considered a threat characterized by an external event generating a peak of demand. To conclude, performances will be evaluated in terms of quality of care and waiting times not just for the ED but also for ordinary patients. The basic purpose of this approach is to evaluate different strategies of integration between the activities of the ED and those to deliver medical services to ordinary patients. This is intended to be a contribution towards a deeper knowledge on the issues emerging when developing a continuity plan in the healthcare domain.

For reaching the thesis objectives and concretely discuss the results, there is the necessity of a preliminary phase of “simulation system design”. To put in place this phase, the very first step was to get in touch with the path and the sequence of processes a patient undertakes when arriving at the Emergency Department both in case of a single patient and in case of a maxi-emergency. This was possible thanks to a series of meeting with the Surgical Activities Director (SAD) of the San Raffaele Hospital (OSR), dr. Roberto Faccincani. In addition, it was very useful also to assist a real Emergency Test that took place in ORS September the 14th.

According to the collected information the simulator was put in place. For building the simulator, a review about the existing modelling techniques has been performed, adopting the most suitable tools among the available ones. The model was built in order to give the possibility to simulate the performances of the Emergency Department under normal operations and in conditions of maxi emergency and to focus on the *switch* from one configuration to the other. Operating rooms, Intensive Care unit and Wards have been inserted in the model in order to evaluate the interaction between ED and these departments. After shaping the basic features of the model, the analysis spread over the possible different strategies available to manage the transitory and the tradeoff between ordinary elective patients and emergency ones; these have been evaluated, in terms of Emergency Department rapidity of response, and on the Continuity of provision of essential medical services to ordinary elective patients. The thesis exploits data from a real case study: the value of the parameters considered to shape the model and the availability of resources refers in particular to the San Raffaele Hospital in Milan.

CHAPTER3

SIMULATION SYSTEM DESIGN

This chapter presents the Simulation System Design process performed for developing the analysis. In a very first phase it will be presented, in summary, the method applied, in particular for what concerns two main topics: the reasons behind the choice of the software selected and of the modelling techniques applied, and the process of information gathering. The second section contains the considerations made to determine in detail the scope of work and the rationalization of it. Then the system is presented as it works in normal operations (baseline), so in its day by day routine. The overall scope of work has been split in sub-processes: for each of them it will be described activities, procedures and the rules that govern it. Thanks to this rationalization all the resources consumed by the system are identified. Afterwards it is described the representation of the system in the software environment. The third phase corresponds to the description of the reconfiguration of resources to deal with maxi-emergencies. In facts, patients pathways are slightly different in case of a single patient with respect to the case of a multiple arrival of patients deriving from an emergency and, most of all, resources configuration varies significantly. In final chapters simulation campaigns and results will be presented.

3.1 Methodological approach

Anylogic is the software selected to put in place the model and run simulations. AnyLogic is a multimethod simulation modeling tool developed by The AnyLogic Company and it is nowadays the leading simulation modelling software utilized worldwide. The reason behind the success of this software is mainly the possibility of integrating more than one simulation modelling technique. Just as brief introduction to the topic, simulation modelling techniques are three: Discrete Event, Agent-Based and System Dynamics. When the system under analysis can naturally be described as a sequence of operations, discrete event modeling should be used, while an agent-based simulation model is arranged as a set of interacting objects so more focused on the relations among them. To conclude, System dynamics is a highly abstract method of modeling. It ignores the fine details of a system, such as the individual properties of people, products, or events, and produces a general representation of a complex system. These abstract simulation models are typically used for long-term, strategic decisions.

Anylogic offers the possibility to integrate these techniques, and, therefore, is able to satisfy two different requirements of the work thesis: by one side representing step by step the path of the patient in ED, and on the other side the way this interacts with the hospital system. In the first case it results particularly appropriate a *discrete event* simulation modelling method, while in the second one *system dynamics* is for sure the most convenient technique. Anylogic is the only software available on the market which permits to integrate two or even three methods. For what concerns the operative units and departments interacting with the ED, it is not necessary for all the same level of detail in describing treatments carried out on the patient, and, in some cases it is hard to believe to represent the flow of activities focusing on the single patient. These are, in summary, the reasons why not all the model has been modelled as a discrete event model. The choice on which modelling techniques applying to represent ICU, ORs, wards, so hospital operative units interacting with the ED, will be better illustrated in the subsequent paragraphs.

Moving to the second step, so the definition in detail of the scope of work and the collection of the necessary information to shape the model, this was based first of all on a series of meeting with dr. Roberto Faccincani, Surgical Activities Coordinator of the San Raffaele Hospital (OSR) ED. This kind of methodology, mainly based on OSR case, by one side reduces the generalizability of the model but on the other side permits to have a clear understanding on the system, a level a detail unachievable basing the model on general data and, most of all, a practical application of the tool which will be developed. In addition, the features of model that are actually *hospital-specific* can be reduced to the availability of resources, while the overall structure of the model can be considered, with very few exceptions, as *hospital-generic*. This is to say that the model can be considered as applicable to all the hospitals similar to OSR in terms of size and resources. In addition, many hospitals, in particular in Lombardy, decided to accept and implement the plan developed in OSR to deal with maxi emergencies (PEMAF) which will be described at the end of this chapter.

Thanks to the collaboration with OSR ED SAD (dr. Faccincani) , it was decided to take the perspective of patient pathway in ED to evaluate medical service delivery capacity. In particular it has been chosen as core process that related to the treatment of serious patients (red), since it is the most critical one and consuming the highest degree of resources. Therefore the starting point of the meetings was the description of activities, processes and resources characterizing patient pathway, and the way it changes in case of maxi emergency. Subsequently it was decided to expand the model with modules representing those areas of the hospital interacting with the ED and generating synergies or trade-offs. Modules to be added emerged along the design work phase with the purpose of making the model as representative as possible. Patients have been subdivided in three sub-classes according to the color code: red yellow and green. The level of detail dedicated to the three sub-groups differs according to the criticality of the patient: red patients have been further divided into surgical patients and non-surgical internist red patient since resources dedicated to these two classes are different. For what concerns yellow patients, it has not been possible to catch exactly the sequence of operations due to the very high variability of the process: for this reason yellow patients pathway has been simplified with the purpose of catching anyway the resources required by yellow patients. To conclude, green patients have been represented just in terms of time spent within the ED, thanks to the data extracted from the database containing information on all the patients treated in OSR ED in the last two years. This was done to catch the degree of crowding of the ED and the workload on it at the moment of the alert of an emergency.

3.2 System representation

In the subsequent paragraphs it will be presented the result of the work, describing for each of the modules mentioned above, starting from the ED, the way it works, its schematization and finally the way it has been translated into the software environment

3.2.1.1 Emergency Department

ED is a health facility dedicated to situations of urgency and emergency, not suitable for solving chronic and non-urgent problems. The OSR ED unit is part of the Emergency Department, Urgency and Acceptance of High Specialty (EAS) of the Lombardy Region. The unit has its own unique staff, available 24/24 and also makes use of close cooperation with all the clinical specialties of the OSR. Compared with other departments, ED has specific structural and organizational requirements, related to the peculiar needs of the urgent patient: equipped with wide spaces, paths dedicated to the pediatric patient and the patient in critical emergency conditions, direct access to the ORs, a dedicated radiology and, not least, easy access from the city. In OSR ED about 62,000 patients per year are assisted and this number is constantly increasing along the years, as well as for any other health service, with the risk of overcrowding.

In this section it will be described first serious red patient (chirurgical and non-chirurgical internist) pathway in OSR ED from the arrival with ambulance or medical car to the moment in which it is decided the final destination (go back home, ICU, OR etc.). As already mentioned, the highest degree of attention has been dedicated to serious patients (*red patients*) and in this case it has been evaluated each operations characterizing the whole process, while for what concerns patients in medical area (*yellow and green patients*) this kind of detailed representation was not possible for high degree of variability, and neither useful for the aim of the thesis.

When an accident of any kind occurs, bystanders call 112. The operative center detects the presence of health problem and notifies it to 118. 118, on the basis of the described patient characteristics (old/young patient, unconscious/conscious etc.) decides whether to send a basic rescue vehicle (ambulance) or an advanced one. There are three types of advanced rescue vehicles:

- Medical car with doctor and nurse on board

- Medical car with only nurses
- Helicopter

In case the description is not precise, the basic rescue vehicle is sent first. In this way, medical personnel can give a more detailed report and decide whether to send the advanced rescue vehicle or bring the patient directly to the hospital. In the majority of the cases, the ambulance (the nearest basic rescue vehicle) is sent directly to have a more precise description and it is decided whether to take the patient to the hospital or to send the advanced vehicle. If the 118 operative center identifies the possible presence of serious patients, there is also a first contact with the various EDs of the nearest hospitals to test their readiness to accept a serious patient.

When the patient leaves the site, with an ambulance or advanced vehicle, the chosen hospital, the one which has given the availability to receive the patient, is re-updated and all the necessary resources alerted, both external and internal: helicopter pad, ambulance for transport from pitch to the ED, and also doctors, nurses, diagnostics (CAT scan) etc.

Once arrived at the ED, in order to start the therapeutic diagnostic path, the patient must be introduced into the informative system. If documents regarding the identity of the patient are available, this can be done in an optimal way, otherwise the registration is done as anonymous. The insertion in the informative system happens in parallel while medical personnel takes the patient out of the ambulance. The patient enters directly into the evaluation room of serious patients (shock room) and begins the diagnostic treatment, while in the meantime administrative personnel in the guardhouse inserts him/her into the informative system. It is necessary to specify that when the patient is sent from the pre-hospital as a serious patient, so he/she has already been classified as such, even before arriving in ED, triage is not repeated. Otherwise, for all other patients, triage is also performed at the time of acceptance. The triage area, in OSR, is the same in which the registration phase takes place, near the guardhouse. This area is defined hot room.

Normally the patient descends from the ambulance continuing to occupy ambulance resources and he/she is accompanied in the shock room: this is a room equipped with ventilator, defibrillator, monitor for resuscitation and trolley with all the necessary medical equipment. In the shock room material and personnel of the ambulance is released, as the patient is transferred to the hospital stretcher. From this moment on the patient is taken in charge by the "trauma team" which is composed of the head general surgeon, the anesthetist, 2 nurses and an auxiliary (OSS). In case of a non-surgical red patient, the trauma team is composed by the anesthetic, 2 nurses, an auxiliary and an emergency internist physician. Nurses can be one or two according to the severity of the patient. This is the minimum team and it is the standard for the reception of the serious patients. Depending on whether it is traumatic thoracic, neurological etc it can be added a specialist for orthopedic, a neuro surgeon etc. In case a general surgeon or an emergency physician is not available it could be directly the specialist surgeon taking care of the patient but it represents a reduction in the level of care.

In case the patient presents particularly serious conditions, since from the time spent in shock room resuscitation maneuvers may be necessary, otherwise the activity is mainly characterized by stabilization and assessment procedures. In shock room the trauma team works in parallel. The length of stay of the patient in shock room changes according to whether he/she is surgical or non-surgical: surgical patients usually occupy the shock room for not more than 60 minutes, while for non-surgical patients the procedures carried out in these spaces may last from 60 minutes to almost 6 hours. From this point on, possible paths are many:

- Second-level diagnostics (CAT scan): if the patient performs a Cat scan, this can give rise to different reports:
  1. actually the patient is not as serious as it seemed and so he/she is sent back in the ED, in particular in shock room, where it is lowered the level of criticality. Now the patient can go either at
     - Home
     - In ward
     - In ICU
     - In OR (OR).
  2. Otherwise after the CAT scan the patient is sent to the OR without going back to ED. Usually in this case there is an indication for OR coming since from before the results of the CAT SCAN.
  3. Last possibility is to send directly the patient to the ICU, but this is less frequent.

- OR: in case the patient is so serious that he/she cannot waste time making further inquiries, he/she goes directly into the OR. Non-surgical red patients do not go in OR, while it is more frequent for them to be moved to the ward.

Along this pathway the surgical patient is always accompanied by an auxiliary for transport, anesthetist, surgeon and sometimes also a nurse. Non-surgical patient requires an internist physician rather than a surgeon. It is important to notice that in case of surgical serious patient sent to the OR, it's directly the general surgeon from the ED that performs the surgery in OR so this resource is not released until the end of this phase.

For what concerns yellow patients the process has been highly summarized. Once arrived at the ED, yellow patients await in the waiting room. Once an internist physician terminates to process a patient, a new one can be visited. Even once passed the waiting area, there could be a condition of awaiting, for diagnostic response etc. Patients requirements are highly variable: in general yellow patients are those presenting an evolutionary condition, thus they risk worsening within 18 hours. Not all of them need a bed, the duration of the visit may be very different etc. After the visit some patients go back home while a significant portion is monitored for even 24 hours, determining an high level of utilization of the areas dedicated to yellow patients monitoring. As it is evident, the process is highly variable and dependent on the characteristics of the patient.

To conclude, green patients are those showing non-critical conditions, so lesions that do not affect vital functions but must be treated anyway. Also in this case there could be a condition of awaiting both in the waiting area and also inside the ED. Due to the low level of priority it has been chosen just to analyze this portion of patients just in terms of time spent within the ED. Resources consumed are more or less the same as yellow patients. By one side the choice comes from the necessity of reducing the complexity of the model. On the other side green patients have not been recognized as a source of constrains on the system, since characterized by the lowest level of priority, despite the significant number. Furthermore, the resources green and red patients compete for are few (internist physicians and nurses), and in case of maxi-emergency these are rapidly released.

3.2.1.2 Rationalization of the system

In the scheme reported in the following page it is represented the way the ED has been translated into a flow chart. This step has been useful to rationalize and subdivide the process in sub-processes. As it is possible to understand from the scheme, ED activities to receive and treat patients can be sub-divided into 4 sub-processes: Pre-hospital, Hot room, Shock Room and Medical area (yellow and green patients). These are highlighted with blue squares. On the other side the orange square contains the interfaces of the ED with the hospital: Cat scan, ORs, intensive care unit and ward.

ED's interfaces (Cat scan, OR, ICU and wards), will be inserted in the model to the extent that they determine the systemic functioning of the hospital. It is possible to describe them as bidirectional relationships in case of Cat scan, OR, ICU and wards: the overall system performs well if the ED is able to face and accommodate incoming patients, as well as Cat scan, OR, ICU and wards are able to sustain ED activity. ICU will be excluded from the analysis of the results due to the marginal number of patients flowing through this area.

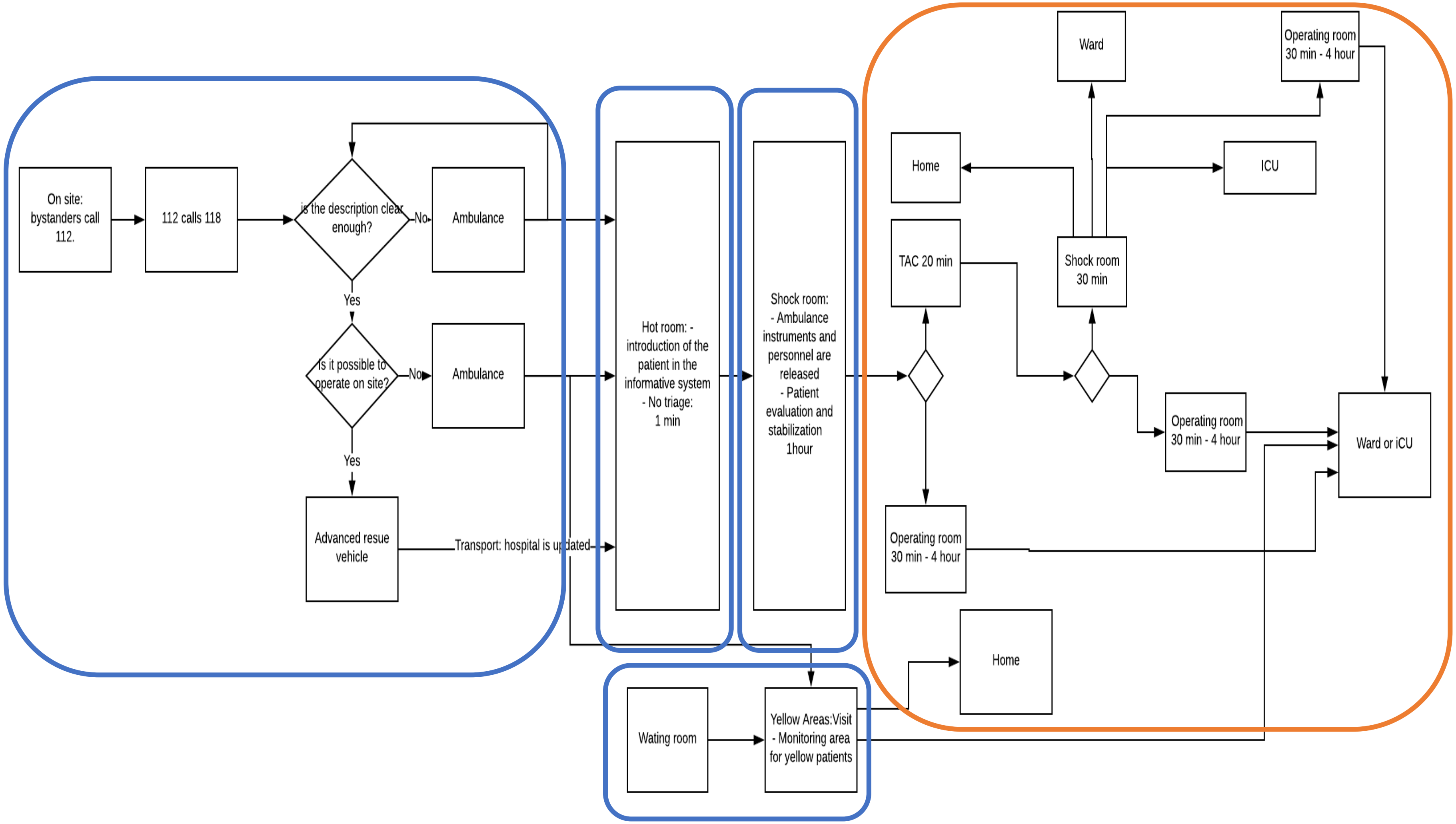


Figure 16 ED Rationalization

Coming back to the ED, pre-hospital has been excluded from the analysis since it is governed by rules and procedures going beyond the scope of work set at the beginning of the paragraph. It will be just taken into account the effect it has on ED functioning. For what concerns Hot room, Shock Room and Medical area, these have been analyzed to extrapolate the resources consumed by the patient, the availability of them in OSR and, more in general, those parameters characterizing ED scenario. These considerations are reported in the table below:

Area/Process	Resources consumed	Descriptive parameters
Hot room	1. Ambulance personnel and instruments 2. Administrative personnel	The length of stay in hot room can be considered as zero in case of serious patient since the activity of triage has already been performed by pre-hospital personnel. In addition the registration of the patient in the informatic system happens in parallel
Shock room	1. One trauma team per surgical patient: general surgeon, anesthetist, 2 nurses, 1 auxiliary 2. One trauma team per non-surgical patient: internist physician, anesthetist, 2 nurses, 1 auxiliay 3. One instrumented room and one bed	1. Length of stay surgical patient: 60 min 2. Length of stay non-surgical patient: 60 min - 6 hour
Medical area	1. Monitored spaces 2. Internist physicians (when the patient is just monitored the physician can treat a different one, so the ratio physician/patient is not one to one).	1. Treatment: from 30 minutes (visited and discharged) to 24 hours (maximum period of observation in ED)

Table 14 ED processes, resources and parameters

It is relevant to notice that the personnel *assigned* to the patient in shock room is the one that accompanies the patient until the end of its pathway in ED.

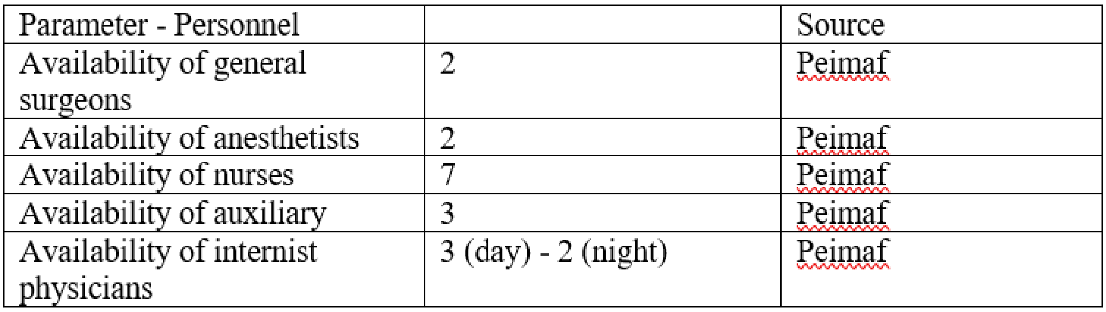
Additional parameters necessary to have a full understanding of the ED are:

- Volume of patients treated (patient/hour or interarrival time)
- Distribution of patients arrival along the day and along the week

- Percentage of red, yellow and green patients
- Fraction of surgical and non-surgical patients among the red ones
- Fraction of patients destined to the ward, to the CAT SCAN, to ORs or to ICU.
- Fraction of patients that after the CAT SCAN have to come back in shock room for further evaluations.
- Lengths of stay in shock room for surgical and non-surgical patients.
- Lengths of stay in medical area for yellow and green patients.

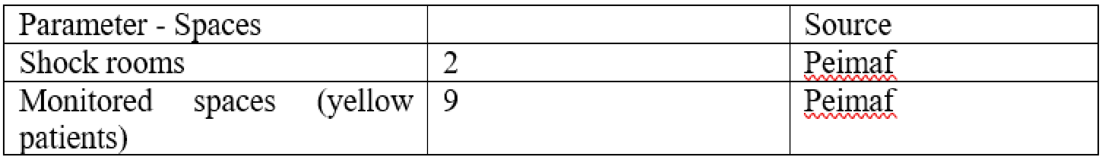
Parameters quantification and calibration.

In tables15, 16 and 17 it is reported a summary of the values of the parameters just described. The sources of information exploited are many: first of all the experience of the expert consulted, the OSR ED SAD (dr. Faccincani), permitted to fulfill many of the parameters identified. Furthermore it has been possible to analyze the database (*database1)* recording patients treated in ED in the last two years and produced by the informative system. This has been useful to determine volume of patients, distribution of arrivals, length of stay etc. These information have been compared with dr. Faccincani experience in order to determine the most representative empirical probability distribution. To conclude, the availability of resources have been deduced by the predefined shifts of the personnel and by the information contained in the so called PEIMAF (*Piano di Emergenza Interno per il Massiccio Afflusso dei Feriti*). This is the document describing the procedure in case of maxi emergency which contains also relevant information on the configuration of resources in normal operations. In the following tables some of the parameters necessary to build the model are reported.



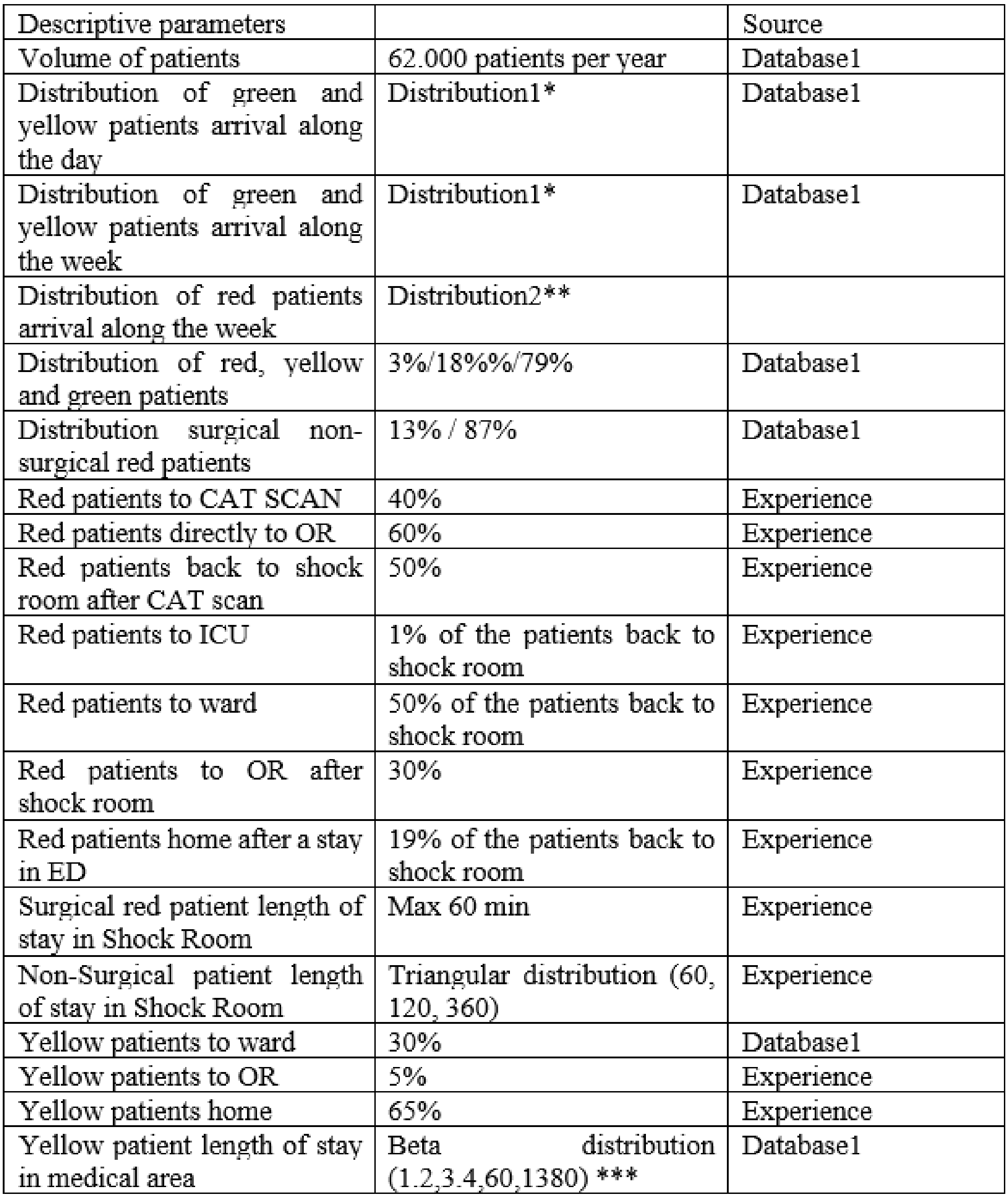
Parameter - Personnel		Source
Availability of general surgeons	2	Peimaf
Availability of anesthetists	2	Peimaf
Availability of nurses	7	Peimaf
Availability of auxiliary	3	Peimaf
Availability of internist physicians	3 (day) - 2 (night)	Peimaf

Table 15 ED - Personnel



Parameter - Spaces		Source
Shock rooms	2	Peimaf
Monitored spaces (yellow patients)	9	Peimaf

Table 16 ED – spaces



Descriptive parameters		Source
Volume of patients	62.000 patients per year	Database1
Distribution of green and yellow patients arrival along the day	Distribution1*	Database1
Distribution of green and yellow patients arrival along the week	Distribution1*	Database1
Distribution of red patients arrival along the week	Distribution2**	
Distribution of red, yellow and green patients	3%/18%%/79%	Database1
Distribution surgical non-surgical red patients	13% / 87%	Database1
Red patients to CAT SCAN	40%	Experience
Red patients directly to OR	60%	Experience
Red patients back to shock room after CAT scan	50%	Experience
Red patients to ICU	1% of the patients back to shock room	Experience
Red patients to ward	50% of the patients back to shock room	Experience
Red patients to OR after shock room	30%	Experience
Red patients home after a stay in ED	19% of the patients back to shock room	Experience
Surgical red patient length of stay in Shock Room	Max 60 min	Experience
Non-Surgical patient length of stay in Shock Room	Triangular distribution (60, 120, 360)	Experience
Yellow patients to ward	30%	Database1
Yellow patients to OR	5%	Experience
Yellow patients home	65%	Experience
Yellow patient length of stay in medical area	Beta distribution (1.2,3.4,60,1380) ***	Database1

Table 17 ED - descriptive parameters

*, **, *** for the computation of Distribution1, Distribution2 and beta(1.2,3.4,60, 1380) it is possible to make reference to Annex1. Distribution1 is an empirical discrete distribution describing yellow and green patients arrival rate along the different days of

the week. The same is valid also for Distribution2 which is, somehow, a sort of red patients arrival *scheduling* replicating the typical week. To conclude, yellow patients length of stay distribution have been described through beta distribution. Its description and test of fitting is reported in Annex1. For what concerns this distribution it is important to specify that it refers to the entire amount of time spent by an patient in ED, not just that of the visits, but also, in case, awaiting.

In the subsequent paragraph it will be described the way the ED, through the schematization and the data just presented, has been translated into the software environment.

3.2.1.3 ED in Anylogic

The analysis developed and described in previous paragraphs allows to represent patient pathway in ED as a series of operations, either for red, yellow and green patients. In addition, resources and agents (patients, physicians, nurses etc.) can be considered punctually, so in a discrete way. Furthermore, despite a considerable degree of variability in some cases, it is still possible to define a probability distribution of the processes durations or, in the worst case, a reliable range. These are some of the reasons behind the choice of *discrete event* as the simulation modelling technique for this section of the model. In Figure17 it is reported the section of the model related to the ED. In the following page it is possible to see the way patients from ED are distributed among the different operative units of the hospital.

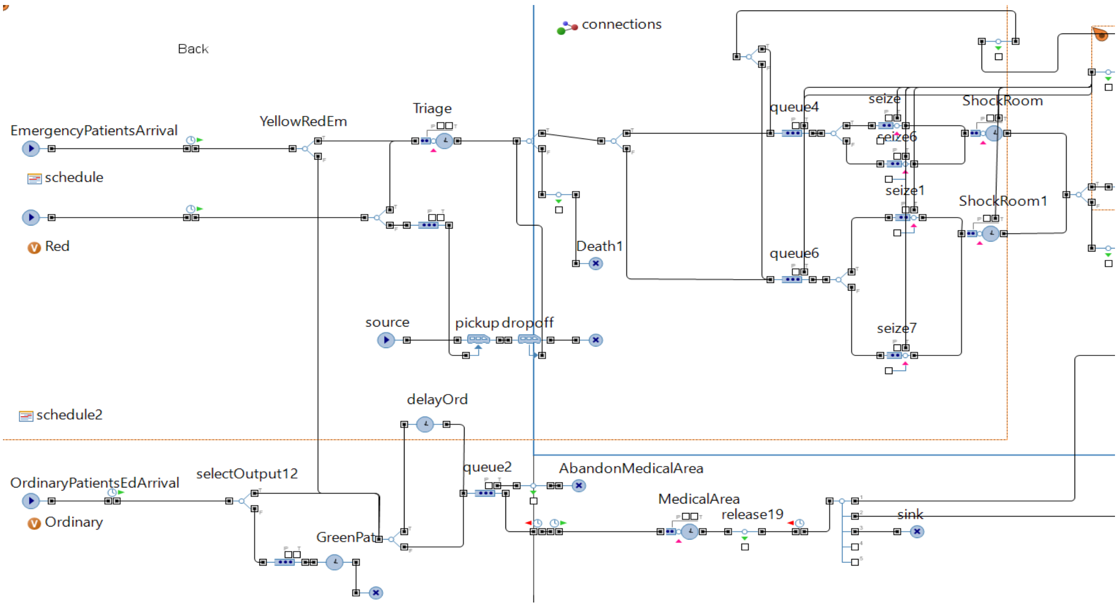


Figure 17 ED, Anylogic

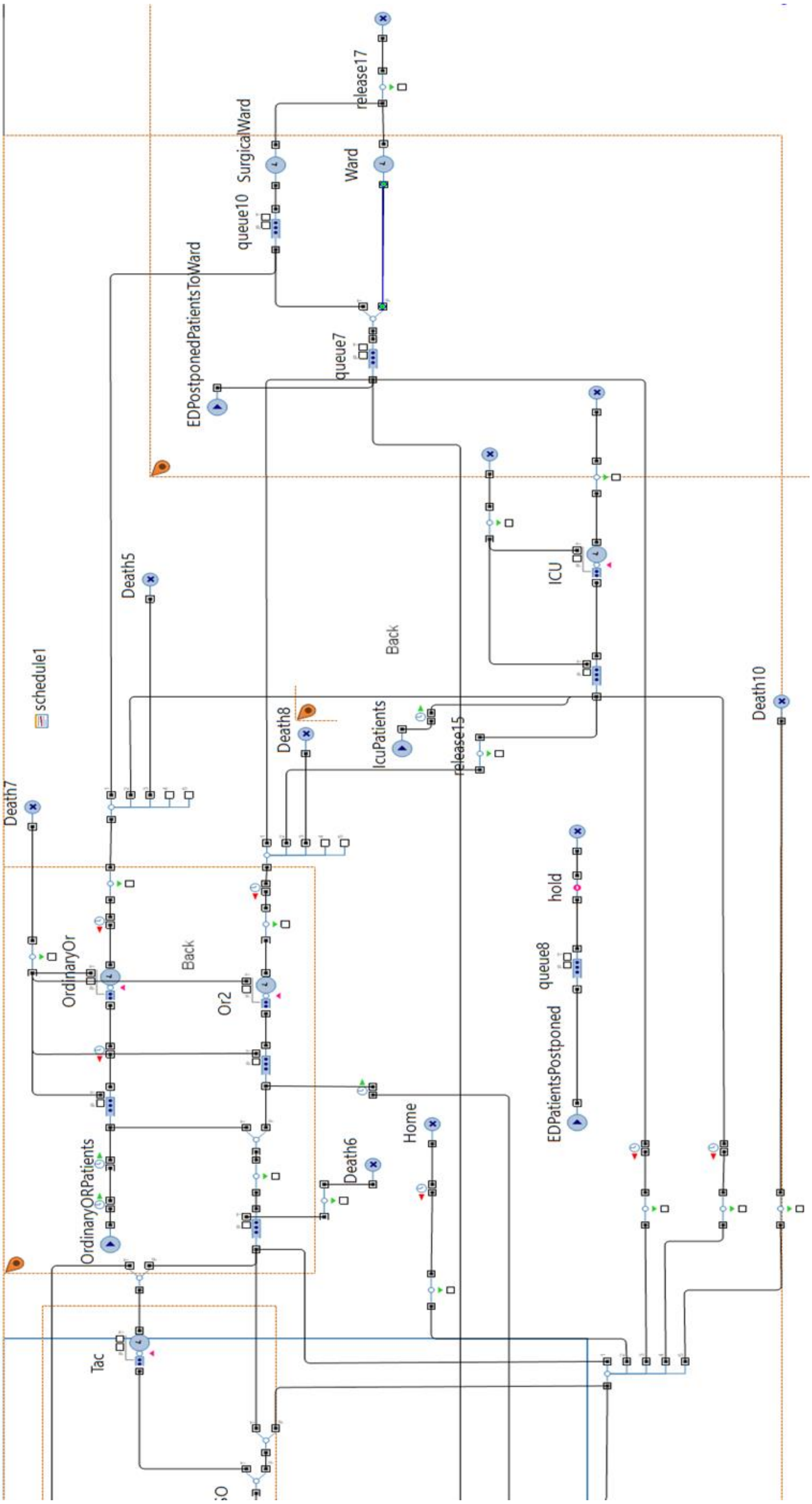
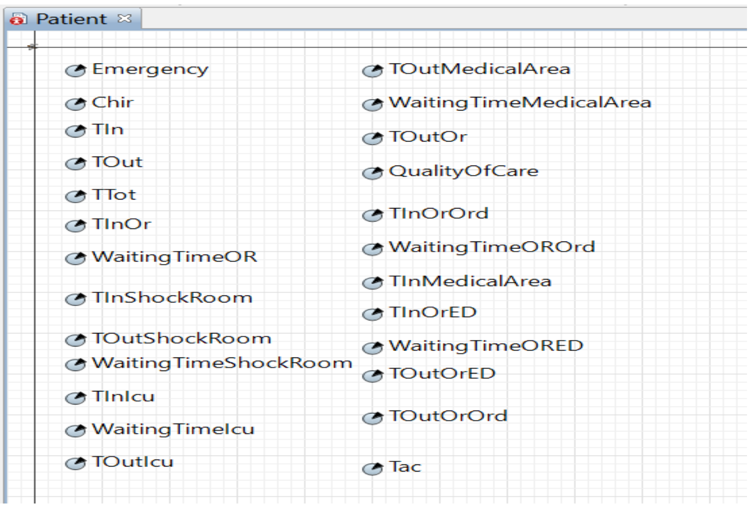


Figure 18 ED interactions

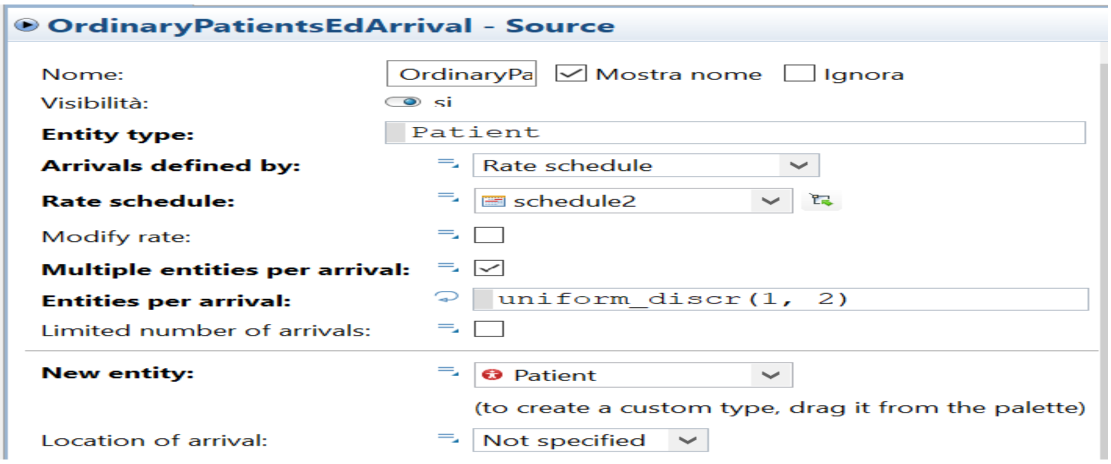
Patients are represented in the system by the *agent* named as “Patient”. This entity is characterized by a series of parameters: some of these are used to shape patients’ features, such as in particular *Emergency, Cat scan or Chir* parameters, while others are necessary to keep track of its steps in the system.



Emergency
Chir
TIn
TOut
TTot
TInOr
WaitingTimeOR
TInShockRoom
TOutShockRoom
WaitingTimeShockRoom
TInIcu
WaitingTimeIcu
TOutIcu
TOutMedicalArea
WaitingTimeMedicalArea
TOutOr
QualityOfCare
TInOrOrd
WaitingTimeOROrd
TInMedicalArea
TInOrED
WaitingTimeORED
TOutOrED
TOutOrOrd
Tac

Figure 19 Patients palette

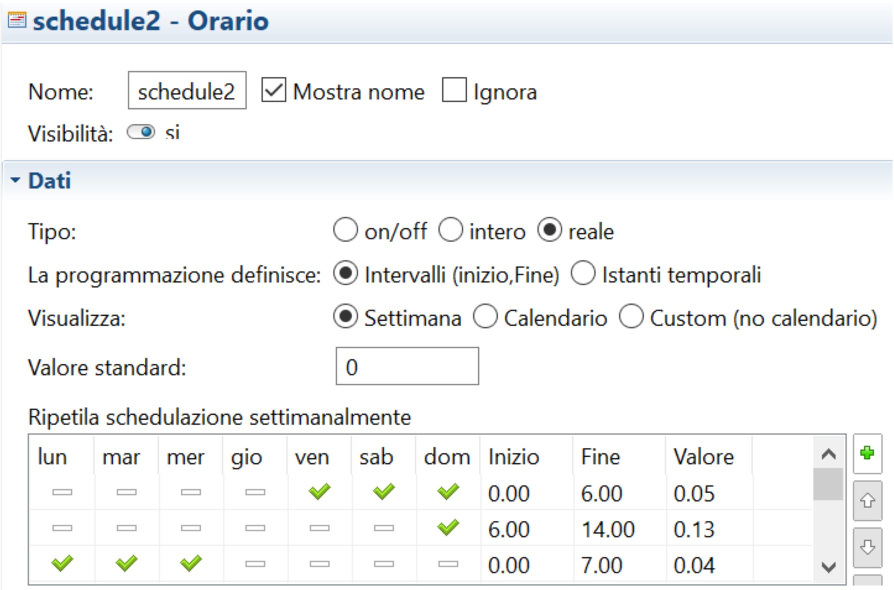
Green and Yellow patients arrival is simulated through a *source* module named as “OrdinaryPatientsEDArrival”. Red patients are generated through a different *source* module which will be described later. “Patients” entities are generated and inserted in the system according to a *schedule* element (“schedule2”) and the arrival of 1 or two patients simultaneously is equally possible, as stated by the uniform discrete function between 1 and 2 representing the number of entities per arrival.


OrdinaryPatientsEdArrival - Source

Nome: OrdinaryPa ☑ Mostra nome ☐ Ignora
Visibilità: si
Entity type: Patient
Arrivals defined by: Rate schedule
Rate schedule: schedule2
Modify rate: ☐
Multiple entities per arrival: ☑
Entities per arrival: uniform_discr(1, 2)
Limited number of arrivals: ☐
New entity: Patient
(to create a custom type, drag it from the palette)
Location of arrival: Not specified

Figure 20 OrdinaryPatientsEdArrival source

Schedule2 has been fulfilled with “distribution1” as described in the previous paragraph. In Figure21 it is possible to see the way it is translated into Anylogic (a limited portion of it).



schedule2 - Orario

Nome: schedule2 ☑ Mostra nome ☐ Ignora

Visibilità: si

Dati

Tipo: ○ on/off ○ intero ● reale

La programmazione definisce: ● Intervalli (inizio,Fine) ○ Istanti temporali

Visualizza: ● Settimana ○ Calendario ○ Custom (no calendario)

Valore standard: 0

Ripetila schedulazione settimanalmente

lun	mar	mer	gio	ven	sab	dom	Inizio	Fine	Valore
▭	▭	▭	▭	✓	✓	✓	0.00	6.00	0.05
▭	▭	▭	▭	▭	▭	✓	6.00	14.00	0.13
✓	✓	✓	▭	▭	▭	▭	0.00	7.00	0.04

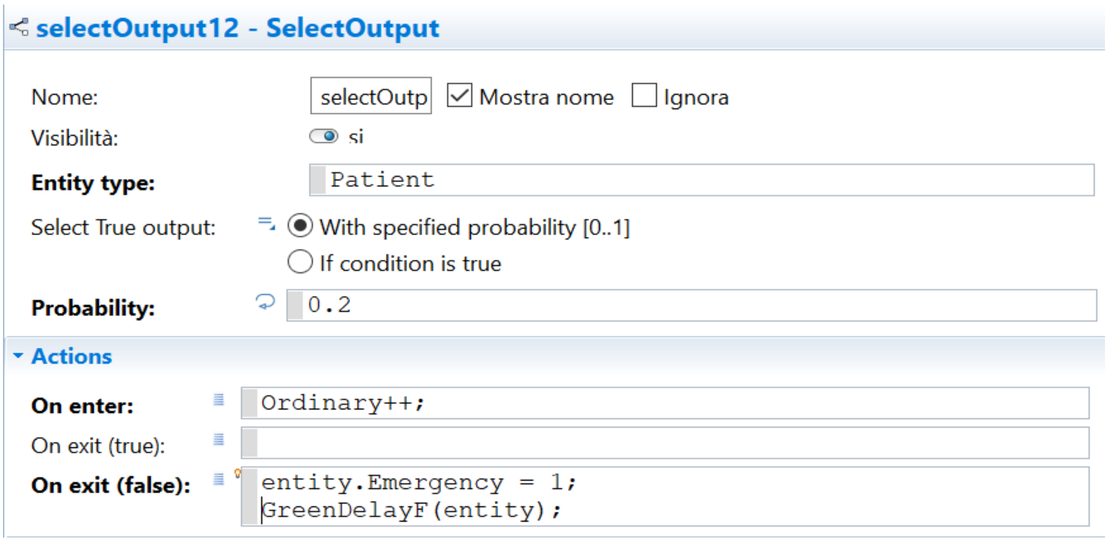
Figure 21 schedule2

Once left the *source* module, the *agent* passes through a *selectOutput* (“selectOutput12”) module to distinguish yellow from green patients. In this case a probability governs the selection of the output: 17% of the patients is yellow, the remaining part is green. In case of a red patient it is assigned a value equal to 3 to the *Emergency* entity parameter, while for yellow that parameter takes a value equal to 2.

Green Patients

To represent green patients it has been chosen a very synthetic approach. After the *selectOutput* module the *agent* is inserted into a *queue* and then a *delay* module named “GreenPat”. This module simulates the time spent by a green patient in ED. Delay time is set equal to an entity specific variable named “GreenDelay”. Through this variable it is possible to replicate the different times of green patients spent within the ED. In facts, thanks to the data available in *database*1 it is possible to quantify the time spent in ED by each of the green patients treated in OSR ED in the last two years. In particular it has been extracted the length of stay of a sequence of green patients passed through ED starting from a generic Monday in the last two years (simulation will start on Monday). This information has been reported into an excel file and then uploaded in Anylogic with the name “EmergencyPatients”: each row of the file represents a patient with its length of stay.

When an agent passes through the exit false port in *selectOutput12* (thus a green patient) entity specific variable “GreenDelay” is updated by calling the method “GreenDelayF(Patient)” with the entity passing through the port as the argument. In addition entity specific variable “Emergency” is updated to 1.



selectOutput12 - SelectOutput

Nome: selectOutp ☑ Mostra nome ☐ Ignora

Visibilità: si

Entity type: Patient

Select True output: ● With specified probability [0..1] ○ If condition is true

Probability: 0.2

Actions

On enter:

```
Ordinary++;
```

On exit (true):

On exit (false):

```
entity.Emergency = 1;
GreenDelayF(entity);
```

Figure 22 selectOutput12

“GreenDelayF” method is coded in order to extract the data contained in “EmergencyPatients” excel file ad update entity specific “GreenDelay” variable. Before the Emergency alert arrives (TimeLev0) “GreenDelay” is updated to the length of stay related to first non-simulated patient contained in “EmergencyPatients” through the “getCellNumericValue() function. Thanks to this function it is read the value contained in the second sheet of “EmergencyPatients” file, in the third column and row equal to the value of “Ordinary” variable. “Ordinary” starts from 1 and it is increased by one anytime an ordinary green patient is generated.

```
if (time()<TimeLev0){;
Patient.GreenDelay=EmergencyPatients.getCellNumericValue(
2, Ordinary, 3); };
```

This way it is possible to replicate exactly the time spent in ED of a real sequence of green patients.

"GreenPat" *delay* module's capacity is set equal to 20 which is considered a reasonable maximum number of green patients occupying ED. Given this limited capacity, when green patients arrival overcomes the workload the ED is able to sustain, it is generated a queue before the "GreenPat" *delay* which represents green patients waiting time. Green patients waiting time is recorded through a series of entity specific and system parameters which will be described in the subsequent paragraph.

Yellow Patients

For what concerns yellow patients, as already anticipated, it has not been possible to model in detail the sequence of operations characterizing patients pathway in medical area. On the other hand, thanks to the available data on yellow patients' length of stay in ED it possible to simulate the occupation of resources generated by them and their overall time spent in ED. In this case, differently from what has been done with green patients, it has been decided to simulate the occupation of resources as realistically as possible.

To translate medical area into Anylogic it is necessary first of all to represent those resources characterizing this portion of the ED. In terms of personnel, patients are treated by internist physicians which are modelled through an *agent class* named "Physician". No further specification in terms of specialties has been introduced in the model, so no parameters characterize these agents. The availability of physicians is governed by the *resourcePool* module "Physicians", which represents a sort of resource container with predefined capacity: anytime an agent needs a resource "Physician" this module checks the availability of the resource. "Physicians" *resourcePool* capacity is set directly equal to3. To differentiate daily shift (3 physicians) from the night and the weekend one (2 physicians) it has been introduced an *event* named "Night" which simulates the night shift setting "Physicians" capacity to 2. The same kind of representation is valid also for "Beds" *resourcePool* and "Yellow areas" *resourcePool.* In this case capacity is defined directly through a parameter ("Nbeds" equal to 30 and "NYellowArea" equal to 9). Parameters are used to define *resourcePools* capacity to make the model as general purpose as possible, so applicable also to other contexts.

Patient pathway in medical area is simulated through a sequence of a *queue* module, *service* module and *selectOutput and sink* module. Some of the modules visible in

Figure23 will be described later when presenting the way resources are reconfigured in case of maxi emergency.

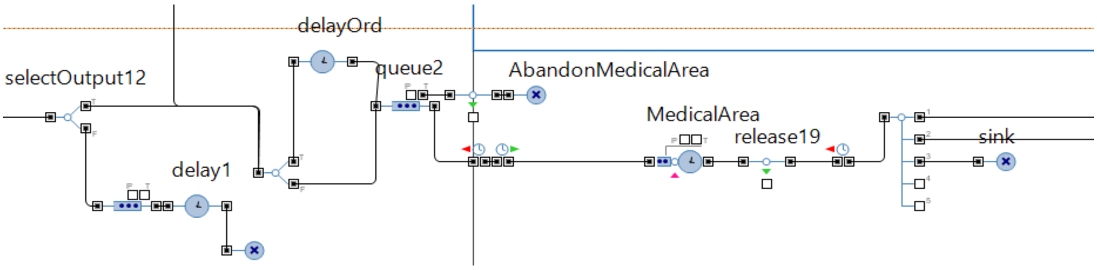
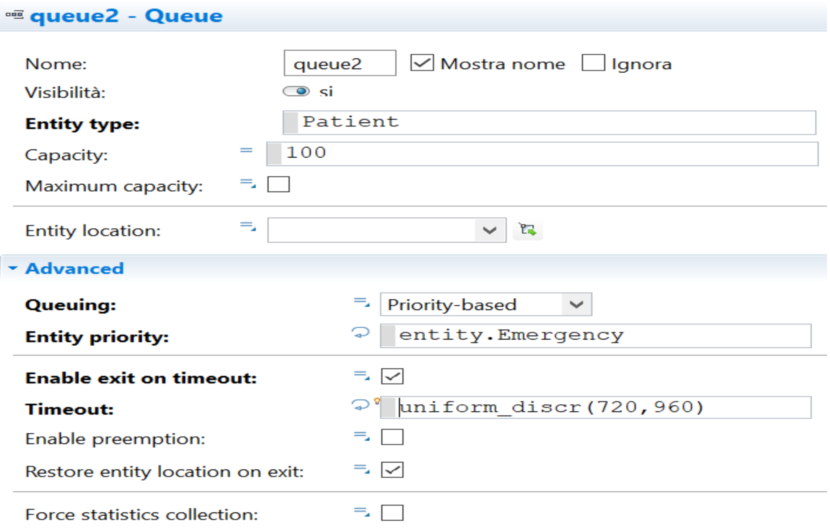


Figure 23 Medical area, Anylogic

1. Queue2 simulates the waiting area. Queue capacity is set at 100 by default by the system. Queueing logic is set "Priority-based" in order to respect the different degrees of priority assigned to the patient according to the "Emergency" parameter. In normal conditions just yellow patients are present here, so actually agents are queued in the same way as they were with a FIFO logic. In case of maxi emergency, as it will be described in subsequent sections, levels of priority will be more than one.

It is enabled the option "exit on time out" to simulate those patients abandoning the waiting area autonomously for a too long waiting time: a "Patient" agent will be pushed out of the queue after a certain amount of time. The time beyond which the agent leaves the queue is taken from a uniform distribution between 720 min and 960 min, to simulate different degrees of "forbearance" on the part of the patients.



queue2 - Queue

Nome: queue2 ☑ Mostra nome ☐ Ignora
Visibilità: si
Entity type: Patient
Capacity: 100
Maximum capacity: ☐
Entity location:

Advanced

Queuing: Priority-based
Entity priority: entity.Emergency
Enable exit on timeout: ☑
Timeout: uniform_discr(720,960)
Enable preemption: ☐
Restore entity location on exit: ☑
Force statistics collection: ☐

Figure 24 queue2, Anylogic

Since the waiting time in medical area and the length of the queue may be interesting parameters to measure ED performances, agents moving within queue, so entering and leaving the module, determine some system variables and agent's parameters being updated. These are declared simply moving the variable or parameter agent from the palette to the canvas. Those parameters or variables which are entity specific are inserted in the "Patient" class (Figure19), while those referred to the whole system are in the "Main" class.

For what concerns times, in particular, it is computed the time spent in waiting area updating agent parameter "TInMedicalArea" (representing the moment in which it enters the module) on entering the module, and "TOutMedicalArea" when leaving the queue. This is done by setting:

`entity.TInMedicalArea = time();` and

`entity.TOutMedicalArea =time();`

so that the two parameters are updated at the current model time when crossing the *in port* and the *out port.* To do that it is has been exploited the coding areas "On enter", "On exit" and "On exit timeout": the portions of code inserted in these areas are executed at the passage of the entity in the correspondent port. This way it is possible to compute the waiting time in queue for each entity leaving it. This is done setting:

```
entity.WaitingTimeMedicalArea=entity.TOutMedicalArea-
entity.TInMedicalArea;
```

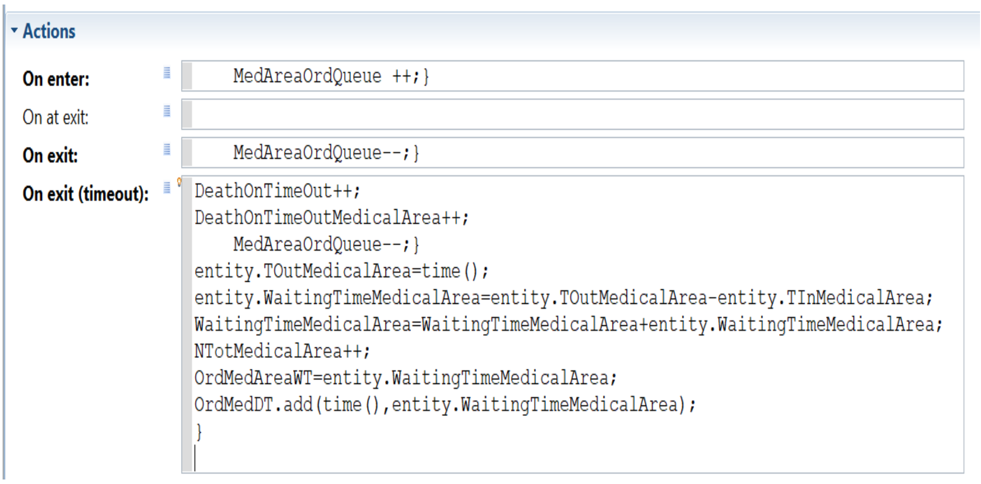
To conclude, thanks to the value collected in the entity variable WaitingTimeMedicalArea, three different system variables are updated:

1. WatingTimeMedicalArea
2. NTotMedicalArea
3. OrdMedAreaWT

The two firsts will be necessary to compute the average waiting time for yellow patients: system variable WaitingTimeMedicalArea is the sum of the waiting times while NTotMedicalArea is the total number of patients flowing through the queue. On the other side OrdMedAreaWT will be useful to represent punctually the waiting time of each patient passing through the medical area. Similarly, moving to the length of the queue, it is updated a system variable anytime an agent enters and leaves the queue. This is done with the following lines of code:

```
MedAreaOrdQueue ++;
MedAreaOrdQueue--;
```

In Figure25 it is possible to see the complete code as inserted in the different coding areas available in Anylogic.



On enter:

```
    MedAreaOrdQueue ++;}
```

On at exit:

On exit:

```
    MedAreaOrdQueue--;}
```

On exit (timeout):

```
DeathOnTimeOut++;
DeathOnTimeOutMedicalArea++;
    MedAreaOrdQueue--;}
entity.TOutMedicalArea=time();
entity.WaitingTimeMedicalArea=entity.TOutMedicalArea-entity.TInMedicalArea;
WaitingTimeMedicalArea=WaitingTimeMedicalArea+entity.WaitingTimeMedicalArea;
NTotMedicalArea++;
OrdMedAreaWT=entity.WaitingTimeMedicalArea;
OrdMedDT.add(time(),entity.WaitingTimeMedicalArea);
}
```

Figure 25 Yellow patients waiting time computation

The same kind of variables and procedures are applied also to green patients in order to collect waiting times.

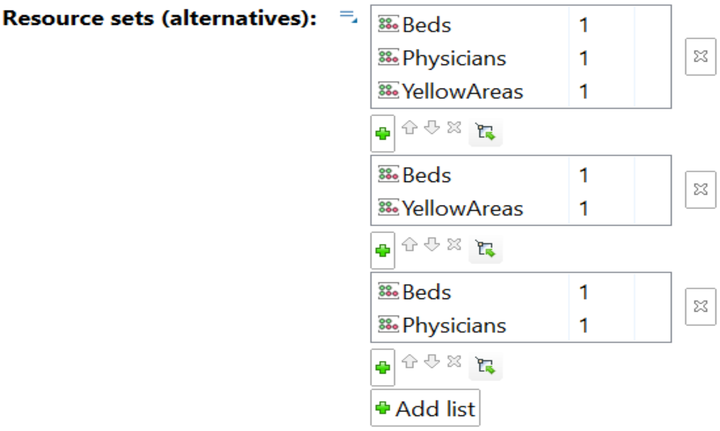
To conclude, the last line of code

```
OrdMedDT.add(time(), entity.WaitingTimeMedicalArea);
```

is necessary to record waiting times in a database internal to the program ("OrdMedDT" is the name of the database dedicated to yellow patients waiting time) and which will be useful to transfer results on Excel and then analyze them. Calling "add" function on "OrdMedDT" database with "time()" as first argument and "entity.WaitingTimeMedicalArea" as the second permits to record on each row of database the waiting time of each *agent* and the moment in time in which it leaves the queue.

2. "Medical Area" *service* simulates the time spent by the patient once left the waiting area. As already mentioned, there is no differentiation between the

various treatments carried on the patients. A *service* module is the combination of three different modules: a *seize*, a *delay* and a *release*. Also a queue is connected to this module but in this case its capacity has been set to 1 to make all the agents awaiting in “queue2”. Through a *seize* module it is possible to occupy a certain set of resources, and they will remain occupied for the length of time indicated in the “delay time” box to characterize the internal *delay* module. To conclude, resources are released through the internal *release* module. Due to the high variability of the activities carried on the patient during the time spent in ED (visit, monitoring etc.) different set of resources (reported in Figure26) are defined and assigned to the entities moving through the module: this way it is possible to implicitly simulate the different pathways a patient may go through in Medical area.


Resource sets (alternatives):

Beds 1
Physicians 1
YellowAreas 1

Beds 1
YellowAreas 1

Beds 1
Physicians 1

Figure 26 Yellow patients set of resources

The first set of resources represents the conditions of patients occupying a bed in one of the yellow areas while visited by a physician. Since physicians do not remain occupied by a patient while in yellow area just for monitoring, it is added also a second set of resources seizing just 1 unit of “Beds” resources and 1 unit of “YellowAreas” resources. To conclude, the third set of resources (1 unit of “Beds” and 1 unit of “Physicians”) represent the case of patients not requiring to be monitored after the visit. It is necessary to specify that this kind of solution represents a simplification, since there will be agents occupying a bed and a yellow area, without never requiring a physician. This is exactly what happens also to green patients in the model, since their resource consumption is not caught by the model. On the other side there are agents occupying a physician for all their length of stay, also in case of durations typical of a monitored patient. These two opposite situations are expected to compensate each other, without affecting the reliability of the results. Reliability of the results will be checked directly by dr. Faccincani.

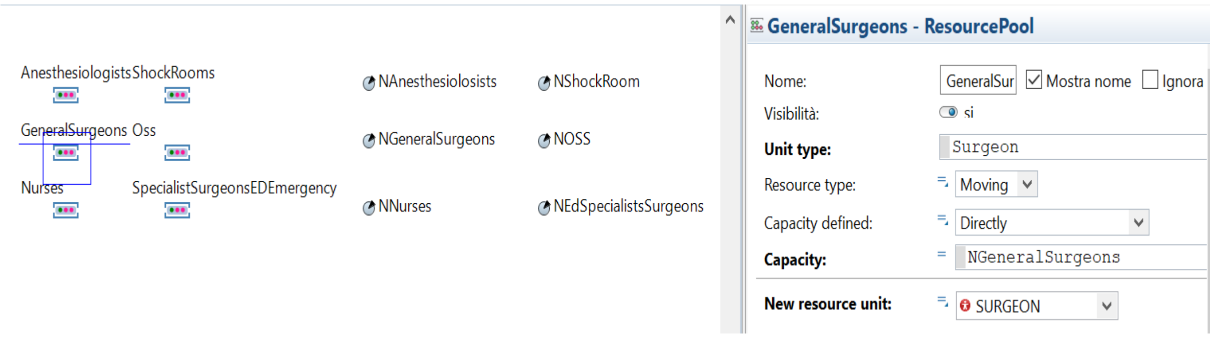
Delay time, as already described in previous section, is set equal to a beta distribution between a minimum equal to 60 minutes and a maximum of 1200. Lower shape parameter is set at 1.1 and higher shape parameter equal to 3 in order to introduce a concavity closer to the minimum.

3. Once the agent leaves the “MedicalArea” module, through a *selectOutput* module it is simulated the different alternative pathways: in 30% of the cases the agent is moved towards the ward area while with 5% probability to agent is directed to ORs. In the remaining 65% of the cases the patient leaves the system.

Red patients

It is described now the way the sequence of activities characterizing a patient classified as red is translated into Anylogic. Also in this case it is necessary first of all to describe the way resources consumed by these kind of activities have been shaped into the model. 6 new *resourcePool* modules are created: “Anesthesiologists”, “GeneralSurgeons”, “OSSs”, “SpecialistSurgeonsEDEmergency”, “Nurses” and “Shock rooms”. An *agent class* is created for each of the aforementioned resources (“Anesthesiologist”, “GeneralSurgeon”, “OSS”, “SpecialistSurgeon”, “Nurse”, “ShockRoom”). In this case it has been chosen to distinguish general surgeons from specialist surgeons since it is specifically a general surgeon to treat a red surgical patient. When a general surgeon or an emergency physician is not available, as it may happen in maxi emergency, a specialist surgeon may take care of the red patient. Anyway this represents a decrease of the quality of care. *resourcePool* modules capacity is set directly through a parameter for each *resourcePool*:

- *resourcePool:* “Anesthesiologists” → *parameter:* “NAnesthesiologists”: 2
- *resourcePool:* “GeneralSurgeons” → *parameter:* “NGeneralSurgeons”: 2
- *resourcePool:* “OSS” → *parameter:* “NOSS”: 3
- *resourcePool:* “SpecilalistsSurgeonsEDEmergency” → *parameter:* “NEdSpecialistsSurgeons”: 1
- *resourcePool:* “Nurses” → *parameter:* “NNurses”: 7
- *resourcePool:* “ShockRooms” → *parameter:* “NShockRooms”: 2



GeneralSurgeons - ResourcePool

Nome: GeneralSur ☑ Mostra nome ☐ Ignora
Visibilità: si
Unit type: Surgeon
Resource type: Moving
Capacity defined: Directly
Capacity: NGeneralSurgeons
New resource unit: SURGEON

Figure 27 ResourcePool, General Surgeons

Red patients pathway is simulated in order to replicate the sequence of operations identified in the schematization reported in previous section. Red patients are generated through a dedicated source module. Arrivals are defined by a schedule equal to *distribution2* as it was described in a previous paragraph. First of all it is inserted a *selectOutput* module to govern the necessity of triage. As already described, in normal conditions a patient indicated as red from pre-hospital operators is not re-evaluated, so in that case triage is not necessary. Situation is different in case of maxi emergency, as it will be described later. Through a *selectOutput* module patients requiring triage are distinguished from patients who don't according to a probability introduced by the parameter "ProbTriage". In normal conditions, probability of triage, so "ProbTriage", is set at zero. In case of normal conditions, instead of Triage, it is simulated the activity of Pre-hospital operators. This is necessary to consider the filter made the operative center of 118: before moving a red patient towards OSR ED, 118 operators have a contact with the hospital to check the availability of resources. In Anylogic this is translated through a series of *queue, pickUp and dropOff* modules:

- All the red patients generated by the source module are placed in the queue
- Through a *pickup* module an agent is picked up from the queue and moved towards the modules representing the ED just in cases resources are available. The condition to be respected is the one reported below

```
ShockRooms.idle()> 0 && Anesthesiologists.idle()>0 &&
            Oss.idle()>0 && Nurses.idle()>0
```

This kind of requirement is not always respected in case of maxi emergency, especially in case the event is very close to the hospital. In facts, once the Emergency Alert arrives *agents* do not pass anymore through this sequence of modules but through the Triage one.

- The *dropOff* module releases the agent and pushes it towards the ED.

Pre-hospital simulation is visible in Figure28 within the orange square.

It is also inserted the possibility of patients dying before being accepted in ED. This is simulated with a *selectOutput* module with probability 0.05%.

Through one more *selectOutput* module surgical patients are distinguished from non-surgical ones. Agents follow true output, that is the surgical one, with a probability equal to 13% deduced from *database1*. That probability is introduced through a parameter named “ProbChir” to have the possibility to change it runtime.

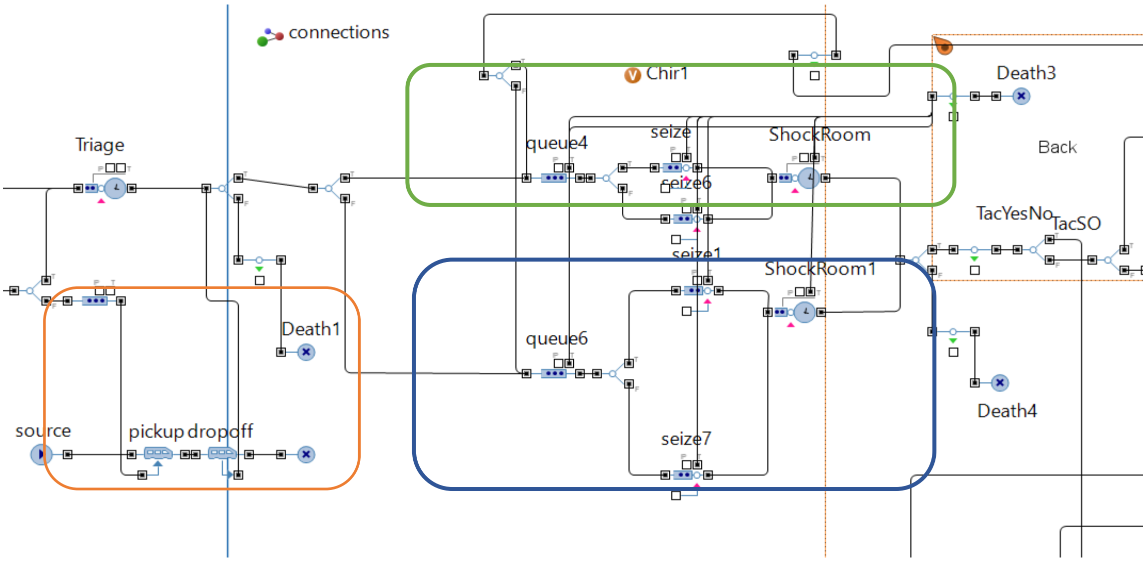


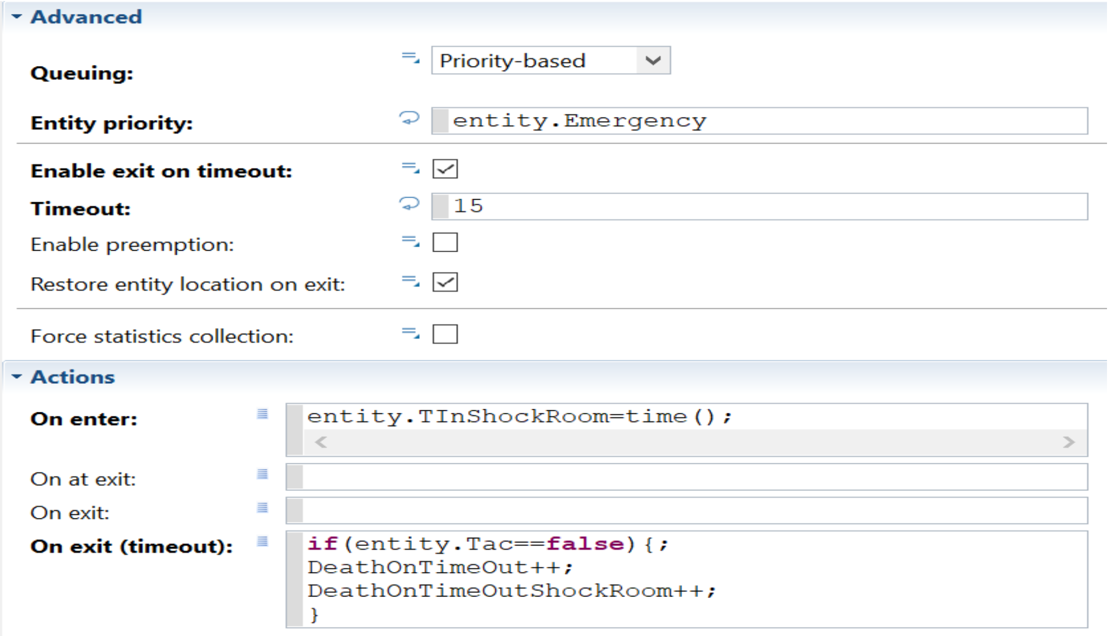
Figure 28 Shock Rooms, Anylogic

An agent flowing through true output, so a surgical one, has its entity variable “Chir” updated to true to differentiate surgical patients from non-surgical ones (default value has been set to false):

```
entity.set_Chir(true);
```

Surgical and non-surgical patients pathway is similar, what changes is the set of resources seized and the length of occupation of them. In both cases agents pass through a *queue*, two alternative *seize* modules, and then a *service* representing the time spent in shock room. In Figure28, green area and the blue one represents respectively surgical patient pathway and the non-surgical one.

1. “queue4” and “queue6” represent a specific physical space which is the hot room where the ambulance stops. These queues are necessary to model those, infrequent, situations in which the patient has to wait for ED personnel: of course this is a very significant risk for a red patient and it’s possible, in case of a too long awaiting, to have a significant decrease in patient conditions. This is represented by the possibility of the agent to leave the queue through the “timeout” exit: it happens if the agent remains in the queue more than a lapse of time equal to 15 minutes. Of course, thanks to the “activity” of the pre-hospital modules this kind of phenomenon is very rare. Situation is different in case of maxi emergency. To keep track of this phenomenon it is defined 2 system variables named “DeathOnTimeOut” and “DeathOnTimeOutShockRoom” which are updated in case of an agent leaving the module through the “exit on time out port”. The second variable is the one that will be considered to quantify the number of patients at risk (PAR) described in chapter4. In Figure29 it is reported the necessary code.



Advanced

Queuing: Priority-based

Entity priority: `entity.Emergency`

Enable exit on timeout: ☑

Timeout: 15

Enable preemption: ☐

Restore entity location on exit: ☑

Force statistics collection: ☐

Actions

On enter:

```
entity.TInShockRoom=time();
```

On at exit:

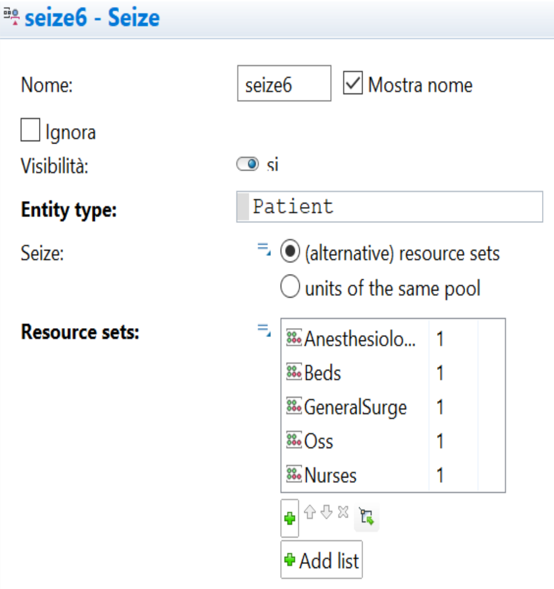
On exit:

On exit (timeout):

```
if(entity.Tac==false){;
DeathOnTimeOut++;
DeathOnTimeOutShockRoom++;
}
```

Figure 29, ShockRoom

2. After the queue the so called “trauma team” is assigned to each agent. This is translated into Anylogic through a system of *seize* modules. “seize6” and “seize7” represents respectively the assignation of the trauma team for the surgical and the non-surgical patient in the best scenario.


seize6 - Seize

Nome: seize6 ☑ Mostra nome

☐ Ignora

Visibilità: sì

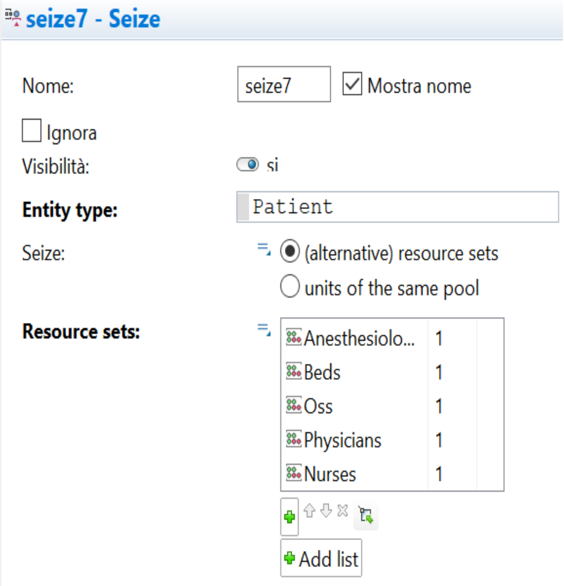
Entity type: Patient

Seize: ● (alternative) resource sets ○ units of the same pool

Resource sets:

Anesthesiolo...	1
Beds	1
GeneralSurge	1
Oss	1
Nurses	1

Figure 31 Seize6


seize7 - Seize

Nome: seize7 ☑ Mostra nome

☐ Ignora

Visibilità: sì

Entity type: Patient

Seize: ● (alternative) resource sets ○ units of the same pool

Resource sets:

Anesthesiolo...	1
Beds	1
Oss	1
Physicians	1
Nurses	1

Figure 30 Seize7

What differs is the personnel composing the team: 1 resource from the "GeneralSurgeons" *resourcePool* is present for the surgical one, 1 from "Physicians" is present for the non-surgical one. "seize" and "seize1" modules will be described in the section related to the reconfiguration of resources in case of maxi emergency.

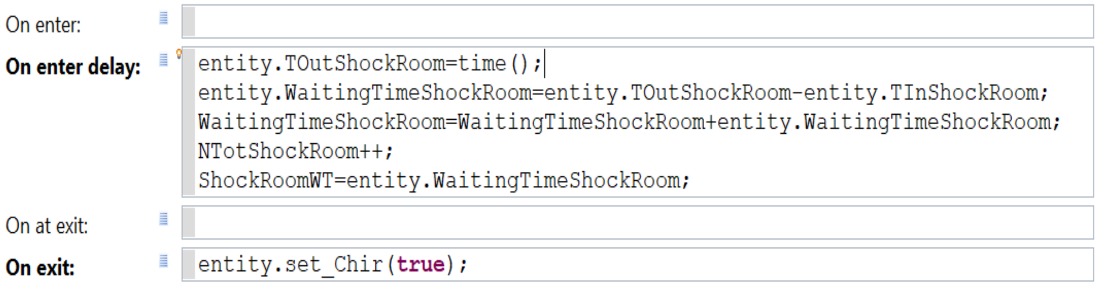
Agents can leave *seize* modules once resources necessary to occupy the subsequent *service* module are free. In this case it is necessary to have one unit free from the *resourcePool* "ShockRooms". Agents leave the queue through the timeout port after 30 minutes and also in these cases are counted in the PAR index. Wait can be longer with respect to the previous *queue* modules since medical personnel is already assigned to the patient. Actually, agents leaving the system through the "timeout" port do not necessarily represent patients dying in ED but just those cases in which the patient does not receive all the resources in a sufficiently rapid time, creating a risk for his/her conditions. In facts, as reported in the PEMAF, red patients are those who may need a surgical intervention in no more than 2 hours. A limitation of the model emerges in this area since it is not able to catch the flexibility of operators: resources remain occupied for a length of time determined according to a certain probability distribution, but once determined it is not possible to modify it, in the model. In reality, in case a patient awaits out of the shock room, procedures inside the shock room are speeded up, to avoid patient conditions worsening. Anyway, it is still interesting to keep track, through the 2 variables aforementioned, of the number of times these situations occur.

Also for what concerns Shock rooms it is computed the waiting time, with a system of entity specific and system variables similar to the one described for Medical area. Entering the queue through the enter port it is updated the entity variable “TInShockRoom” at the current time.

3. “ShockRoom” and “ShockRoom1” *service* modules simulate the time spent by the patient in shock room. Once 1 unit from the “ShockRooms” *ResourcePool* is free the agent occupies that resource and, thanks to the coding area “on enter delay”, the entity variable representing the end of the waiting time is updated:

```
entity.TOutShockRoom=time();
```

The entire code necessary to compute and record the entire amount of time spent by the agent awaiting for occupying a “ShockRooms” resource is reported in Figure32. It is analogous to the one described for Medical Area.



On enter:

On enter delay:

```
entity.TOutShockRoom=time();
entity.WaitingTimeShockRoom=entity.TOutShockRoom-entity.TInShockRoom;
WaitingTimeShockRoom=WaitingTimeShockRoom+entity.WaitingTimeShockRoom;
NTotShockRoom++;
ShockRoomWT=entity.WaitingTimeShockRoom;
```

On at exit:

On exit:

```
entity.set_Chir(true);
```

Figure 32 Red patients waiting time computation

In case of surgical patient, so in “ShockRoom” *service* module, length of stay is determined through a parameter “ShockRoomDelay” equal to 60 minutes. For what concerns non-surgical patients, so in “ShockRoom1” *service* module, length of stay is determined according to a triangular distribution. Minimum, maximum and most frequent values are represented by three parameters (min1, freq1 and max1) equal respectively to 60, 120, 360.

Agents are picked up from the queue according to a priority rule based on the entity variable “Emergency”: the higher the value the sooner the agent is treated.

For what concerns “ShockRoom1” *service* it is selected the option “task may preempt”. Thanks to this option the task carried on in this module can preempt another one, even carried on in a different module. Task priority is determined according to the “Emergency” entity parameter. In this way, in case all the physicians are occupied for yellow patients, “ShockRoom1” task preempts the ones carried on in medical area, so that red patient is treated with an higher degree of priority with respect to yellow patients.

Once terminated the delay time, the agent leaves the module and resources are released.

Selection of the destination

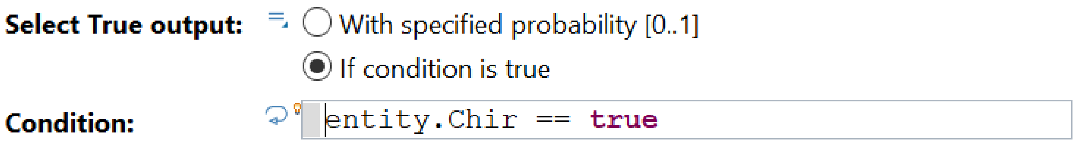
As already introduced in the previous section, once left the shock room, red patients may require further diagnostic investigations through the CAT SCAN, or being moved to another area of the hospital. When the *agent* leaves “ShockRoom” or “ShockRoom1” module it is introduced in a *selectOutput* module (“TacYesNo”) to check whether the a*gent* already passed or not through the Cat Scan module. In facts, as it will be described in the next paragraph, there is a portion of patients which are sent back to Shock room after the analysis and it is necessary to avoid them moving to the Cat scan module once again. To do that, in *selectOutput* “TacYesNo”, *agents* are moved towards the true output (so that not passing through Cat scan) in case entity specific variable “Tac” is equal to true. This variable is set to false by default and it is updated to true only when the *agent* passes through the Cat scan module.

1. If the *agent* takes the false output, a second *selectOutput* module (“TacSO”) distinguishes those patients who may require a Cat scan from those who don’t. This is determined through a probability, in particular the variable “ProbTac”, which is set, in normal conditions, equal to 0.4.
    a) If the *agent* takes the true output, so it is pushed towards the Cat scan, it is inserted in a *service* module named “Tac”. Here three different resources are seized: 1 unit of “Tacspaces”, 1 unit of “Radiologists” and 1 unit of “RadiologyTechnicians”. “TacSpaces”, “Radiologists” and “RadiologyTechnicians” are three *resourcePool* modules introduced in the model to represent the resources consumed by the patient when it gets a Cat Scan. Delay time is equal to 25 minutes. Once left the *service* module entity specific variable “Tac” is updated to true.

```
Entity.Tac = true;
```

Subsequently the *agent* passes through a *selectOutput* module which distinguishes patients going back to ShockRoom from those requiring an surgeryin OR. This is done according to a probability equal to 0.5. *Agents* oriented to Shock Room are inserted in "queue4" and "queue6" with a lower level of priority. ORs will be described in the following section.

b) If the agent takes the false output it meets another *selectOutput* module to distinguish surgical from non-surgical patients. In facts the only possibility for surgical patients is to go directly to ORs, while non-surgical patients may also be directed to other areas of the hospital. So *agents* takes the true output, that directed to ORs, if they are surgical, so according to the following condition:



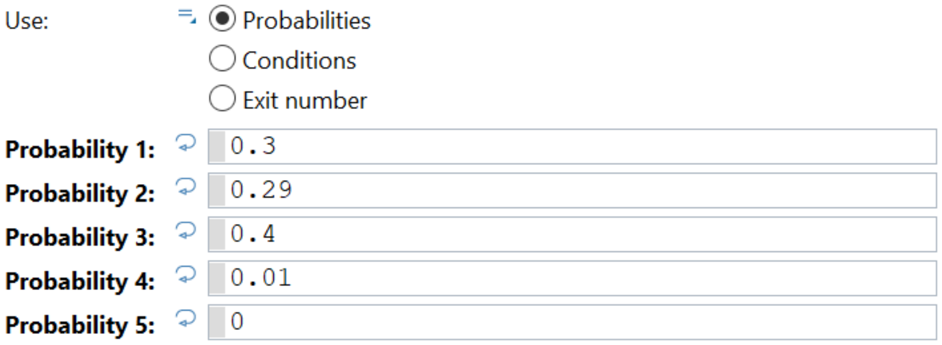
Select True output: ○ With specified probability [0..1]
● If condition is true

Condition:
```
entity.Chir == true
```

Figure 33 selectOutput

Otherwise *agent* is directed towards "selectOutput6" which is described in the following paragraph

2. If the *agent* takes the true output (in "TacSO" *selectOutput* module) it is directed towards another *selectOutput* ("selectOutput6") module that splits agents destined to the different areas of the hospital according to a set of probability and conditions. As already anticipated two kind of patients arrive here: non-surgical patients and surgical patients after the cat Scan. For all of them it is assumed the same probability of being moved towards ORs, Home, ICU and Ward. These are reported in Figure34:



Use: ● Probabilities
○ Conditions
○ Exit number

Probability 1: 0.3
Probability 2: 0.29
Probability 3: 0.4
Probability 4: 0.01
Probability 5: 0

Figure 34 Red patients destinations probabilities

(Probability1 → OR, Probability2 → Home, Probability3 → Ward and Probability4→ ICU)

Here it is concluded the description of the ED in Anylogic, since all the generated *agents* have been moved to another area of the hospital. In the next sections it will be replicated the same structure applied for the description of the ED: first the real system is analyzed, then the way is has been schematized and finally the translation into Anylogic.

3.2.2 ED-Hospital system interfaces

In this section it will be presented the portion of hospital that has been considered within the scope of work of the thesis. In particular it will be described the system of ORs, Wards and ICU.

3.2.2.1. Operating block

The OSR operating block includes 28 ORs, where general surgery, gynecology and obstetrics, orthopedics, ophthalmology, neurosurgery interventions and many others surgeries are performed. The operative block is organized with a medical manager responsible for the whole organization and with medical managers responsible for each of the specialized surgical branches. Elective surgical activity begins at 8:00 a.m. and ends at 8:00 p.m., without interruption. There is also an OR dedicated to emergencies and an OR dedicated to day surgery. The function of the operative block is in facts to perform scheduled and emergency surgeries, guaranteeing the conditions of safety and sterility to the patient and to the healthcare staff. In 2017, in OSR approximately 34,000 surgical interventions were performed.

The areas the operating block is divided in are many and various, beside ORs:

- filter area at the entrance;
- personal preparation area, where staff change to access the sector;
- surgeon preparation area;
- patient preparation area;
- patient awakening area;
- irons washing room;
- material sterilization area;
- surgical instrument storage;
- deposit of sterile materials;

- personal nursing room;
- staff toilets;
- dirty material deposit, on a path called dirty.

Elective/ordinary surgical activity refers to all the surgeries carried on in a non-urgent regime. In this case patients are introduced in a waiting list and surgeries are scheduled according to the availability of the rooms and to a scale of priority. As a matter of facts, among the elective patients, there are very different degrees of priority and importance: generally it is possible to affirm that a surgery scheduled long time before suggests a low level of urgency, while there are cases of surgeries carried on propaedeutically to urgent therapies and to be undertaken in a very specific lapse of time. In addition it is worth to distinguish “solvent” patients from those scheduled through the National Health System. OSR is in facts an accredited private hospital with a portion of private patients who autonomously decide to pay a fee to sustain surgeries or other treatments. To conclude it is also possible to distinguish patients in day surgery from those hospitalized. This is to say that actually the activity of ORs is very heterogeneous, considering also the very wide range of specialties and operations carried on.

To synthetize, it is possible to say that the flow of a patient inside the Operating Block can be schematized in 5 phases:

1. The patient is taken in charge by a first nurse who initiates him to the inductive phase.
2. If a bed set up specifically for anesthesia is available (“Anesthesia room”), the patient is accompanied to the room and anesthesia takes place there. Otherwise the patient is brought to the OR assigned to him and anesthesia takes place there.
3. Once in the OR, in the presence of the anesthetist, three nurses (OR equipe) and two surgeons (one general surgeon and specialist one) surgery can take place.
4. Once the operation has been completed, the awakening phase begins, which, can take place in the OR or in the induction room in the presence of only one nurse.
5. Once this phase is completed, the patient can return to the ward. In some cases it is necessary to move the patient to the post-operative intensive care unit.

As already anticipated, in OSR it is available an OR dedicated 24/24h 7/7 to urgencies. Patients coming from ED to this room are followed by the trauma team that received them in shock room: a general surgeon, an anesthetis and an OSS. Generally nurses remain in ED. Once an urgent patient arrives in the OR dedicated to urgencies, beside the resources that already accompany him/her, it is added also an equipe of nurses specialized and generally also a specialist surgeon. Also for what concerns patients leaving the OR dedicated to urgencies, possible destinations are ICU, or ward.

3.2.2.1.2 Rationalization of operating block

In the scheme reported in the following page it is represented the way ORs have been translated into a flow chart.

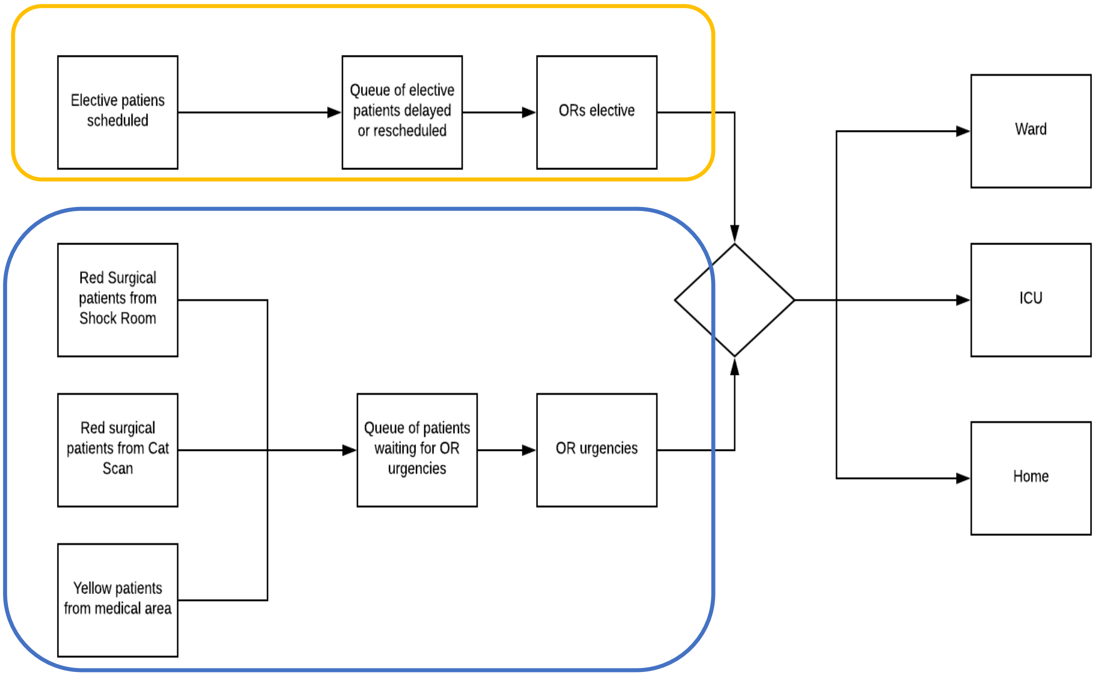


Figure 35 ORs rationalization

The scheme permits to clearly identify two sub-areas working in parallel and interacting very frequently: ORs dedicated to ordinary surgeries and OR for urgencies. These are represented respectively by orange and blue squares. Interaction is intense between the two systems since, of course, in case of two simultaneous patients from ED in need of an surgery there is the possibility to shift urgent activity on elective ORs. Elective patients scheduling is the input to the elective ORs, while three different categories of patients are input for the Or dedicated to urgencies:

1. Red surgical patients from Shock Room:
   - Red surgical patients recognized as in need of surgery directly in Shock room
   - Red surgical patients recognized as in need of surgery after the Cat scan and passing once more in shock room
2. Red surgical patients from cat scan
3. Yellow patients from medical area

As it is possible to notice from the scheme, Operating block has been considered as a "black box", since there is no distinction between induction room, OR and recovery room. This was considered as a level of detail appropriate for the aim of the thesis. In addition this kind of representation permits to clearly analyze the resources consumed by the patient, elective or urgent, passing through the Operating block. Results of this analysis, as well as some considerations on the parameters useful to describe this area of the hospital, are reported in the following tables and paragraphs

Area/process	Resources	Descriptive parameters
Elective ORs	1 Ordinary general Surgeon 1 Ordinary Anesthetist 1 Operating room equipe of nurses 1 specialist surgeon 1 OSS 1 OR for elective patients	Surgery duration
Urgent OR	1 ED general Surgeon 1 ED Anesthetist 1 Operating room equipe of nurses 1 specialist surgeon 1 OSS 1 OR for urgencies	Surgery duration

Table 18 ORs resources and descriptive parameters

As a comment to table18 just presented it is important to notice the distinction between general surgeons and anesthetists operating in elective ORs and those coming from ED. As already introduced in the previous paragraph, when an urgent patient arrives to the OR dedicated to urgencies he/she is accompanied by a trauma team composed by a general surgeon, an anesthetist and an OSS (generally nurses remain in ED since they role is covered by OR equipe of nurses). To complete the necessary personnel, it is added to the trauma team a specialist surgeon and the operating room equipe of nurses. Differently, there is a set of general surgeons and anesthetists devoted to elective patients. In this section general surgeons coming from ED are named "ED general surgeon" to distinguish them from ordinary ones, but it's the same personnel described in the previous section related to ED.

Additional parameters necessary to complete the qualitative description of the OR is the percentage of patients going back to wards for a long period, those directed to ICU and those who are sent back home after a short stay in OR.

Parameters quantification and calibration

In table19 it is reported a summary of the values of the parameters just described. The sources of information are the same already presented in the section related to the quantification of ED parameters. In addition, for what concerns the length of stay in OR, the analysis has been based on a database (*database2*) containing the durations of the most frequent procedures.

Personnel	
Ordinary general surgeons (per shift)	28
Ordinary anesthetists	28
ED General surgeons	2
OR equipe of nurses	28
ED Anesthetists	2
OSS	3
Specialist surgeons	28*

Table 19 ORs staff

*The number of specialist surgeons is a parameter very hard to be determined since their activity is not strictly bounded to the one of the OR. In addition, to give a highly detailed representation of OR system it is not actually sufficient to know the number of "specialist surgeons" in general, but the exact number of gynecologists, orthopedic surgeons and the schedule of their work in OR. This has been considered as not significant for the aim of the thesis so it has been chosen a number of specialist surgeons that would permit to activate all the 28 ORs simultaneously.

Spaces	
ORs for elective patients	27
OR for urgent patients	1

Table 20 ORs spaces

Descriptive parameters	
Surgery duration	Triangular (30, 60, 240)
Patients back to ward	95%
Patients back home	3%
Patients to ICU	2%

Table 21 ORs descriptive parameters

As already anticipated the probability distribution of surgeries duration has been extracted from a database containing the standard durations of all the possible surgeries carried out in OR. The analysis of it suggests to establish a triangular distribution between 30 and 240 minutes and 60 minutes as the most frequent value. Surgeries scheduling is set, of course, in order to saturate ordinary ORs as much as possible according to the availability of the staff.

3.2.2.1.3 Operating block in Anylogic

Also for what concerns the translation of The Operating block into the software environment it has been chosen, among the simulation modelling techniques, the approach based on *discrete events*. The basic reason behind this choice is the necessity of considering resources, in terms of personnel and spaces, in a discrete way. As it will be described in the following section, one of the crucial points of the thesis concerns with the allocation of ORs and ORs personnel either to urgent or elective patients. To do that it is necessary to have the possibility to consider resources punctually. Furthermore, despite in a more simplified manner compared with ED, activities can be easily and precisely represented as a series of steps undertaken by the patient when entering the Operating block: this is a clear indicator of the viability of *discrete event* simulation modelling.

In Figure36 it is possible to see the entire portion of model devoted to the representation of Operating block activity. Some modules visible in Figure36 are related to the reconfiguration of resource, so they will be described later.

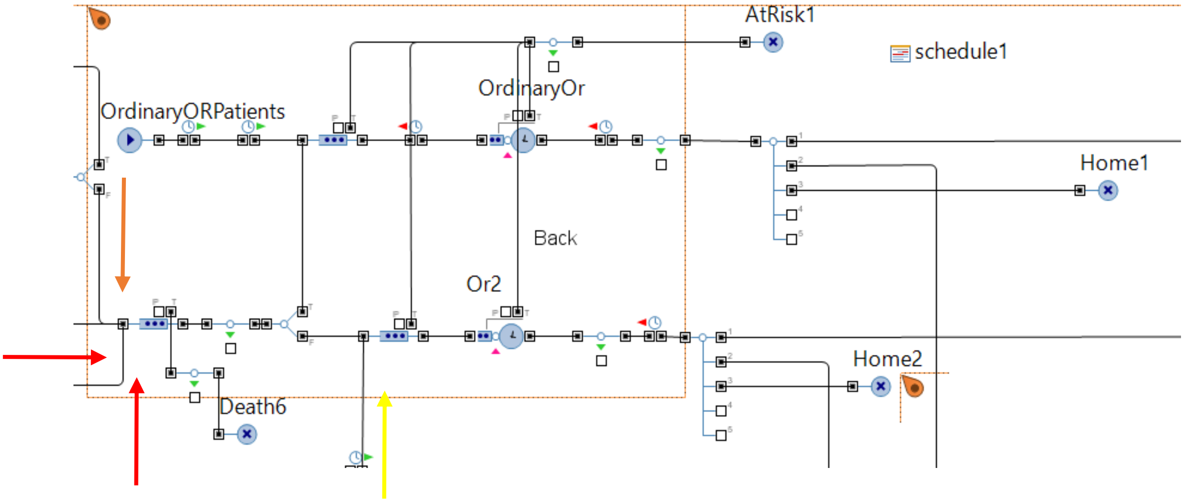


Figure 36, ORs, Anylogic

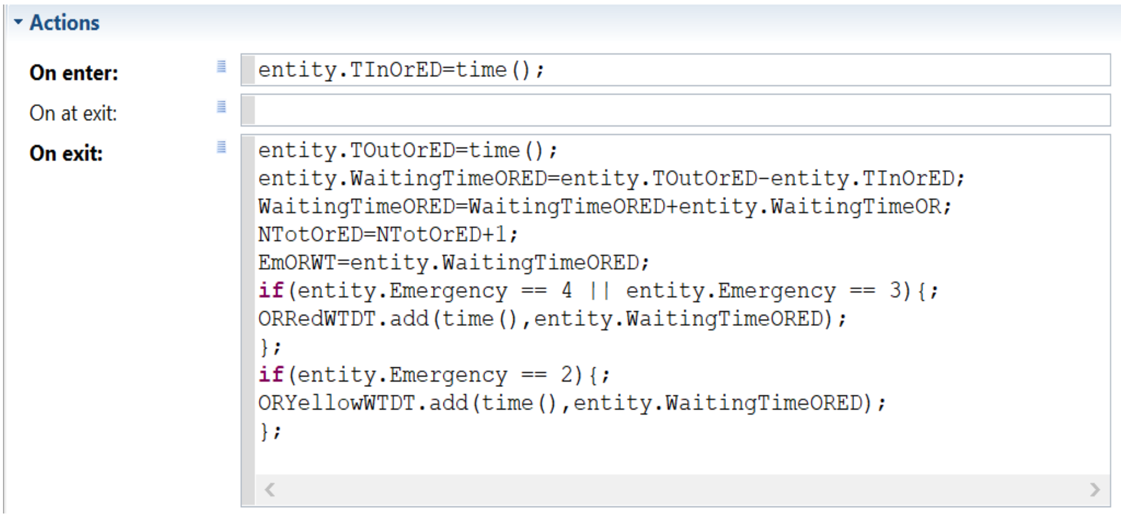
Colored arrows are useful to identify the 3 already mentioned flows of patients passing through ORs and to have a link with the previous section dedicated to ED:

1. Red arrows: red surgical patients from Shock Room:
   - Red surgical patients recognized as in need of surgery directly in Shock room
   - Red surgical patients recognized as in need of surgery after the Cat scan and passing once more in shock room
2. Orange arrow: red surgical patients from cat scan
3. Yellow arrow: yellow patients from medical area

It will be described first the set of modules dedicated to urgent patients, and subsequently the ones for elective patients

Urgent patients OR

All the *agents* pushed to the OR dedicated to urgencies are inserted in a queue module ("queue5"). Queueing rule is based on priority, in particular on the entity specific variable "Emergency": the higher the value of the variable the sooner the *agent* will be pushed towards the OR. In this case there are two different levels of priority, so introducing a queuing rule is absolutely necessary: red patients (Emergency=3) have to be treated before yellow patients (Emergency=2). The time spent by the *agent* in queue is recorded through a system of entity specific and system variables similar to the one described for *agents* in ED. In Figure37 it is reported the lines of code (in "queue5") that govern the recording of waiting times.



On enter:

```
entity.TInOrED=time();
```

On at exit:

On exit:

```
entity.TOutOrED=time();
entity.WaitingTimeORED=entity.TOutOrED-entity.TInOrED;
WaitingTimeORED=WaitingTimeORED+entity.WaitingTimeOR;
NTotOrED=NTotOrED+1;
EmORWT=entity.WaitingTimeORED;
if(entity.Emergency == 4 || entity.Emergency == 3){;
ORRedWTDT.add(time(),entity.WaitingTimeORED);
};
if(entity.Emergency == 2){;
ORYellowWTDT.add(time(),entity.WaitingTimeORED);
};
```

Figure 37, ORs waiting time computation

As it is possible to notice, it is distinguished red patients waiting time from yellow patients waiting time:

```
if(entity.Emergency == 4 || entity.Emergency == 3){;
ORRedWTDT.add(time(),entity.WaitingTimeORED);
};
if(entity.Emergency == 2){;
ORYellowWTDT.add(time(),entity.WaitingTimeORED);

};
```

Two different databases are created: “ORRedWTDT” for red patients and “ORYellowWTDT” for yellow patients. Items are added, through the “add” function previously described, to the first database just in case entity specific “Emergency” parameter assumes a value equal to 3 or 4 (4 is the level of emergency of patients deriving from Maxi-emergency, as it will be described later).

Once left the queue the *agent* is inserted in a *service* module named “Or2” representing the activities carried out in OR. To complete the description of this module it is necessary first of all to present the way the resources consumed in this module have been modelled. As already introduced in the previous section, units of resources representing the staff taking care of the patients are still seized to the *agent* when arriving in OR for urgencies. In facts it has been necessary to model just ORs, OR equipe of nurses (specialists surgeons has already been described) operating in OR. The procedure applied to model these resources is the same already presented for other resources:

1. Creation of agent class (“OperatingRoom”, “EquipeOperatingRoom”, - “SpecialistSurgeon” already presented)
2. Creation of a correspondent *resourcePool* but specific for OR for urgencies (“OperatingRoomEd”, “EquipeOperatingRoomEd”, “SpecialistSurgeonOR”)
3. Definition of *resourcePool* capacity through parameters:

- “NoperatingRoomEd” → 1;
- “NequipeOperatingRoomEd” → 1
- “SpecialistSurgeonOR” → 28

It is interesting to notice that “SpecialistSurgeon” *agent class* is the same introduced to model specialist surgeons operating in ED. The distinction between specialist surgeons operating in ED from those operating in OR is introduced thanks to the *resourcePool.* The same kind of approach is applied to distinguish ORs designated to elective patients from those to urgencies.

When the *agent* passes through the “Or2” *service* module 1 unit of “OperatingRoomEd”, 1 unit of “SpecialistSurgeonEd” and 1 unit of “EquipeOperatingRoomEd” is seized to the *agent* and after the delay time they are released. Delay time is set equal to a triangular distribution with minimum, maximum and most frequent value equal to 30, 60 and 240 minutes. This represents a reasonable probability distribution of the surgeries duration, as already anticipated in the previous section. Once left “Or2” module the *agent* is directed towards “Home”, “Ward” and “ICU” through a *selectOutput* module based on the probabilities anticipated in the previous section.

Elective patients ORs

To understand the simulation modelling logic applied to elective patients ORs it is necessary first of all to understand the *aim* of this process. In facts, this is the first area of the hospital completely out of the ED. This means that the aim is not to model and have a representation of the activity of the ORs themselves, but just of the way they interact with the ED. Based on this consideration, simulation modelling approach is mainly oriented towards the timely representation of ORs workload, rather than on ORs performance. This is the reason why it has not introduced a real schedule into the model, but just a *realistic* schedule that would permit to have ORs saturated in a credible manner.

Agents representing elective patients are inserted into the model through a *source* module named “OrdinaryORPatients”. New entities are generated starting from “Patient” class according to a schedule module (“schedule1”). This is established in order to simulate the beginning of daily activities at 8:00 a.m. In that moment 27 new *agents* are generated in order to completely saturate ORs. Once generated, *agents* pass through a queue before entering “OrdinaryOr” *service* module. In this case it is necessary to assign to the *agent* the entire set of resources necessary to perform an surgery. The process to model these resource is the same described for all the other resources and it is summarized in table22:

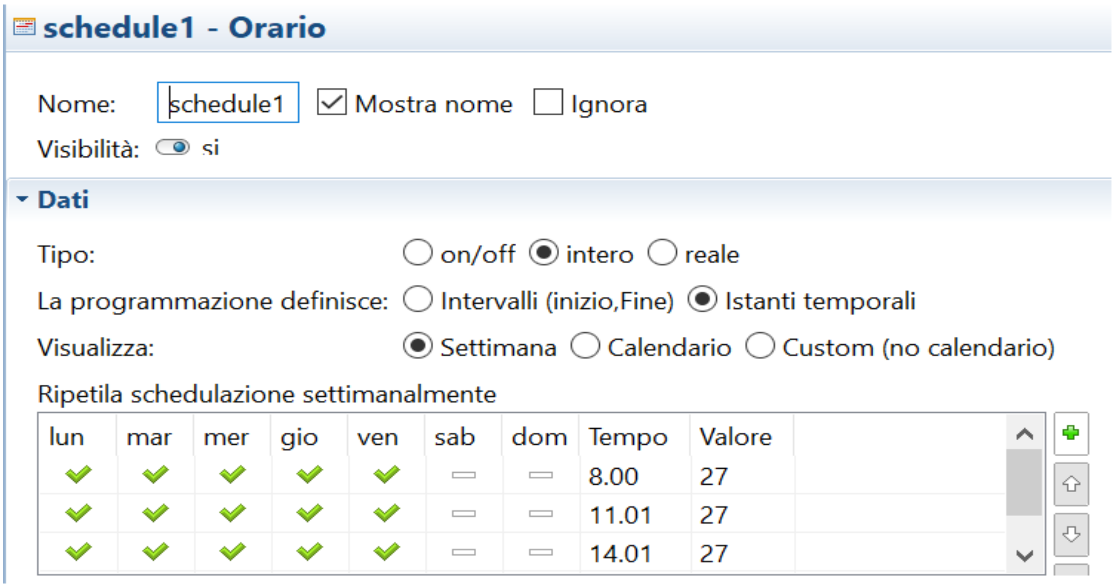
Resource	Class agent	ResourcePool	Capacity
Specialist Surgeon	“SpecialistSurgeon”	“SpecialistSurgeonsOR”	28
Operating Room	“OperatingRoom”	“OrdinaryOperatingRooms”	27
Equipe Operating room	“EquipeOperatingRoom”	“EquipeOperatingRoom”	27
Anesthesiologist	“Anesthesiologist”	“AnesthesiologistsOR”	27
General surgeon	“GeneralSurgeon”	“GeneralSurgeonsOR”	27

Table 22 ORs resourcePool modules

As already anticipated, thanks to the usage of different *resourcePool* modules it is possible to distinguish resources according to the area they operate in. To make some examples, “AnesthesiologistsOR” and “GeneralSurgeonsOR” are the *resourcePool* modules containing those anesthesiologists and general surgeons available for OR, which are different from the ones operating in ED. Once the *agent* passes through the “Or2” module, a set of resources composed by one unit from each of the *resourcePool* described above is assigned to the *agent.* Delay time is set equal to a triangular distribution between 30 and 240 minutes, with 60 minutes as the most frequent value. Once terminated the delay resources are released and the *agent* is pushed towards a *selectOutput* module exactly equal to the one described in the section dedicated to urgent patients.

Coming back to the description of the schedule, a new pool composed by 27 *agents* is introduced into the model every three hours until 5:00 p.m, in order to simulate a daily shift from 8:00 a.m. to 8:00 p.m. the same schedule is repeated from Monday to Friday.

Of course this represents a simplification of the activities in the Operating block, since a new patient is introduced into the Operating Block anytime the previous surgery is completed, not just every three hours. On the other side it would have been out of the scope of the thesis to simulate the exact schedule of the patients, while this approach has been considered coherent with the *aim* described at the beginning of this section. In addition it permits to consider potential delays in the schedule (there are surgery which may last more than 3 hours, since the maximum value of the triangular distribution is 240 minutes) and, somehow, also the *set up* time consumed by the activities to change and re-arrange the room between one patient and the following one. In facts, it would have been non-realistic to simulate two surgeries with no time in between. Below it is reported a portion of the schedule as it is in Anylogic



schedule1 - Orario

Nome: schedule1 ☑ Mostra nome ☐ Ignora

Visibilità: si

Dati

Tipo: ○ on/off ● intero ○ reale

La programmazione definisce: ○ Intervalli (inizio,Fine) ● Istanti temporali

Visualizza: ● Settimana ○ Calendario ○ Custom (no calendario)

Ripetila schedulazione settimanalmente

lun	mar	mer	gio	ven	sab	dom	Tempo	Valore
✓	✓	✓	✓	✓	☐	☐	8.00	27
✓	✓	✓	✓	✓	☐	☐	11.01	27
✓	✓	✓	✓	✓	☐	☐	14.01	27

Table 23 schedule1

3.2.2.2 Intensive care unit

Intensive Care Unit (ICU) is the hospital unit where intense care is given to patients with particular states of health of medium or high severity, such as the support of vital functions. In OSR this unit can be subdivided into some different clinical specialties:

- General reanimation
- Cardiothoracovascular resuscitation
- Reanimation of the Head-Neck District
- Coronary intensive care

ICU is characterized by an advanced set of instruments for each bed, such as an automatic respirator, multi-parameter monitor, manual defibrillator, etc; in the ward a specialized nursing assistance is guaranteed in a number not less than one unit every two beds and at least one doctor for the whole department, normally an anesthetist. ICU is classically constituted by a single hospitalization area so as to guarantee at any time, by all the staff present, the easy control of what happens in the ward and the guarantee of immediate surgeries in case of need. A special mention is worth for post-surgery intensive care unit which receives patients after recent major surgery.

3.2.2.2.2 Rationalization of ICU

Intensive care unit, given its nature, can be represented through a single step representing the period of stay of the patient in this department. In Figure38 it is represented the way it has been schematized

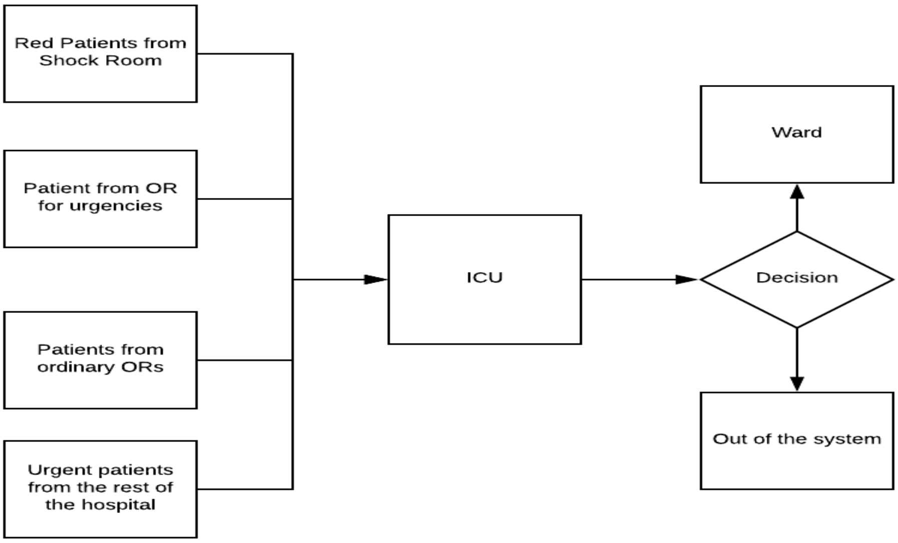


Figure 38 ICU rationalization

Four different categories of patients may require a treatment in ICU, given the structure of the model as it has been presented up to now:

- Red patients directly from shock room
- Patients from OR for urgencies
- Patients from ordinary ORs
- Urgent patients from the rest of the hospital

Despite 4 different flows of patients acceding to ICU, the overall number of patients that pass through this area is low with respect to the other areas of the hospital already presented and those presented in following paragraphs.

Similarly to what has been done for ORs, ICU has been considered as a black box, since no distinction has been introduced on the activities which are carried out in this department. In addition, with respect to ORs, it has not been considered the personnel operating in there but just the number of beds available. This is reasonable and does not affect the reliability of the model since there is a standard ratio between the number of patients and the number of nurses or doctors (generally one nurse every two patients, and at least one physician, usually an anesthetist, for the whole area). In addition there is not a particular trade off in terms of resource with the rest of the areas introduced in the model. To be coherent with the procedure followed in previous sections, in table39 it is reported the analysis on the processes carried on in ICU:

Area/Process	Resources	Parameters
ICU - Rest	Bed and related instruments	Length of stay

Figure 39 ICU resources and descriptive parameters

Parameters quantification and calibration

As it is easy to catch from the rationalization of the ICU proposed in previous section, parameters to be quantified in order to represent this area are mainly two:

1. Beds availability in intensive care unit: summing up all the beds available in the different clinical specialties it resulted an overall availability of 30 beds. In this case, despite the high cost of instruments, beds are not generally completely saturated. This is a conscious choice of the hospital since, due to the characteristics of the patients admitted to this area, it would take long time to free beds in case of emergency. According to dr. Faccincani, on average, 26 beds are occupied over the 30 available beds.
2. Length of stay in ICU: in order to quantify this parameter, which is highly variable, it has been scanned briefly the available literature on the topic. As a reference, it has been chosen the data proposed by Alex Hunter, Leslie Johnson and Alberto Coustasse in 2014. From their work it has been determined a triangular distribution with minimum, maximum and most frequent values respectively equal to 360, 3600 and 4320 minutes.

3.2.2.2.3 ICU in Anylogic

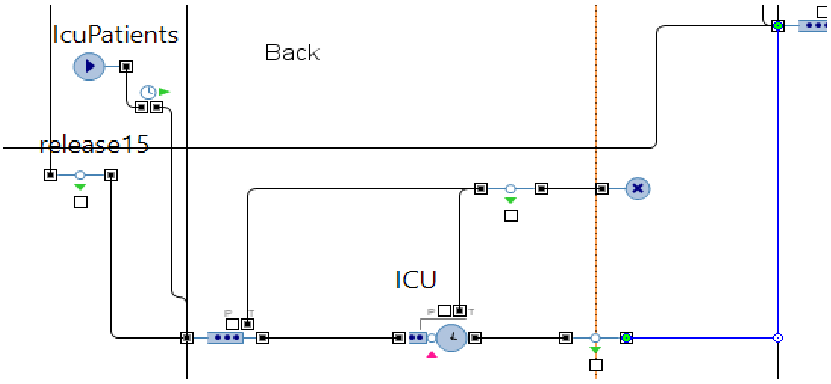
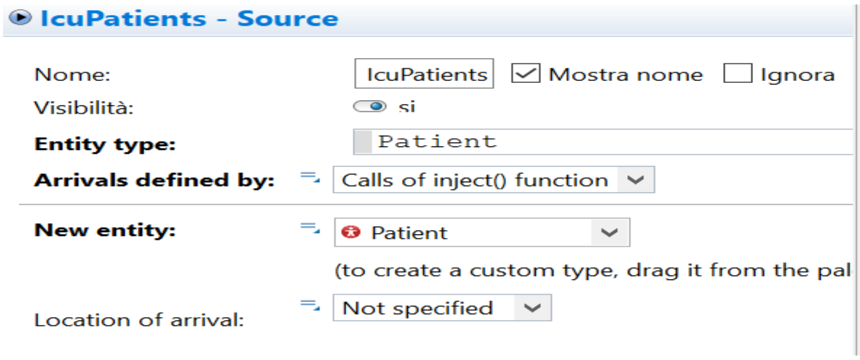


Figure 40 ICU, Anylogic

Also for what concerns ICU it is valid the premise made for elective ORs related to the aim of the representation: also in this case, in fact, the purpose of the modelling process is that of simulating the workload on ICU and the average level of saturation in order to evaluate the interaction with ED. Given this premise, the structure of the model is similar to the one applied for ordinary ORs:

1. A *source* module, named "IcuPatients" injects new agents into the model. These represent those patients coming from the areas of the hospital not taken into considerations in the model. Differently from other *source* modules previously described, in this case *agents* arrival is defined by the call of "inject()" function: anytime "inject()" function is called on "IcuPatients" *source* module a new *agent* is injected in the system.



IcuPatients - Source

Nome: IcuPatients ☑ Mostra nome ☐ Ignora
Visibilità: si
Entity type: Patient
Arrivals defined by: Calls of inject() function
New entity: Patient
(to create a custom type, drag it from the pal
Location of arrival: Not specified

Figure 41 ICUPatients source

In order to simulate the average level of saturation, 26 new *agents* are injected at model time equal to 0 thanks to the introduction of an event scheduled for time()=0. Then, anytime an *agent* leaves the *service* module representing ICU, the inject() function is called.

It is worth to remember that this is not the only input flow to ICU, but also those flows coming from ORs and ED.

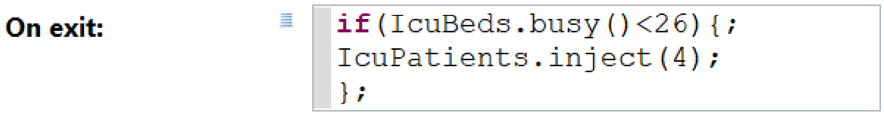
2. When *agents a*rrive in the area representing ICU they pass first through a queue (“queue3”). Waiting time related to ICU is recorded starting from this moment through a system of variables exactly equal to the one presented in previous sections. In case an *agent* remains in the *queue* module for too long it leaves it through the “time out exit” port representing those patients at risk for too long waiting. Timeout is set equal to a uniform distribution between 180 and 360 minutes.
3. To represent the time spent in ICU it is introduced a *service* module named “ICU”. Resources sized to the a*gent* in this case are just 1 unit of “IcuBed”. This resource has been defined through a process equal to the one described for the other resources and summarized by table24.

Resource	Agent class	Resource Pool	Capacity
ICU bed	“IcuBed”	“IcuBeds”	30

Table 24 ICU resourcePools

Delay time is set equal to a triangular distribution (min: 360, most frequent: 3600, max:4320).

As already anticipated, when an a*gent* leaves the module, in case the level of saturation is below 26/30 it is called the inject() function in order to generate a new a*gent.* This is obtained thanks to the lines of code reported in Figure42.



On exit:

```
if(IcuBeds.busy()<26){;
IcuPatients.inject(4);
};
```

Figure 42 New agents injection to ICU

4. To conclude *agents* are pushed towards the area of the model representing wards.

3.2.2.3. Hospitalization in ward

To conclude the representation of the hospital system in normal operations it is now proposed the analysis carried on the processes characterizing hospitalizations in wards.

Ordinary hospitalizations and those in day hospital regime take place on the recommendation of a general practitioner or following a specialist visit. The specialist doctor establishes the actual need for admission and inserts the name of the user on the waiting list in relation to the pathology and the urgency. Also a significant portion of patients passing through ED conclude their care process with a stay in ward, before going back home. For OSR ordinary patients accesses modes are three:

1. In agreement with the NHS.
2. In solvency. All services provided are invoiced according to the Solvents Price List deposited with the General Management of the Lombardy Region and at the ASL City of Milan.
3. In agreement with other external institutions. All services provided are invoiced directly to the partner organization (direct agreement) or to the user (indirect agreement) according to the agreed price list.

Reasons for hospitalization are many: a scheduled surgery, a therapy to be carried on, monitoring etc. Once concluded the period of hospitalization it is released to the patient its clinical records and hospitalization certificate.

3.2.2.3.2 Rationalization of wards

In Figure43 it is reported the way the flow of patients through wards has been conceptualized. Of course it represents a strong simplification but it is coherent with the aim of the thesis.

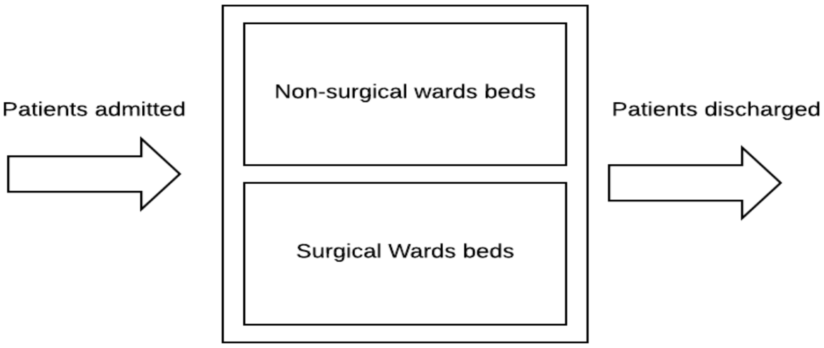


Figure 43 Wards rationalization

Wards are conceived as a black box where patients to be hospitalized in day hospital or ordinary regime, as well as those who entered the hospital through the ED, enter, spend a certain lapse of time and then they are discharged. Incoming patients, according to the way the model has been structured, are:

- Patients from ORs:
- Patients from ICU
- Red patients from shock room
- Yellow patients from Medical area
- Ordinary patients

It is important to specify that patients from ORs already have a bed assigned in ward and so this flow simply represents that of patients coming back to ward after a surgery.

The balance between the inflows and outflows determine the level of saturation of wards beds. These are subdivided into non-surgical and surgical to keep into consideration the significant difference between these two kinds of wards. Similarly to what has been done for the other areas of the hospital, it is reported below the analysis on the process characterizing wards, and corresponding resources and descriptive parameters.

Area-Process	Resources	Descriptive parameter
Hospitalization in surgical beds	Surgical bed	Length of stay
Hospitalization in non-surgical beds	Non-surgical bed	Length of stay

Table 25 Wards resources and descriptive parameters

Parameters quantification and calibration

Similarly to the analysis carried out relatively to ICU, also in this case parameters are mainly two:

- Availability of Surgical and Non-surgical beds: according to OSR website, wards beds, overall, are almost 1350. Analyzing the different clinical specialties wards are divided into surgical or non-surgical, and keeping into consideration the number of available beds for each of them, it resulted that surgical beds in wards and more or less 300, while non-surgical beds are 1050. As dr. Faccincani suggested, surgical beds level of saturation is higher (90%) than the one characterizing non-surgical beds (85%).

- Length of stay: this parameter is of course highly variable and hardly representable. On the other side this kind of variability is not crucial to represent the system as it is necessary for the aim of the thesis. For these reasons it has been assumed an average value of 24 hours for the hospitalization of patients. This value is reasonable also considering that long lasting hospitalizations are not carried on anymore in hospital such as OSR, but in smaller structures dedicated exclusively to this kind of activities.

3.2.2.3.3. Wards in Anylogic

Compared with the other areas of the hospital previously described, wards present some peculiarities to be kept into considerations when selecting the most suitable simulation modelling technique in relation with the aim of the thesis and the desired level of detail:

- Processes cannot be represented as a series of operations because of the high complexity of the system. In addition it is not possible to recognize a linear series of activities characterizing patient pathway in wards, due to the high variability of patients requirements. This characteristics is shared also with ICU.
- Just a limited portion of the resources consumed by the hospitalized patient can be clearly linked with its period of stay and in a ratio 1 to 1 with the patient. More precisely, just the bed occupied by the patient remains occupied for the entire length of time spent by the patient in ward and it is released with the patient itself is discharged. Also in this case, this characteristics is shared also with ICU.
- Differently from all the other units of the hospital, wards inflows and outflows cannot be described in a discrete manner since it is not possible to focus on single patient pathway for all the patients admitted and discharged. This is a very important factor to be kept into considerations and it is peculiar of the activities undertaken in wards

In table26 it is summarized the set of factors taken into consideration to select the most appropriate simulation modelling technique:

Area	Processes as a series of operations	Connection processes/resources	Representability of the flows	Simulation modelling technique
ED	Yes	Yes	Yes	Discrete event
OR	Yes	Yes	Yes	Discrete event
ICU	No	No	Yes	Discrete event
Ward	No	No	No	?

Table 26 Simulation modelling technique analysis

Given the characteristics presented above *discrete event* simulation does not appear as the most appropriate, at least not sufficient to represent wards entirely. The limit related to the representability of the flows, in particular, obliges to consider a way different from the flow of *agents* to simulate the average level of saturation of the resources. Given these considerations it has been selected a simulation modelling technique that integrate *discrete events* and *system dynamics:* introducing stocks and flows (typical of *system dynamics*) allows to simulate inflows and outflows of patients without focusing on the single agent. In the following paragraphs it is presented the implementation of this approach. In Figure44 it is possible to see the part of the system simulated through a *discrete event* approach (orange square) and that based on a *system dynamics* one (blue square).

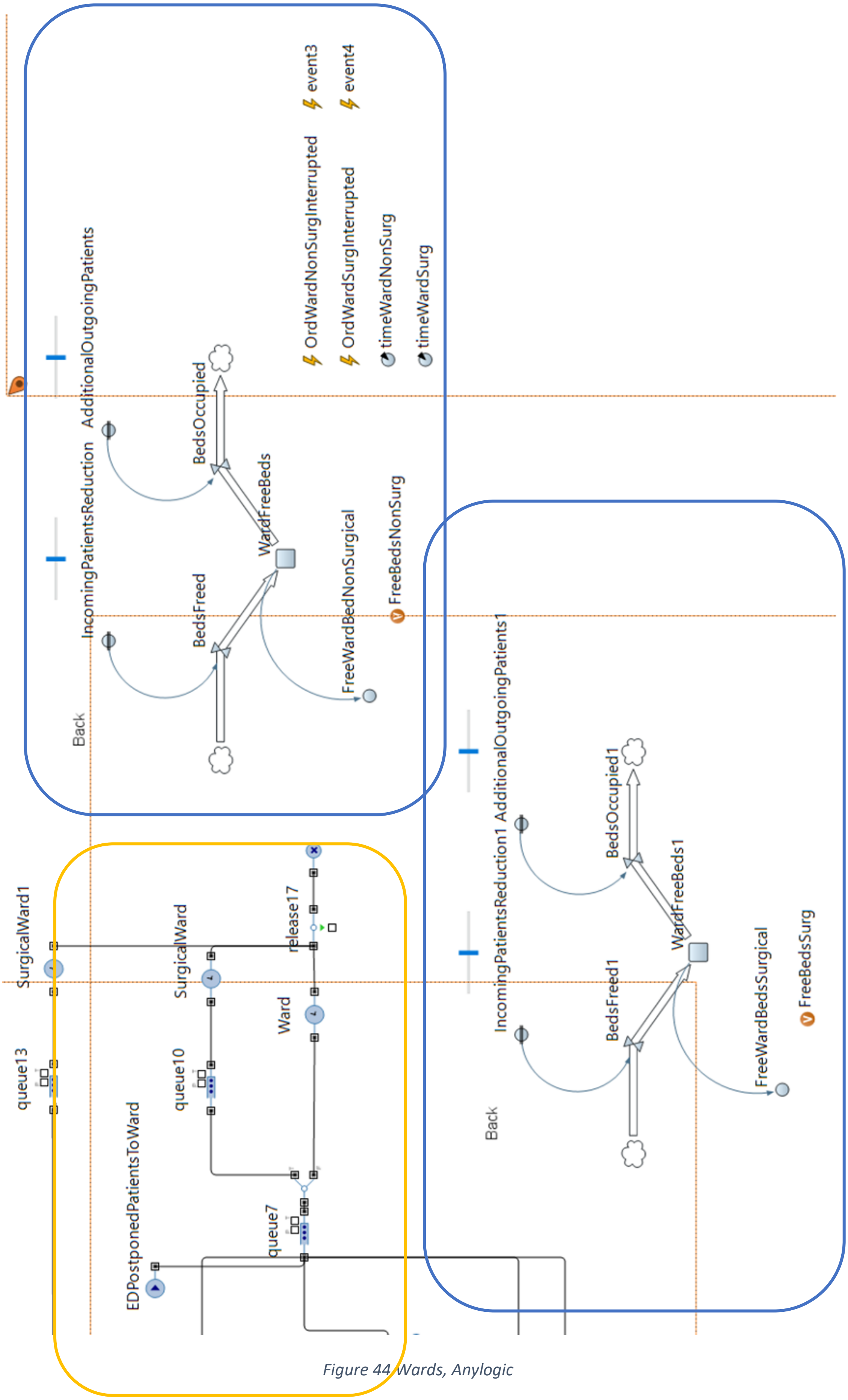


Figure 44 Wards, Anylogic

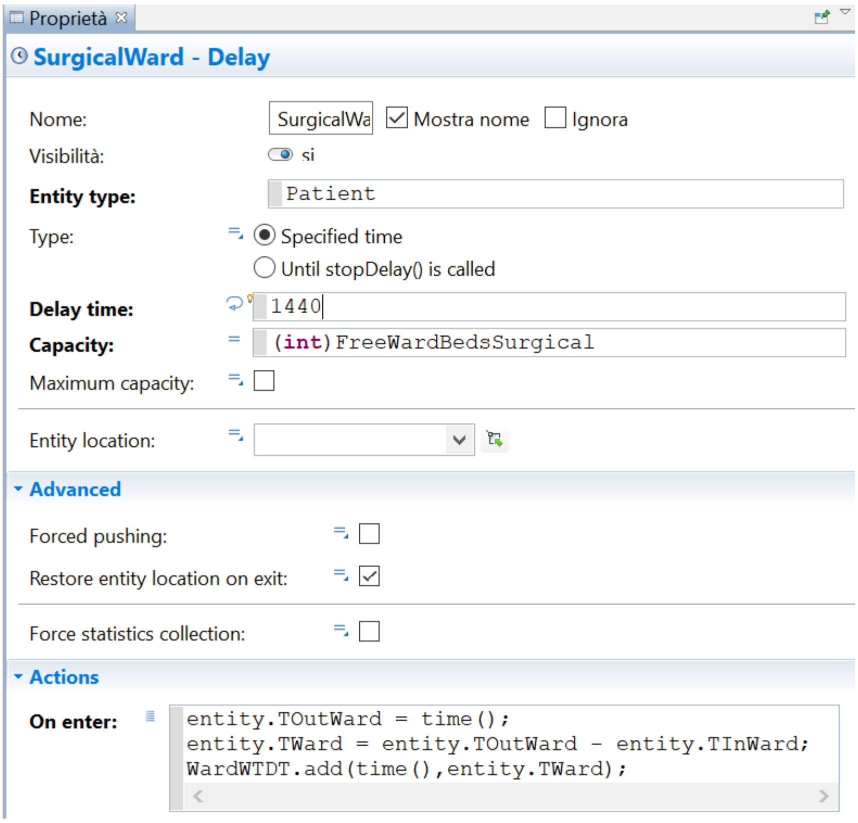
Starting the description from the modules contained in the orange square, it is distinguished the entrance of *agents* coming from ordinary ORs from those coming from the other areas of the hospital (OR for urgencies, ICU, medical area). In this second case *agents* are first of all inserted in a queue (“queue7”). Also in this case queueing logic is priority based. After the queue, *agents* pass through a *selectOutput* module which distinguishes surgical patients from non-surgical patients:

1. *agents* take the true output (that for surgical patients) just in case the entity specific variable “Chir” is equal to true. In that case *agents* are inserted in a queue (“queue10”) and then in a *delay* (named “SurgicalWard”) module representing the duration of the hospitalization. *Agents* representing surgical elective patients coming from OR move through a different series of *queue* and *delay* since they do not actually compete for a bed with patients from ED: as previously specified, elective patients in OR already have a bed assigned.

In “SurgicalWard” *delay,* delay time is set equal to 1440 minutes (24 hours), as anticipated in the previous paragraph. Entering the *delay* it is recorded the waiting time thanks to a system of variables exactly equal to the one described in other sections.
Once completed the delay a*gents* leave the system

2. *agents* who take the false output, so non-surgical patients, pass through a *delay* module similar to the one described for surgical patients and then leave the system

The most interesting element characterizing the two *delay* modules introduced to represent the time spent in ward is the definition of capacity. This is the point of connection between the portion of model structured with a *discrete events* approach and that with a *system dynamics* one. “SurgicalWard” *delay* capacity is, in facts, set equal to a variable named “FreeWardBedsSurgical”, while non-surgical wards capacity is governed by a variable named “FreeWardBedsNonSurgical”. These two variables represent the number of beds non occupied by patients to be hospitalized in ordinary or day hospital regime, so actually those beds available for patients coming from ED.



Nome: SurgicalWa ☑ Mostra nome ☐ Ignora
Visibilità: sì
Entity type: Patient
Type: ● Specified time ○ Until stopDelay() is called
Delay time: 1440
Capacity: (int)FreeWardBedsSurgical
Maximum capacity: ☐
Entity location:
Forced pushing: ☐
Restore entity location on exit: ☑
Force statistics collection: ☐
On enter:

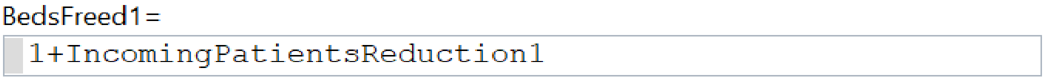
```
entity.TOutWard = time();
entity.TWard = entity.TOutWard - entity.TInWard;
WardWTDT.add(time(),entity.TWard);
```

Figure 45 SurgicalWard delay

“FreeWardSurgicalBeds” and “FreeWardNonSurgicalBeds” variables are influenced by the two different systems of stocks and flows visible in Figure44 within the blue squares and that will be now described.

Referring to the portion dedicated to surgical beds, “WardFreeBeds1” stock represent the percentage of beds which are non-occupied: as anticipated in a previous section, this value is usually equal to 10% so, by default, the stock is set at a value equal to 0.1. This value is modified by the balance between input flow and output flow:

- Input flow (“BedsFreed1”) represents the amount of patients which are discharged freeing this way a bed in one of the surgical wards. This flow is set, by default, equal to 1 per minute. This value is purely fictitious, useful just to determine the balance between inflows and outflows. A variable named “IncomingPatientsReduction1” is added to 1. This will be useful in case of maxi emergency and it is equal to 0 in case of normal operations.



BedsFreed1 =

```
1+IncomingPatientsReduction1
```

Figure 46 BedsFreed flow

- Output flow ("BedsOccupied1") represents the amount of patients which are admitted, occupying this way a bed in one of the surgical wards. This flow is set, by default, equal to 1 per minute. A variable named "AdditionalOutgoingPatients1" is added to 1. This will be useful in case of maxi emergency and it is equal to 0 in case of normal operations.

Being inflow and outflow balanced, the stock remains constantly equal to 90% for surgical beds. The same structure is replicated for non-surgical beds determining a level of saturation equal to 85%. The way this level is modified will be described in the section related to the reconfiguration of resources in case of maxi emergency.

"WardFreeBeds1" and "WardFreeBeds" stocks directly influence the two variables mentioned above representing the capacity of "SurgicalWard" and "Ward" *delays.* In facts, dynamic variable "FreeWardBedsSurgical" is set equal to

```
(int) Math.round(WardFreeBeds1*300)
```

This function restitutes the integer number obtained rounding up the product between "WardFreeBeds" (10% in normal operations") and 300, which is the overall number of surgical beds. Similarly "FreeWardBedsNonSurgical" is set equal to

```
(int) Math.round(WardFreeBeds*1050)
```

This analysis concludes the section related to the representation of the system in normal operations. In the subsequent sections it will be dedicated space to the way the system changes in case of maxi emergency and to its representation in Anylogic

3.2.3 “As-is” resource reconfiguration in case of emergency: PEMAF in OSR

In this section it is described system reconfiguration in case of maxi emergency. Maxi emergencies (attacks, air crashes, rail and road accidents etc.) are becoming more frequent and they involve an increasing number of people, putting at risk health organization and essential services. As a response to this threat, in this thesis it is presented the logic proposed by the so called PEMAF *(Piano di Emergenza per il Massiccio Afflusso di Feriti)* and in particular its application in OSR. With “PEMAF” it is intended that set of organizational and procedural provisions that allows a hospital to cope with a Maxi-emergency maintaining a standard of treatment of patients comparable to that granted to the single patient (Sicut, 2017). It is a legal requirement for all hospitals to have both external and internal emergency plans which also take into account the municipal and provincial plans, and the role of the 118 operative center, which is entrusted with the coordination of territorial resources. In facts, maxi emergencies must be managed according to levels of assistance that depend on a *network.* It is interesting to specify that sending to the hospital facility patients during a maxi-emergency by the extra-hospital system follows the procedures already in place for the single urgent patient. In particular, traumatized patients will be sent to the hospital facilities belonging to the “Integrated Network of Trauma” (designed and defined in the State-Regions Agreement of April 4, 2002 and April 29, 2004). These hospitals already have, by definition, the minimum requirements to manage the traumatized patient in case of a single event (immediate availability of a general or emergency surgeon, adequate number of nurses trained in the critical area, etc,) and fall within the definition of the “First Aid Trauma Providers (in Italian, PST)”. OSR falls within this category and, as it will be described in the following chapter, this factor is crucial in defining OSR role in the overall network. For this work thesis, it has been taken into considerations the operative plan produced by OSR to manage maxi emergencies from the territory in compliance with the legal requirement indicated above, and, in addition, also the document issued by SICUT (*Società Italiana di Chirurgia d’Urgenza e del Trauma*). This is a guideline to draw up hospital PEMAFs and, at the same time, it proposes concrete actions for the planning of hospital response to a traumatological emergency. It is dedicated particular attention to traumatological events since, although maxi-emergencies may also be non-traumatological (infectious, nuclear, chemical), experience shows that they remain the most frequent and probable.

This is the reason why this thesis is focused in particular on traumatological maxi emergencies.

Before concluding this introduction and moving to the description of OSS operative plan it is worth to spend some words on the definition of Maxi Emergency:

"Maxi-emergency means a sudden and unexpected event that generates a number of patients that exceed the response capacity of the local health system. The term maxi-emergency therefore refers to the number of patients involved, but also to the number of available resources and so, ultimately, identifies a condition of disproportion between these two parameters, regardless of their absolute number. A traumatological emergency is an event that generates patients whose prevalent injuries are traumatic, even without necessarily excluding others (intoxication, contamination). In relation to the absolute number of traumatized ones generated by the event, it is commonly spoken of:

- multiple accidents if the number is minimal (but not only one);
- major incident, if the number is significant, but can still be managed by the health system in its normal activity configuration;
- mass incident, if the number is such that to maintain a high standard of treatment level the health system must activate special procedures for the recruitment of additional resources
- disaster, if the event is so important that it cannot be managed by the healthcare system, even with the use of additional resources or same system responsible for responding to the event is affected itself"

(Sicut, 2017)

In the next paragraph it is presented the procedure of processes re-arrangement and resources reconfiguration actuated by OSR in case of maxi emergency, and more specifically a mass incident.

3.2.3.1 OSR plan for resources reconfiguration in case of maxi emergency

In the case of a maxi traumatic emergency, so characterized by many individual traumatized patients, the plan includes a series of steps to deal with it: the first one is that of "alarm". The alarm triggers the "alert" phase. When the hospital receives an alarm, the so-called "gestore unico", or Hospital disaster manager (HDM), present in the hospital, makes a recognition of the available resources. He also tries to understand what will happen and puts staff on alert. In particular, critical resources are counted and the attempt is to understand:

- What are the staff resources that are actually free?
- What is the workload on the ED?
- How many operating rooms are occupied?
- How many beds in ICU are occupied?
- How many shock rooms are occupied?
- Etc.

At this time of the description of the plan it is good to make a specification: OSR has chosen to have a plan that is activated in two steps, and procedures to carry them out are completely different between daytime and night/weekend scenario. In working hours, beyond the ED staff, there is a very well codified portion of staff that is moved to ED automatically in case of emergency. If the number of incoming patients exceeds significantly the available resources, all the physicians, nurses, surgeons etc. present in the hospital receive the signal to go in ED. In both cases ordinary activities are interrupted. For what concerns the scenario of a maxi emergency during the night or in the weekend, the situation is completely different. All the “on call” staff is activated, in order to create, as stated by the document by OSR, 4 different trauma teams in not more than 30 minutes. If the number of incoming patients increases, it exists a second level which refers to staff “available” to be called in case of maxi emergency, but this is not strictly codified and so it is not considered in this work thesis.

The activation of the plan takes place with a mechanism inside the hospital. The hospital receives an alarm from outside which may come from the 118 central unit, or from different channels but always verified by the 118. Inside the hospital, information are managed by a single person, the HDM previously mentioned that is usually the head surgeon. After a meeting with hospital's management, and on the basis of the information he/she has (proximity to the event, characteristics of the event, probability that a certain amount of patients arrive in OSR), HDM decides whether or not to activate the plan. In case it is decided to activate the plan, the next phase consists in the actual reconfiguration of resources. This is constituted by different elements that can be grouped into spaces and processes reconfiguration.

First of all it changes the flow of ambulances within the ED: under normal conditions ambulances enter and leave the hot room on the same side. In case of maxi emergency, an unidirectional flow is created that ends at the roundabout in “via Vigorelli”. This makes sure that the ambulances do not enter and leave the same side. Moreover, ambulances tend not to enter the hot room: in this way only and exclusively triage activities are carried out in the hot room. Even patients tagged as red must be re-evaluated, in order to establish a real scale of priority among the many patients arriving. Since, as anticipated, triage activities are moved to the hot room, in this space the resources of the shock room necessary for the reception of the patient are moved: stretchers for the transfer, instruments for the first evaluation etc.

ED spaces are reorganized in terms of patients' severity: red, yellow, green (and no longer by type of pathology: this kind of organization may not emerge from the description made in the previous section since resources dedicated to the different patients have been described separately). It is added also a blue area for irrecoverable patients and the black area for corpses. This reconfiguration is implemented before first patient arrival. By doing this it is possible to identify two additional shock rooms and up to 11 monitored yellow areas. As it will be explained below, the surgical area (mainly constituted by shock rooms), which is to become the red area, is freed by filling the medical area that will become the yellow area, since the red one is the one that will have to suffer the most significant shock. The green area is instead an area made available for low-gravity patients and it has been identified the church as the most suitable space.

With regard to the staff, a fixed number of trauma teams is created as the resources available to receive red patients are very strictly codified: in half an hour, in any turn, 4 trauma teams can be created. At the arrival of the fifth serious patient the same team is dismembered, so basically the level of care is lowered. The resources available to create these 4 teams are only partially resources of the ED, while in part they are staff “on call” either at home or in the hospital according to the shift. As anticipated, if the level of incoming patients exceeds this capacity, the plan foresees to draw from all the available people, and not only from those “on call”. In case of daytime scenario it is possible to re allocate all the medical staff present in OSR to the ED.

Prior to the arrival of the first maxi emergency patient, areas of care are freed from previously admitted patients:

- Waiting room is emptied by trying to send home patients who are available to do so.
- Already admitted patients who can be discharged are discharged, while others are hospitalized with a rapid hospitalization procedure in order to free up resources for the arrival of the first maxi emergency patients.
- Since the area that absorbs the most significant impact is the shock room, patients who are already in these rooms are transferred to the medical area. Here they are processed by the personnel waiting for the first maxi emergency patients in order to discharge or send them in wards. All the processes are significantly accelerated.

Information systems are not considered able to face an event characterized by many patients, generally with few generalities. Moreover, because the systems themselves can stop working, maxi emergencies are not managed with computer systems, but through a system entirely on papers. In facts there are already prepared patient files that are assigned to each patient upon arrival and which allow manual management of patients.

Patient diagnostic therapeutic iter is similar to the one in normal operations, but faster: the diagnostic part is reduced and the clinical one is favored. The use of resources such as Cat scan is extremely limited. So after the triage patients can be sent either:

- To the red area (shock room),
- To the yellow area (medical area),
- To the green area (medical area).

From the red area, patients can go either:

- In the Operating block,
- In ICU,
- In Wards

The patient sent to the yellow area has the same alternatives

As a last consideration it is good to specify that, since it is clear that all these resources work simultaneously, structuring a precise command line is crucial: a single figure is in charge of managing critical resources in ED, but also ORs, beds in wards etc.

To conclude, any patient not referred to the maxi emergency that should come spontaneously in the ED will be managed as those patients from maxi emergency, signaling the extraneousness to the event.

Summarizing, drivers of reconfiguration are basically five:

- resources emptying,
- activation of additional personnel,
- spaces reconfiguration for intensity of care,
- management of patient arrival and triage in hot room,
- simplification of the diagnostic-therapeutic iter.

For what concerns the ordinary activity of the hospital, in the implementation phase of the plan, it is clearly stated that the activation of it includes blocking elective patients admissions in wards and non-urgent surgical interventions. This means that all the scheduled surgeries are postponed to a date to be established. This is a crucial point since it represents the topic around which the work thesis and the first simulation campaign that will be proposed in following paragraphs deal with. The logic behind the choice of interrupting completely the activity of elective ORs, and also the admissions in wards, lays in a principle of prudence. When the alert arrives, hospital management still does not know what is the magnitude of the event, what is the sudden influx of patients that will arrive and, consequently, resources to kept free. These kind of information are interrelated with many factors, such as the event itself, the decisions taken by the 118 operative unit, the possibility of first care on site etc. This is basically the reason why all the resources are made available to the ED, included ORs with related personnel, and beds in wards: it is considered much more desirable not to lose one patient from the maxi emergency rather than carrying on all the non-urgent surgeries and admissions scheduled for the day.

To conclude this section related to the representation of the system in case of maxi emergency, it is necessary to describe the closing phase. The closure of the state of emergency is signaled by the HDM. In that moment all the resources activated beyond the staff normally present in ED are sent back to the department of the hospital they were taken from. Of course, in case the emergency terminates during the night, it is not possible to restart ordinary activities until the following day.

What has been just presented is the strategy currently applied in OSR in case of maxi emergency. In the section related to the simulations it will be named as “As-is”.

3.2.3.2 Resource reconfiguration rationalization

In this section it is presented the process applied to schematize and rationalize the amount of information described in the previous section. The logic applied is that of analyzing different moments in time: before, during and after the maxi emergency. This approach follows the logic proposed by the document produced by OSR to describe the plan.

Before the event:

Activities and processes taking place in the lapse of time between the activation of the plan and first patient arrival are basically two:

1. Resources (spaces and staff) are freed up to desaturate ED.
2. In case of necessity, additional resources are activated.

For what concerns the first set of activities, in Figure47 it is proposed a schematization useful to identify elementary processes.

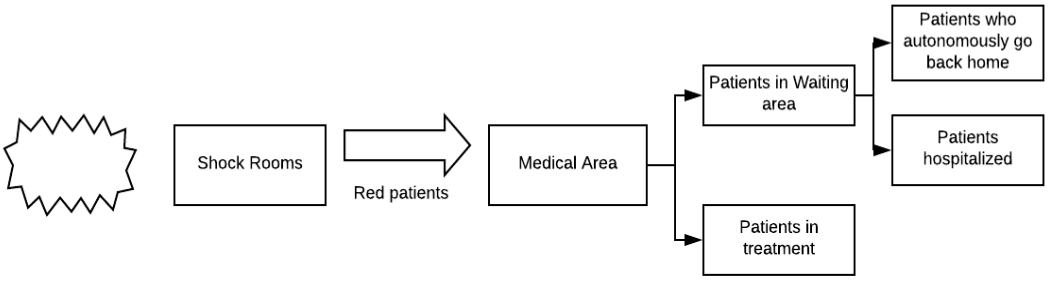


Figure 47 ED desaturation rationalization

The basic logic is that of freeing up resources in those areas where the shock with the external environment may be tougher, in particular shock rooms. In facts red patients treated in shock room at the moment of plan activation, as already anticipated, are processed faster and moved to the medical area. This is the first elementary process.

Similarly, resources occupied by yellow and green patients (staff and spaces) are freed up as fast as possible. In this case there are two different categories of patients which are the object of this process:

- Patients in waiting room: in this case there are two possibilities related to the intentions of patients occupying waiting room:
  - Patients who autonomously decide to abandon the ED and go back home.
  - Patients who decide to remain. In this case they are hospitalized in other areas of the hospital and not treated in ED.
- Patients already admitted in the ED rooms: this portion of patients has to be processed. In this case procedures are generally faster than those in normal operations.

To wrap up, elementary processes to be considered in the model are:

1. Shifting red patients in medical area;
2. Emptying of the ED thanks to those patients who autonomously decide to go back home;
3. Hospitalization of patients who do not accept to go back home;
4. Processing and hospitalization of already admitted patients;

Similarly to what has been done in previous sections, the identified activities and processes are analyzed in terms of necessary resources and descriptive parameters. In this case all the information come directly from the experience of an expert (dr. Faccincani) since it does not exist a proper codification of these parameters.

Process/Activity	Resources	Descriptive parameters
Process1	All the available resources*	Time necessary to prepare the patient before having the possibility to move him/her in medical area: 60 mins**
Process2	All the available resources*	Time = alarm**
Process3	All the available resources*	Time = alarm**
Process4	All the available resources*	Time necessary to re-evaluate patients and, in case, hospitalize them: 30 mins**

Figure 48 Elementary processes analysis

*In case of maxi emergency plan activation, before the arrival of the first patient, all the available resources are devoted to free up the ED from patients as much as possible. This means that all the physicians and nurses will be involved in processing the patients admitted but waiting for a response, or in a monitoring condition. Similarly surgeons and anesthetists will work in order to move red patients from shock rooms to medical area in complete safety.

** for what concerns descriptive parameters, they basically refer to the lapse of time necessary to treat patients and free up resources. Following dr. Faccincani indications, it has been assumed that, in any condition they are, it is necessary 30 minutes for a green or yellow patients to be prepared for hospitalization, and 60 minutes for a red patient to be moved to medical area.

Moving to the second set of activities, so those relative to the activation of additional resources, it is worth to distinguish two different scenarios: the one during the night or weekends, and that of working hours. The two scenarios are significantly different since it changes the amount of available resources as well as the time necessary to activate them. Note that it is considered, for the night scenario, just the first level of activation, while for the daytime scenario the possibility to mobilize all the staff present in hospital.

To describe the first scenario it is necessary to quantify those resources, in terms of staff, that can be defined as “on call”. “On call” medical staff guarantees to be in ED in no more than 30 minutes later than the alarm to integrate the personnel present in ED 24/24. In table27 it is summarized the staff present in ED 24/24 (first column) and that resulting from the activation of the plan during the night shift.

Resource	ED 24 7/7	"On call"
ED beds	30	30
OSS	3	5
Anesthetists	2	4/5
General surgeons	2	4/5
Specialist surgeons in ED	1 orthopedic	7 (different specialties)
Nurses	7	15
Radiologist	1	2
OR equipe	1	4
Internist physician	2	3
Cat scan	1	2
ICU	4 Available	4 available
Shock room	2	4
Beds or stretchers for green/yellow patients	28	56
ORs	1	4

Table 27 Night shift resources

Thanks to this kind of analysis it is possible to quantify OSR ED capacity to respond to maxi emergency in 4 red patients plus a variable number of yellow and green patients. This is the reason why general surgeons and anesthetists are quantified as 4/5, since actually just 4 of them are available to take care of patients while the remaining two will cover a managing position.

The scenario changes completely in case of maxi emergency in working hours since the amount of available staff in OSR is much higher. In addition, it is neither necessary to take into considerations a delay in the arrival of physicians, nurses etc. since they will be already present in OSR. This is the reason why the time necessary to activate additional resources in working hours scenario has been considered equal to zero, despite it represents, of course, a simplification. In table28 below it is summarized the personnel available in ED if the plan is activated during working hours compared with the one usually in ED

Resource	ED 24 7/7	Working hours scenario
ED beds	30	30
OSS	3	5
Anesthetists	2	28
General surgeons	2	28
Specialist surgeons in ED	1 orthopedic	7 (different specialties)
Nurses	7	15
Radiologist	1	2
OR equipe	1	28
Internist physician	2	3
Cat scan	1	2
ICU	4 Available	6 available
Shock room	2	4
Beds or stretchers for green and yellow patient	28	56
ORs	1	28
Monitored yellow areas	9	11

Table 28 Working hours resources

As it possible to understand, available resources are significantly higher than the ones available during the night shift, increasing ED capacity to take care of patients. On the other side, as anticipated, it is interrupted hospital ordinary activity, as highlighted by the number of ORs available for urgent patients, but also by the interruption of ordinary hospitalizations. This is done in order to *prepare* all the system to the shock due to the emergency event, and move all the resources to the area that may suffer the toughest shock, of course ED. These considerations are not significant during the night shift. The topic related to the trade-off between urgent patients requirements and ordinary hospital activity will be deepened in subsequent sections.

To conclude, as it is suggested by table28, increasing significantly the staff present in ED permits to activate also more spaces and exploit them in a more efficient way. In facts, the number of Shock room passes from 2 to 4 and monitored spaces for yellow patients from 9 to 11.

During the event

For what concerns the representation of ED during the event and the way it changes compared with the condition of normal operations, it is necessary to focalize the attention on patient pathway. In Figure49 it is reported a scheme summarizing the different paths a patient arriving to the ED in case of maxi emergency may undertake. It is interesting to notice the crucial role assumed by the triage activity, applied to all the incoming patients, included red patients.

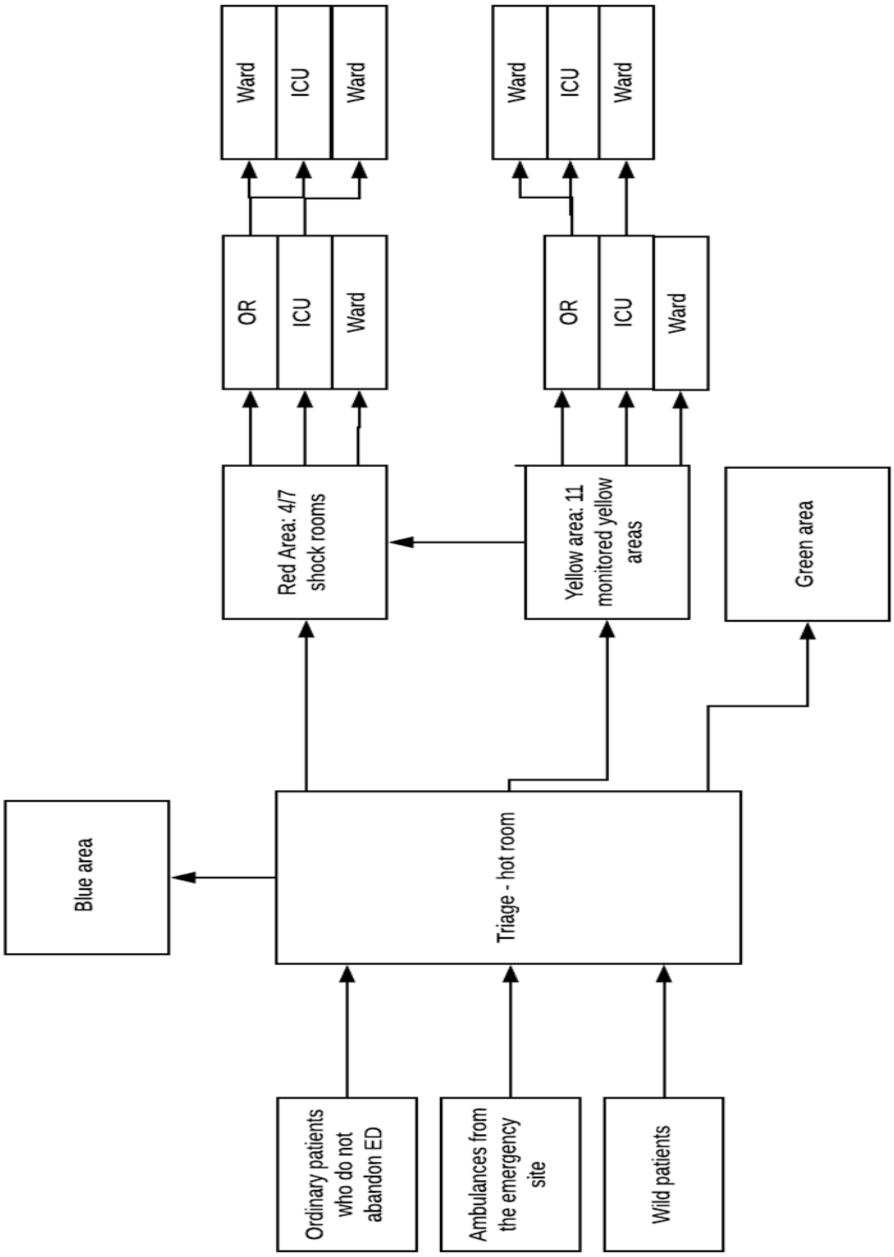


Figure 49 Patient pathway rationalization

The most significant differences compared with the configuration in normal operations lay in the organization of spaces in terms of intensity of care and a significant simplification of patient pathway: as it is possible to see from the scheme, it has been assumed that diagnostic instruments such as Cat scan are bypassed completely. In table28 it is reported the analysis on the available resources (as an integration to tables 27 and 28) and descriptive parameters.

Area/Process	Resources	Descriptive parameters
Triage	1 Tiage anesthetist or 1 Triage surgeon	Length of time necessary for triage: 5 minutes
Yellow area: in this case it is described the staff available for the whole area, since it is not codified a ratio staff/patient	3 Physicians 11 monitored spaces 60 beds and stretchers	Length of stay
Green area: in this case it is described the staff available for the whole area, since it is not codified a ratio staff/patient	3 Physicians 11 monitored spaces 60 beds and stretchers	Length of stay**
Red Area	1 trauma team per patient	Length of stay: 30 minutes
ORs	In addition to the staff assigned to the patient in ED: 1 Specialist surgeon 1 OR equipe 1 OR	Duration of the surgery
ICU	1 ICU bed	Length of stay
Wards	1 Bed in wards	Length of stay “Intensity” of ordinary activity reduction. *

Table 29 Resources, descriptive parameters

* Regarding ordinary patients hospitalization process, it necessary to distinguish the interruption of admissions from the capacity to create new spaces discharging some patients. As it will be described, both processes have an impact on the interaction between ED and wards: in case of maxi emergency plan activation no additional patients are admitted to wards. In addition, it is assumed a capacity of the hospital to free up beds equal to 0.01% of the overall capacity per minute. The unit of measure of this indicator depends on the representation of wards given in Anylogic. Using this kind of approach, it is possible to keep into consideration the delay necessary to complete

the process of care of a patient, even speeding it up, and proceed with a discharge. A more detailed analysis on this topic will be proposed in the following section.

For what concerns descriptive parameters, it is necessary to distinguish the approach towards different patients severities. Focusing on red patients in shock room, coherently with the logic of reducing the diagnostic side of the care process, it is preferred to move the patient as soon as possible to its final destination. This is the reason why the length of stay in Shock room can be reduced to 30 minutes, while for yellow patients it is not reasonable to consider any difference with respect to normal operations. To conclude, it is assumed a length of stay in ED 30% higher than the one in normal operations for what concerns green patients. This is done in order to catch longer waiting times among the overall length of stay in ED. Regarding the availability of resources, it is possible to make reference to table28 and table29 distinguishing the night scenario from the daytime scenario.

After the event

To conclude the process of system rationalization in case of maxi emergency plan activation it is dedicated a section to the processes and activities put in place to return to normal operations. Three different parameters are evaluated to briefly represent this section

1. Moment in time to deactivate the plan: it is assumed that the deactivation of the plan is triggered by the choice of the HDM. In that moment it is given the signal of completing all the procedures and treatments in progress and then re-direct resources and spaces to the original destination. It is assumed to wait 2 hours after last patient arrival for a matter of prudence.
2. Staff downsizing: staff downsizing involves the return to the normal operations conditions (first column, table28).
3. Spaces downsizing: spaces downsizing involves the return to the normal operations conditions (first column, table28).

In particular, it is important to highlight the approach towards ORs and hospitalizations: just from the moment in which it is given the deactivation signal, ORs are once again available to elective patients (once surgeries in progress are terminated) Similarly it restarts the admission of ordinary patients in wards. What is important to underline for the aim of the thesis is that ORs and hospitalizations reactivation does not happen, according to the plan, in a gradual manner but in one single step. One last comment is worth to be spent on the reallocation of resources to ordinary activities in case the emergency is declared concluded late in the night. In that case, in facts, it is not possible to reactivate ordinary activity in ORs as well the admissions to wards. To synthetize this concept, it will be considered ordinary activities to be reactivated just the morning following the emergency. The queue created by the delay in surgeries and admissions will keep the same order as the one in normal operations regime.

3.2.3.3 Resources reconfiguration in Anylogic

To describe the translation in Anylogic of the schematization reported in previous paragraphs it is followed the same temporal logic applied before.

Before the event

For what concerns the representation of processes and activities put in place before the arrival of the first patient it is possible to recognize, also in Anylogic, the same set of activities described in the previous section, so related to the liberation of resources and to the activation of additional resources.

In order to simulate the lapse of time between the arrival of the alarm and the decision to activate the plan it has been introduced into the model an *event* named "EmergencyAlert". This event is scheduled in a precise moment in time which is established starting from the moment in which it is desired the maxi emergency to *start*. For a complete understanding of the process applied to determine the triggering moment of "EmergencyAlert" event it would be necessary to have completely clear the representation of maxi emergency patients arrival, which is describe in following chapter. For the moment it is sufficient to specify that "EmergencyAlert" *event* is triggered 30 minutes before the arrival of the first patient, representing this way the lapse of time between the alarm and the activation of the plan. Of course it is different the moment selected for the night scenario and that in daytime scenario.

The only role of the *event* is that of updating the value of a system variable named "TimeLev0" to the current model time.

```
TimeLev0=time();
```

"TimeLev0" is the first of a set of variables introduced in the model to manage the delays in resources reconfiguration. 30 minutes later than "EmergencyAlert" *event* it is triggered a second *event* representing the choice of activating the plan. It is named "ResourceReconfiguration" and triggered when the following condition is verified:

```
time()>TimeLev0 + 30
```

"ResourceReconfiguration" *event* is coded in order to distinguish working hours scenario from the night/week end one. To do so it is introduced a couple of functions named "isWeekend()" and "isWorkingHour()":

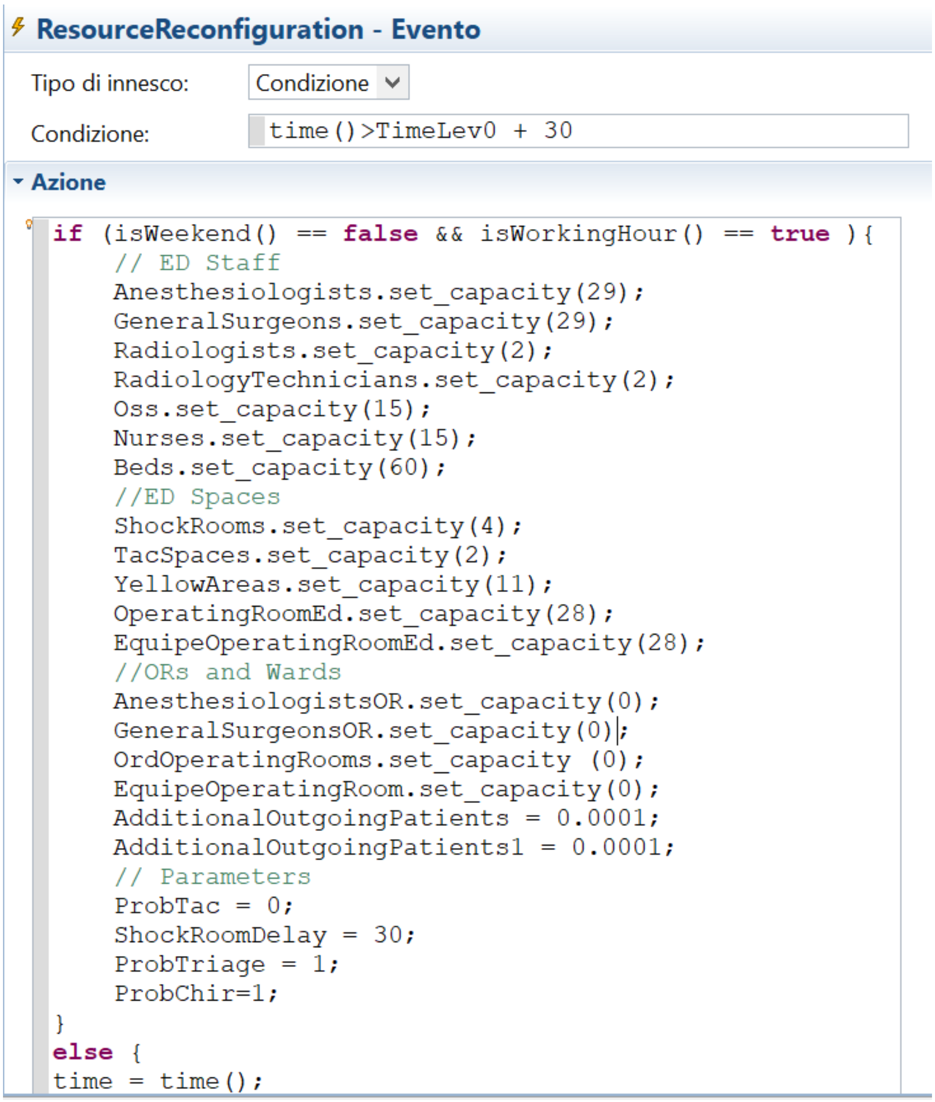
1. "isWeekend()" is a function that checks the day of the week and restitutes the Boolean value "true" in case it is Saturday or Sunday. It is reported the code:

   ```
   int weekday = getDayOfWeek();
   if (weekday == SATURDAY || weekday == SUNDAY){
   return true;
   }
   else {
   return false;
   }
   ```

2. "isWorkingHour()" is a function that checks the moment of the day and restitutes the Boolean value "true" in case it is night shift. It is reported the code:

   ```
   int hourOfDay = getHourOfDay();
   if (8 < hourOfDay && hourOfDay < 20){
    return true;
   }
   else {
   return false;
   }
   ```

Coming back to the description of the "ResourceReconfiguration" *event*, as first thing it is checked the model time. In case it is night or weekend the only command is to update the value of a second variable named "time" at the current model time, which will be useful to activate the actual resource reconfiguration in case of night shift. On the other side, if the two functions restitute respectively “false” and “true”, it is activated the set of actions characterizing the reconfiguration of resources as it has been described in previous paragraphs. It is reported in Figure50 the entire code composing “ResourceReconfiguration” *event*. To clarify the different statements they have been subdivided into different categories according to the object of reconfiguration: ED staff, ED spaces, ORs, Wards and parameters.



ResourceReconfiguration - Evento

Tipo di innesco: Condizione

Condizione: `time()>TimeLev0 + 30`

Azione

```
if (isWeekend() == false && isWorkingHour() == true ){
    // ED Staff
    Anesthesiologists.set_capacity(29);
    GeneralSurgeons.set_capacity(29);
    Radiologists.set_capacity(2);
    RadiologyTechnicians.set_capacity(2);
    Oss.set_capacity(15);
    Nurses.set_capacity(15);
    Beds.set_capacity(60);
    //ED Spaces
    ShockRooms.set_capacity(4);
    TacSpaces.set_capacity(2);
    YellowAreas.set_capacity(11);
    OperatingRoomEd.set_capacity(28);
    EquipeOperatingRoomEd.set_capacity(28);
    //ORs and Wards
    AnesthesiologistsOR.set_capacity(0);
    GeneralSurgeonsOR.set_capacity(0);
    OrdOperatingRooms.set_capacity (0);
    EquipeOperatingRoom.set_capacity(0);
    AdditionalOutgoingPatients = 0.0001;
    AdditionalOutgoingPatients1 = 0.0001;
    // Parameters
    ProbTac = 0;
    ShockRoomDelay = 30;
    ProbTriage = 1;
    ProbChir=1;
}
else {
time = time();
```

Figure 50 ResourceReconfiguration event

To simulate the increase of staff and spaces in ED, as well as the interruption of ordinary surgeries, it is modified *resourcePool* modules capacity. To do so it is exploited “set_capacity()” function that permits to modify the capacity of the *resourcePool* it is called on. For what concerns the lines dedicated to parameters, it is worth to dedicate just few words on them:

1. Setting “ProbTac” variable equal to 0, it is excluded the possibility for *agents* to be directed to Cat Scan modules. In facts, as already described, “ProbTac” is the probability governing “TacSO” *selectOutput* module.
2. Setting “ShockRoomDelay” equal to 30 permits to reduce the time spent by *agents* in the shock room modules.
3. “ProbTriage” equal to 1 obliges all the *agents* to pass through the module representing Triage activities.
4. “ProbChir” variable will be described in the section related to the representation of the maxi emergency event.

The second set of processes and activities, as they were described in the previous section, regards the liberation of spaces and resources in ED before first patient arrival. To translate this kind of processes in Anylogic two different couples of *events* have been introduced into the model:

- Green and yellow patients management is represented by “EDIsFreedGreenYellowPatient1” and “GreenYellowPatietsDischarged” *events.*
- Red Patients management is represented by “EDIsFreedRedPatients” and “RedPatientsDischarged” *events.*

The first element of each of the two couples refers to the sudden liberation of resources in ED:

1. “EDIsFreedGreenYellowPatients1” is triggered 60 minutes later than TimeLev0, so 30 minutes after “ResourceReconfiguration” *event* introducing this way the delay described in the previous section. To simulate already admitted patients care process termination the lines of code reported below have been introduced:

```
if (MedicalArea.delaySize()==1){;
Patient A = MedicalArea.delayGet(0);
MedicalArea.delayRemove(A);
};
```

```
if (MedicalArea.delaySize()==2){;
Patient B = MedicalArea.delayGet(0);
Patient C = MedicalArea.delayGet(1);
MedicalArea.delayRemove(B);
MedicalArea.delayRemove(C);
……
```

This code is repeated until the test on delay size equals to 9, which has been recognized as the highest possible number of *agents* simultaneously delayed by “MedicalArea” module. The logic behind this code is to extract each *agent* delayed, assigning it to a variable *Agent* and remove that *agent* through the indication MedicalArea.delayRemove (Agent). The same is applied on “delay1” for green patients.

Within this *event* it is called also a function named “RemoveAllMedicalArea()”. This is useful to simulate the process of emptying waiting room. In particular it removes a*gents* from the queue before “MedicalArea” *service* module, while “GreenYellowPatientsDischarged” is the element introduced to simulate patients being hospitalized. “RemoveAllMedicalArea()” *event* consists on a *for* cycle to check the length of the queue and remove all the *agents*. The code useful to do so is reported below:

```
for(int i = queue2.size(); i>=0; i--){
     queue2.removeFirst();
}
```

“removeFirst” function takes the a*gent* that occupies position 0 in the queue and removes it. The same applies for “queue12” for green patients.

To wrap up, “EDIsFreedGreenYellowPatients1” *event* simulates green and yellow patients in waiting room being removed and patients already admitted being processed faster.

“GreenYellowPatientsDischarged” *event*, as anticipated, works as the process of patients hospitalization. In this case it is assumed that no yellow patients decide to leave waiting room, while all the green patients decide to do so. This is done in order to represent a significant amount of ordinary workload putting pression on the ED and to be considered in case of maxi emergency. So the *event* results in the injection of *agents* into wards area. Three categories of a*gents* are injected into “queue7” before wards de*lay* modules:

  - *Agents* in “queue2” before entering Medical area
  - *Agents* in “MedicalArea”, after being treated
  - *Agents* in “delay1” already admitted as green patients.

The *event* is triggered 60 minutes later then the alarm, in order to simulate the 30 minutes delay with respect to the activation of the plan necessary to move patients from medical area. A new *source* module useful to inject *agents* into “wards” is introduced and named “EDPostponedPatientsToWard”.

2. For what concerns red patients, EDIsFreedRedPatients” and “RedPatientsDischarged” *events* work similarly to what described above. Main differences are basically two:
    - Triggering occurs 90 minutes later than TimeLev0 for both
    - A*gents* in shock room are injected into “MedicalArea”

In the following timeline it is summarized the way the transient from normal operations to emergency resources configuration in ED results in Anylogic

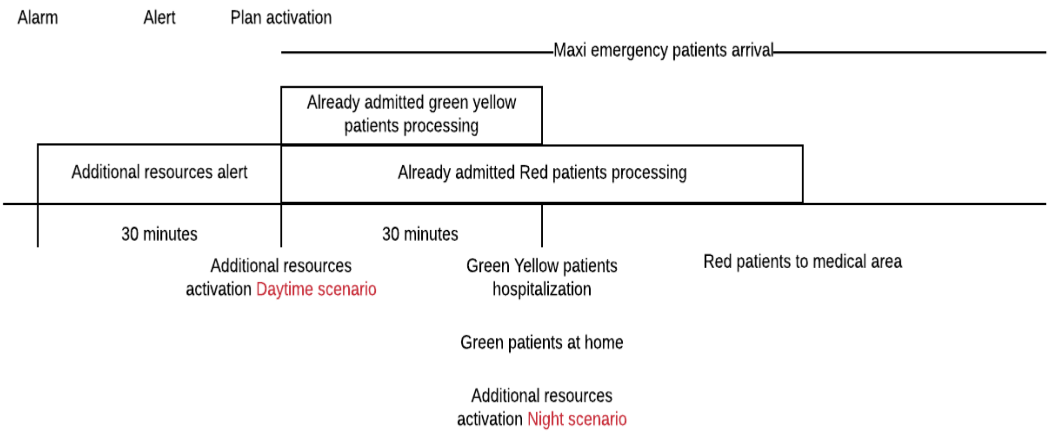


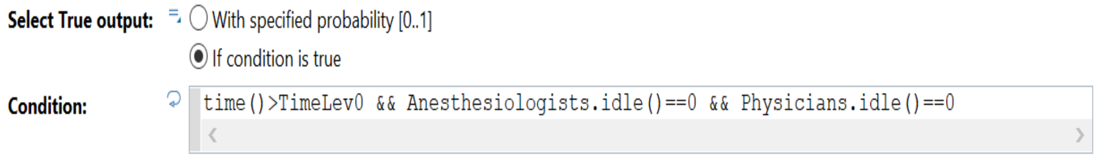
Figure 51 Resources reconfiguration transient in ED

During the event

In this section it is described the way patient pathway in ED in case of maxi emergency is translated into Anylogic. Modifications with respect to normal operations can be identified in 3 elements: introduction of Triage, possible reduction of the quality of care dismembering trauma teams in case of necessity and elimination of diagnostic steps such as Cat scan.

For what concerns the introduction of Triage activity into Anylogic, it is done modifying the probability determining *agents* destination in “selectOutput4” module. In case of maxi emergency all the a*gents* are directed towards “Triage” *service* module. In this module, 1 unit from the “TriageSurgeon” *resourcePool* and 1 unit from the “TriageAnesthetist” *resourcePool* are assigned to the *agent*. These are two modules useful to distinguish staff dedicated to take care of patients and that portion of staff occupying management positions.

As anticipated in the paragraph related to system representation in case of normal operations, once an *agent* is pushed towards modules representing ShockRoom and distinguished between surgical and non-surgical patient, it passes in both cases through a *selectOutput* module. These are necessary to represent the possibility of a lower level of care in terms of staff assigned to the patient. In facts, beside “seize6” and “seize7” already described, it is also introduced a second set of *seize* modules (“seize” and “seize1”) in which a “second best” set of resources is assigned to the *agent*. This is done to represent those episodes in which not all the resources necessary to compose the trauma team are available and so a different resource is selected to treat patients: typically there might a specialist surgeon taking care of a red chirurgical patient rather than a general surgeon. Actually it is very rare in normal conditions and more frequent in case of a maxi emergency. *Agents* move towards these modules according to a *selectOutput* module: in case of maxi emergency (time() > TimeLev0) and both anesthesiologists and general surgeons (or physicians for non-surgical patients) are busy, *agents* are directed towards “seize” and “seize1”. In Figure52 d it is reported the case related to non-surgical patients.



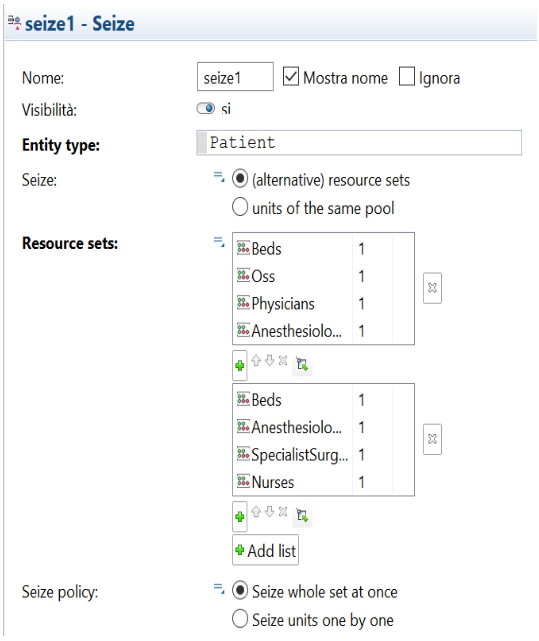
Select True output: ○ With specified probability [0..1]
● If condition is true

Condition:

```
time()>TimeLev0 && Anesthesiologists.idle()==0 && Physicians.idle()==0
```

Figure 52 selectOuput

Anesthesiologists.idle() restitutes 0 in case no anesthesiologists are free, so in that case checking Anesthesiologists.idle()==0 the result is a Boolean value “true”. The same happens regarding “Physicians” *resourcePool* (“GeneralSurgeons” for surgical patients). When both checks restitute “true” the *agent* is directed towards “seize” or “seize1”. In both cases it is updated a system variable named “LowerLevelOfCare” counting the number of patients treated not by the best set of resources. In *seize* module "seize" it is checked the availability of two different set of resources: in the first case the anesthesiologist is accompanied by a specialist surgeon rather than a general one, while in the second case the anesthesiologist is missing.



seize1 - Seize

Nome: seize1 ☑ Mostra nome ☐ Ignora
Visibilità: sì
Entity type: Patient
Seize: ● (alternative) resource sets ○ units of the same pool

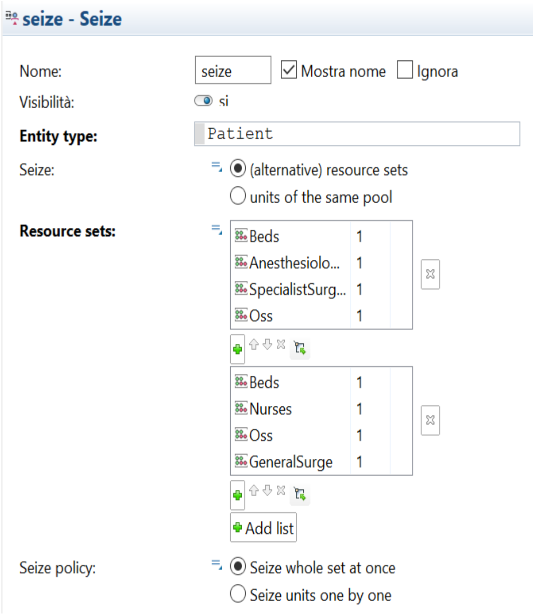
Resource sets:

Beds	1
Oss	1
Physicians	1
Anesthesiolo...	1

Beds	1
Anesthesiolo...	1
SpecialistSurg...	1
Nurses	1

Seize policy: ● Seize whole set at once ○ Seize units one by one

Figure 53 seize1



seize - Seize

Nome: seize ☑ Mostra nome ☐ Ignora
Visibilità: sì
Entity type: Patient
Seize: ● (alternative) resource sets ○ units of the same pool

Resource sets:

Beds	1
Anesthesiolo...	1
SpecialistSurg...	1
Oss	1

Beds	1
Nurses	1
Oss	1
GeneralSurge	1

Seize policy: ● Seize whole set at once ○ Seize units one by one

Figure 54 seize

In "seize1", which is referred to non-surgical patients, the first set of resources which is checked is composed by 1 unit of "Beds", 1 unit of "Oss", 1 unit of "Physicians" and 1 unit of "Anesthesiologists". Secondly it is checked a set of resources without 1 unit of "Physicians" but 1 unit of "SpecialistSurgeons". One last remark is necessary to specify that the sets of resources with no anesthetists are useful to simulate the cases in which one single anesthesiologist has to take care of more than one patient simultaneously.

It is worth to add a comment to patient pathway in case of maxi emergency regarding the elimination of the loop related to the CatScan. It is obtained thanks to the reduction to 0 of the variable "ProbTac". Thanks to this modification all the *agents* passing through "TacSO" *selectOutput* module will be directed towards the false output.

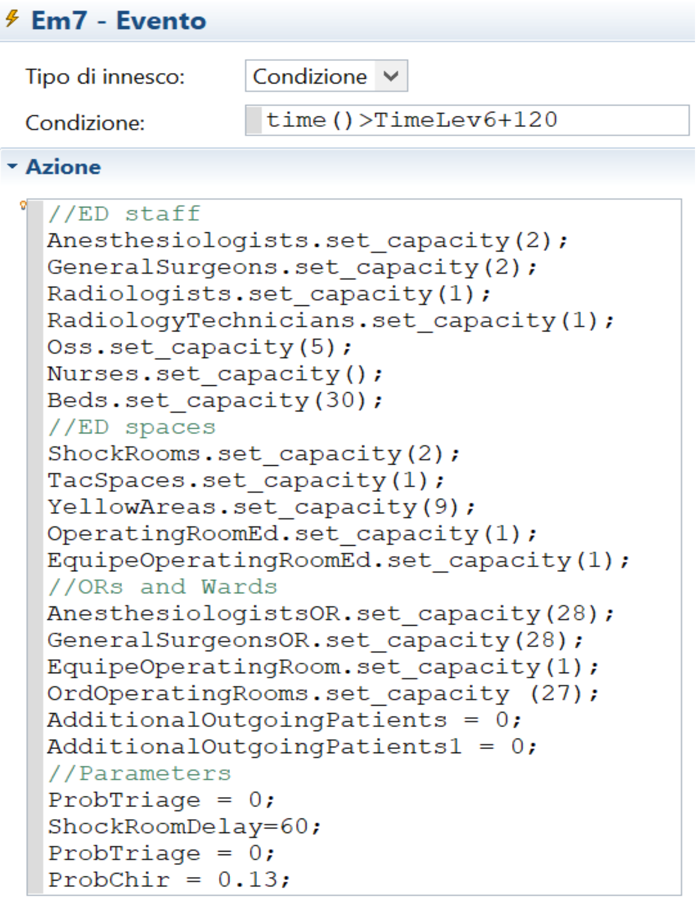
As a conclusion of this section it is necessary to specify the solution found to simulate green patients waiting time in case of maxi emergency. With respect to what anticipated, it is added the code related to the a*gents* injected in the system after the beginning of the maxi emergency:

```
if (time()>TimeLev0){;
Patient.GreenDelay=(EmergencyPatients.getCellNumericValue
(2, Ordinary, 3))*1.3;
};
```

Any time an *agent* passes through “queue12” its “GreenDelay” variable is updated to the value extracted from the database containing green patients lengths of stay in case of normal operations and it is 30% increased, as explained in the previous section.

After the event

To conclude the description of resources reconfiguration in Anylogic it is proposed now the representation of plan deactivation. All the process is contained in one single e*vent* named “Em7” which is triggered after a certain amount of time according to the scenario. To understand the process applied to identify the adequate moment to trigger “Em7”, it would be necessary to introduce maxi emergency patients arrival simulation. This will be proposed in a subsequent paragraph. For the moment it is sufficient to know that “Em7” is triggered 120 minutes later than the arrival of the last a*gent* related to the maxi emergency as anticipated in the previous paragraph. In case the emergency is declared concluded during working hours, it is actually possible to consider ordinary activities to be resumed. To clarify this assumption it is considered the emergency event simulated which will be described in the next chapter. According to the shape selected, it takes between 5 and 6 hours to declare it as concluded. In the morning scenario the alert is given around 11:00 a.m. In that case it is assumed ordinary activities to restart and conclude, for example, all the surgeries scheduled for the day. This assumption is reasonable thinking to keep ORs active until later in the night with respect to normal operations. It is reported below the code putting in place all the necessary modifications to the system to return to normal operations configuration of resources in this case.



Tipo di innesco: Condizione

Condizione: time()>TimeLev6+120

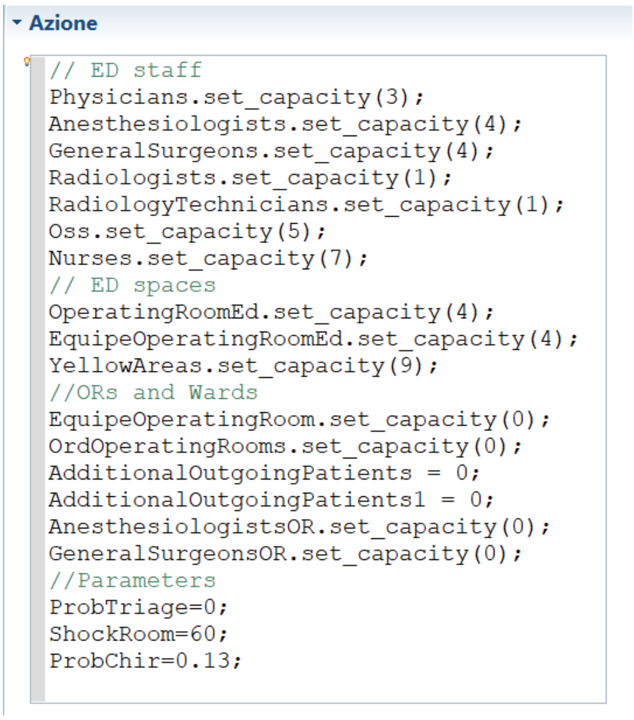
```
//ED staff
Anesthesiologists.set_capacity(2);
GeneralSurgeons.set_capacity(2);
Radiologists.set_capacity(1);
RadiologyTechnicians.set_capacity(1);
Oss.set_capacity(5);
Nurses.set_capacity();
Beds.set_capacity(30);
//ED spaces
ShockRooms.set_capacity(2);
TacSpaces.set_capacity(1);
YellowAreas.set_capacity(9);
OperatingRoomEd.set_capacity(1);
EquipeOperatingRoomEd.set_capacity(1);
//ORs and Wards
AnesthesiologistsOR.set_capacity(28);
GeneralSurgeonsOR.set_capacity(28);
EquipeOperatingRoom.set_capacity(1);
OrdOperatingRooms.set_capacity (27);
AdditionalOutgoingPatients = 0;
AdditionalOutgoingPatients1 = 0;
//Parameters
ProbTriage = 0;
ShockRoomDelay=60;
ProbTriage = 0;
ProbChir = 0.13;
```

Figure 55 Em7

For what concerns the scenario in which the alarm is triggered during the night, "Em7" is the same as the one presented above since it is assumed the emergency to be declared concluded more or less at 8:00 a.m so corresponding to the moment in which ordinary activity restarts. The approach is different in case of an emergency beginning in the afternoon and declared concluded during the night. In that case, in facts, it is not possible to reactivate ordinary activities. In Figure56 it is reported the code characterizing "Em7" in this case. The assumption made is that of keeping the resources made available by the PEMAF in ED (apart from ORs) but do not reactivating ordinary activity until the following morning. To do it, it is introduced an *event* named "Day" (the code is reported below) that represent the moment in which ordinary activity in ORs is resumed

```
OrdOperatingRooms.set_capacity (27);
OperatingRoomEd.set_capacity(1);
EquipeOperatingRoomEd.set_capacity(1);
EquipeOperatingRoom.set_capacity(27);
Anesthesiologists.set_capacity(2);
GeneralSurgeons.set_capacity(2);
```

```
AnesthesiologistsOR.set_capacity(27);
GeneralSurgeonsOR.set_capacity(27);
```



```
// ED staff
Physicians.set_capacity(3);
Anesthesiologists.set_capacity(4);
GeneralSurgeons.set_capacity(4);
Radiologists.set_capacity(1);
RadiologyTechnicians.set_capacity(1);
Oss.set_capacity(5);
Nurses.set_capacity(7);
// ED spaces
OperatingRoomEd.set_capacity(4);
EquipeOperatingRoomEd.set_capacity(4);
YellowAreas.set_capacity(9);
//ORs and Wards
EquipeOperatingRoom.set_capacity(0);
OrdOperatingRooms.set_capacity(0);
AdditionalOutgoingPatients = 0;
AdditionalOutgoingPatients1 = 0;
AnesthesiologistsOR.set_capacity(0);
GeneralSurgeonsOR.set_capacity(0);
//Parameters
ProbTriage=0;
ShockRoom=60;
ProbChir=0.13;
```

Figure 56 "Em7" afternoon scenario

Following, it is reported a table summarizing the main parameters of the model.

Input parameters		
Parameter	Calibration	Scenario – Random/Specific
Spaces – ED		
Shock rooms	2	Baseline – specific
	4	“As-is” – specific
Monitored spaces (yellow patients)	9	Baseline – specific
	11	“As-is” – specific
Green area capacity	20	Baseline – specific
Spaces – Ors		
ORs for elective patients	27	Baseline – specific
	0	“As-is” – specific
	0	Night
OR for urgent patients	1	Baseline – specific
	28	“As-is” – specific
	4	Night - specific
Spaces – ICU		
Beds	30	Baseline – specific
Free beds	4	Baseline – specific
Spaces – Wards		
Surgical Beds	300	Baseline – specific
Surgical beds saturation	90%	Baseline – specific
Non-Surgical Beds	1350	Baseline – specific
Non-surgical beds saturation	85%	Baseline – specific
Staff – ED		
General surgeons	2	Baseline – specific
	29	“As-is” – specific
	4	Night scenario
Anesthetists	2	Baseline – specific
	29	“As-is” – specific
	4	Night scenario
Nurse	7	Baseline – specific
	15	“As-is” – specific
	15	Night – specific
OSS	3	Baseline – specific
	5	“As-is” – specific
	5	Night – specific
Internist physicians	3 (day) - 2 (night)	Baseline – specific
Specialist surgeons	1	Baseline – specific
	7	“As-is” – specific
Staff – ORs		
Ordinary general surgeons (per shift)	28	Baseline – specific
	0	“As-is” – specific

Ordinary anesthetists	28	Baseline – specific
	0	“As-is” – specific
OR equipe of nurses	28	Baseline – specific
Specialist surgeons	28	“As-is” – specific
Descriptive parameters – ED		
Volume of patients	62.000 patients per year	Baseline – random
Probability triage red patients	0	Baseline – specific
	1	“As-is” – specific
Distribution of green and yellow patients arrival along the day	Distribution1	Baseline – random
Distribution of red patients arrival along the week	Distribution2	Baseline – random
Distribution of red, yellow and green patients	3%/17%%/80%	Baseline – random
Distribution surgical non-surgical red patients	13% / 87%	Baseline – random
	100%/0%	“As-is” – specific
Red patients to CAT SCAN	40%	Baseline – random
	0%	“As-is” – specific
Red patients directly to OR	60%	Baseline – random
Red patients back to shock room after CAT scan	50%	Baseline – random
Red patients to ICU	1% of the patients back to shock room	Baseline – random
Red patients to ward	50% of the patients back to shock room	Baseline – random
Red patients to OR after shock room	30%	Baseline – random
Red patients home after a stay in ED	19% of the patients back to shock room	Baseline – random
Surgical red patient length of stay in Shock Room	Max 60 min	Baseline – specific
	30 min	“As-is” – specific
Non-Surgical patient length of stay in Shock Room	Triangular distribution (60, 120, 360)	Baseline – random
	30 min	“As-is” – specific
Yellow patients to ward	30%	Baseline – random
Yellow patients to OR	5%	Baseline – random
Yellow patients home	65%	Baseline – random
Yellow patient length of stay in medical area	Beta distribution (1.2,3.4,60,1380)	Baseline – random
Green patients length of stay	“EmergencyPatients” database	Baseline - random
	“EmergencyPatients” database * 1.3	“As-is” – random
Yellow patients time out	Uniform (720;960)	Baseline – random
Red patients time out	15 + 30 + 30	Baseline – specific
Cat scan delay	25	Baseline – specific
Descriptive parameters – ORs		
Surgery duration	Triangular (30, 60, 240)	Baseline – random
Patients back to ward	95%	Baseline – random
Patients back home	3%	Baseline – random

Patients to ICU	2%	Baseline – random
Descriptive parameters – ICU		
Length of stay ICU	Uniform (360 3600 4200)	Baseline – random
Descriptive parameters – Wards		
Length of stay wards	1440	Baseline – specific
Descriptive parameters – other		
Time to free up waiting area	30 min	“As-is” - specific
Time to free up medical area	30 min	“As-is” - specific
Time to free up shock rooms	60 min	“As-is” - specific

Table 30 Parameters summary

CHAPTER4

SIMULATION CAMPAIGNS

In this section it is described the logic behind the set of simulations run thanks to the simulator presented in previous sections, and the way it is linked with the objectives set at the beginning of the thesis. As a first step, it will be illustrated the reasons behind the choice of carrying out a certain set of simulations and the way they have been structured. It will be dedicated a specific focus on the KPIs selected to evaluate the results suggested by the different simulations and to the process applied to create them. As a conclusion of this introduction, before showing the results of the simulations in the next chapter, the results related to the baseline scenario will be presented. Baseline scenario is the one not simulating a maxi emergency but just the way OSR ED works in normal operations. Thanks to these results it has been possible to assess qualitatively the validity of the model and its limits.

In order to present the line of reasoning followed to establish the set of simulations to be run it is necessary to recall the objectives set at the beginning of the thesis. In particular it is declared the intention to investigate the relation between ED and ordinary activity of the hospital in case of emergency to develop resilient capabilities at an hospital system level. It is dedicated particular attention to the trade-offs emerging from resources which are shared between ED and the other areas of the hospital. The overarching goal is that of assessing the level of resilience not just of the ED, but of the overall hospital system. More specifically, both the dimensions to determining the level of resilience of a system will be considered: robustness and rapidity. This means that simulations have been carried out in order to establish hospital system performances in responding to an emergency and return to normal operations applying different strategies of incident response management. The importance of keeping a systemic view, rather than focusing just on ED or other areas of the hospital, lays in the possibility of optimizing resource allocation to ordinary and urgent activities, giving the right *weight* to each category of patient. Shifting the unit of analysis from the single operative unit to the whole hospital permits to move towards a systemic business continuity perspective approach. In facts, as it will be described in detail, trade-offs constraining the provision of essential medical services emerge analyzing the interaction between departments, and, in case of maxi emergency, in particular between the ED and the other areas of the hospital. The attempt of this thesis is to propose a potential solution to some of the most relevant trade-offs to foster the continuity of medical services both in ED and to ordinary patients.

The starting point to achieve the objective has been evaluating the As-Is situation in order to identify potential criticalities in the perspective just presented, so in terms of interaction between urgent and ordinary hospital processes. Two different streams of analysis have been identified along the simulation design process and they represent the main topics assessed through the simulator. They can be summarized as follows:

1. PEMAF rigidity in activation and deactivation;
2. Night scenario medical services delivery capability;

Along the description of the PEMAF, as it is applied in OSR, these two topics emerged frequently. The first one refers to the on/off approach stated in the plan that consists in activating and deactivating resources reconfiguration in one single step. The main consequence of this approach is the ordinary activities interruption as soon as the plan is activated and resumption when it is stopped. The logic guiding such approach is that of guaranteeing all the potential medical services delivery capability to the ED for a matter of prudence. It is in facts considered unacceptable to put at risk the conditions of urgent patients arriving to the ED because of an emergency to guarantee ordinary services. This consideration is undoubtably the basis for all the analysis that will be proposed from now on. On the other hand, the disservice induced to ordinary patients is the drawback of this approach. When considering ordinary patients, in particular those scheduled for a surgery in OR, it is worth to remember the heterogeneity of the necessities and treatments to be carried on. There are cases in which a delay represents a very significant issue, beyond an important cost for the hospital. In Figure57 it is represented the approach suggested by the PEMAF.

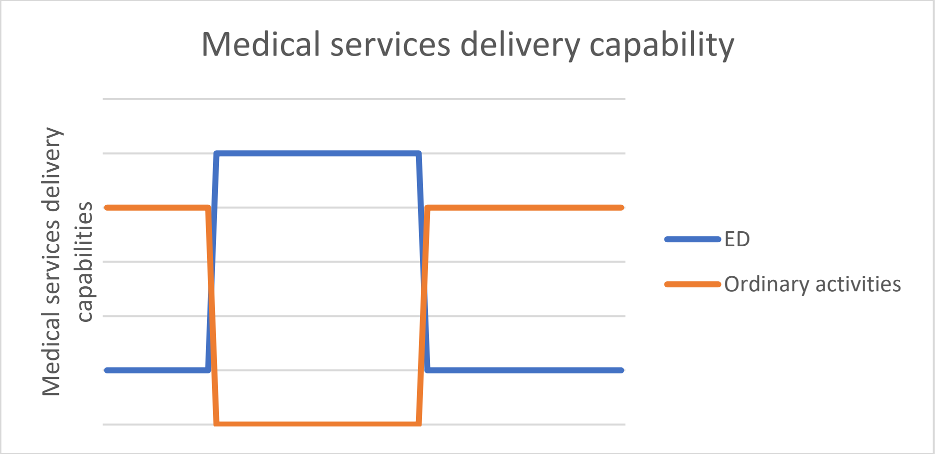


Figure 57 Current medical services delivery capability distribution logic

Given these two premises, the simulator will be exploited to compare hospital system performance in responding to a maxi emergency applying the current strategy suggested by PEMAF and two more "flexible" strategies which will be presented in the following paragraphs. The logic applied is that of trying to identify whether a more flexible strategy may permit to limit the issue of ordinary activities interruption without worsening ED capacity to respond to the emergency. The underlying objective is that of proposing insights that can be helpful in structuring a complete continuity plan and sustaining the HDM in contingent decisions.

The second stream of analysis is that related to the night/weekend scenario since it is for sure the most critical one. OSR document for PEMAF application is mainly built considering this case, in order to properly establish medical services delivery capability in the worst condition. In particular it is dedicated specific attention to the number of red patients OSR ED is able to treat with resources available once the plan is activated. Through the simulator it will be proposed an analysis on critical resources, in order to identify the most efficient way to increase ED capacity to treat red patients.

Before moving to the detailed representation of the different simulation campaigns it is dedicated a section useful to position this work according to three variables identified at the beginning of the thesis: threats, scope of work and KPIs. This is done to specify some crucial elements of the model and the way it is exploited. Then, it will be dedicated a section to the validation of the simulator, analyzing the results regarding the baseline. To conclude, the three simulation campaigns will be detailed.

4.1 Threat, Scope of work, KPIs

In order to highlight points of novelty of the work it is positioned with respect to the three variables selected to analyze literature in a cross sectional way. Furthermore, this kind of assessment is necessary to define in detail the system object of the analysis, its boundaries and the way its performances have been evaluated.

4.1.1 Threat

It is described now the disruptive event simulated through the model and the way it has been translated into Anylogic. First of all it is worth to remember the aim of this work, which is evaluating resilience and business continuity performances at the hospital system level, not focusing on just one single unit. The event to be simulated should be, then, such to put a very significant pression on the system, potentially overcoming the capacity of response. In particular it has been chosen to consider an external event generating a sudden influx of patients to the ED. This is coherent with the global objective of the thesis, since it represents a threat to the hospital system capability to provide essential medical services to the amount of patients showing up to the ED. As a result, when representing the event in Anylogic, no effects on the availability of resources have been considered. A further development of this analysis could be the introduction of elements reducing medical services delivery capability, in order to simulate an event affecting internally the hospital.

As partially introduced at the beginning of the simulation system design, it is assumed a traumatological event, although maxi-emergencies may also be non-traumatological (infectious, nuclear, chemical). Nevertheless experience shows that events characterized by an high percentage of traumatized patients with surgical requirements remain the most frequent and probable one. This is the reason why this thesis is focused in particular on traumatological maxi emergencies. In addition, hospital response to non-traumatological events, such as for example pandemics, is very poorly codified in terms of procedures and staff. Furthermore, in many terms, a traumatological event puts much more pression on the hospital due to higher resource consumption of a traumatized patient. While in case of, for example, an infectious maxi emergency the ratio between medical staff and number of patients is significantly below one, each traumatized patient consumes an entire team, composed by surgeons, anesthesiologists etc. Anyway, as a further improvement of the work, it would be interesting to analyze also a non-traumatological event in order to highlight differences and touchpoints. In general it is possible to affirm that the two categories of emergencies differ in terms of temporal development: a traumatological event results a shocking event, characterized by a peak of demand soon after the alarm but limited in time. On the other side a pandemic can be described as a continued pression on the hospital diluted in time. Of course system responses are significantly different. To conclude the description of the considered event nature, before moving to its representation in Anylogic, it is necessary to specify the assumption made on the nature of the patients arriving in OSR. In particular, it has been assumed that no green patients, more than the ordinary ones, arrive in OSR from the maxi emergency site. Despite it may represent a simplification of the system, it has been considered reasonable not to contemplate any additional green patient to simulate a maxi emergency managed *properly* by the 118 operative unit. In facts, given OSR high competences and resources to treat severe patients and its role in the hospital network, a cautious emergency management should avoid to overcrowd OSR with non-urgent (green) patients, diverting them on smaller hospitals.

The process applied to introduce a maxi emergency event into the model is based on three steps and it focuses on urgent patients arrival:

1. Qualitative representation of the event to be simulated;
2. Stochastic representation of the event and patient arrival recording;
3. Deterministic replication of the event

The logic behind this process is that of generating stochastically a sequence of patients, recording it, and replicating the same sequence deterministically in every simulation in order to simulate always the same event.

Point number one is basically represented by the considerations made on the nature of the emergency to be simulated, made as introduction of this section. The emergency resulting from that analysis can be summarized in some key elements:

- External event: all the resources are considered as available and no damages to the hospital are conceived
- Traumatological event: temporal development of the event is concentrated in a relatively small lapse of time with a relevant peak of demand. Patients can be mainly considered as surgical
- No green patients are sent to OSR

To replicate these features it is established an event characterized by a bell shaped arrival rates. The resulting number of incoming patients have been chosen to represent a stressful event, but not a disaster. In the following table it is reported the sequence of arrival rates:

Sequence	Arrival rate (patients/minute)	Delay
Level 1	0.2	Alarm + 30 minutes
Level 2	0.3	Level 1 + 60 minutes
Level 3	0.4	Level 2 + 30 minutes
Level 4	0.3	Level 3 + 30 minutes
Level 5	0.2	Level 4 + 30 minutes
Level 6	0	Level 5 + 60 minutes

Table 31 Emergency events delays

The result, considering also the lapse before deactivating the plan (120 min), is a 6 hours long lasting event characterized by an amount of patients between 46 and 54.

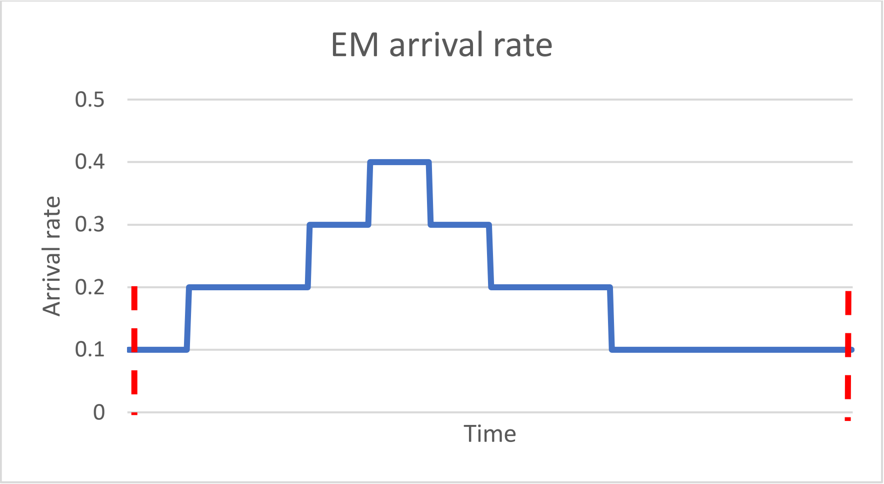


Figure 58 Emergency arrival rates

In Anylogic, the emergency is represented by a system of variables useful to consider the different delays. As anticipated in previous paragraphs, “EmergencyAlert” *event* updates “TimeLev0” variable to the current model time. Given this value a series of *events* named “Em1”, “Em2” etc. are triggered according to the delays indicated in table31. Each *event* updates a new variables useful to trigger the following one as well as patients arrival rate. In particular, it is introduced a new *source* module named “EmergencyPatientsArrival” injecting in the system those a*gents* representing emergency patients according to the arrival rates described below. In table32 it is reported a summary of the *events* just described

Event	Triggering condition	Actions
“Em1”	Time()>TimeLev0+30	Arrival rate = 0.2 TimeLev1=time()
“Em2”	Time()>TimeLev1+60	Arrival rate = 0.3 TimeLev2=time()
“Em3”	Time()>TimeLev2+30	Arrival rate = 0.4 TimeLev3=time()
“Em4”	Time()>TimeLev3+30	Arrival rate = 0.3 TimeLev4=time()
“Em5”	Time()>TimeLev4+30	Arrival rate = 0.2 TimeLev5=time()
“Em6”	Time()>TimeLev5+60	Arrival rate = 0 TimeLev6=time()

Table 32 Emergency events

Agents generated by this s*ource* module pass through a *selectOutput* module that distinguishes red from yellow patients. In this case it is assumed an high percentage of red patients (0.5). As anticipated, "ProbChir" variable, representing the probability of *agents* to be surgical, is updated to 1.

Moving to point number 2, a preliminary simulation has been run to generate a sequence of patients arrival according to the *events* just described, and record it. To record patients arrival it has been updated the first sheet of an excel file already mentioned: " "EmergencyPatients". In the first sheet of "EmergencyPatients" it is recorded, in column number 1, the moment in time an a*gent* leaves "EmergencyPatientsArrival" *source* module. The same procedure is applied to generate a sequence of patients representing a maxi emergency in

- Daytime scenario in the morning: Tuesday, 17th September at 11:00 a.m
- Daytime scenario in the afternoon: Tuesday, 17th September at 04:00 p.m
- Night scenario: Wednesday, 18th September at 02:00 a.m.

Each sequence is recorder in a different sheet of "EmergencyPatients" excel sheet. The resulting sequences are reported in the following diagrams.

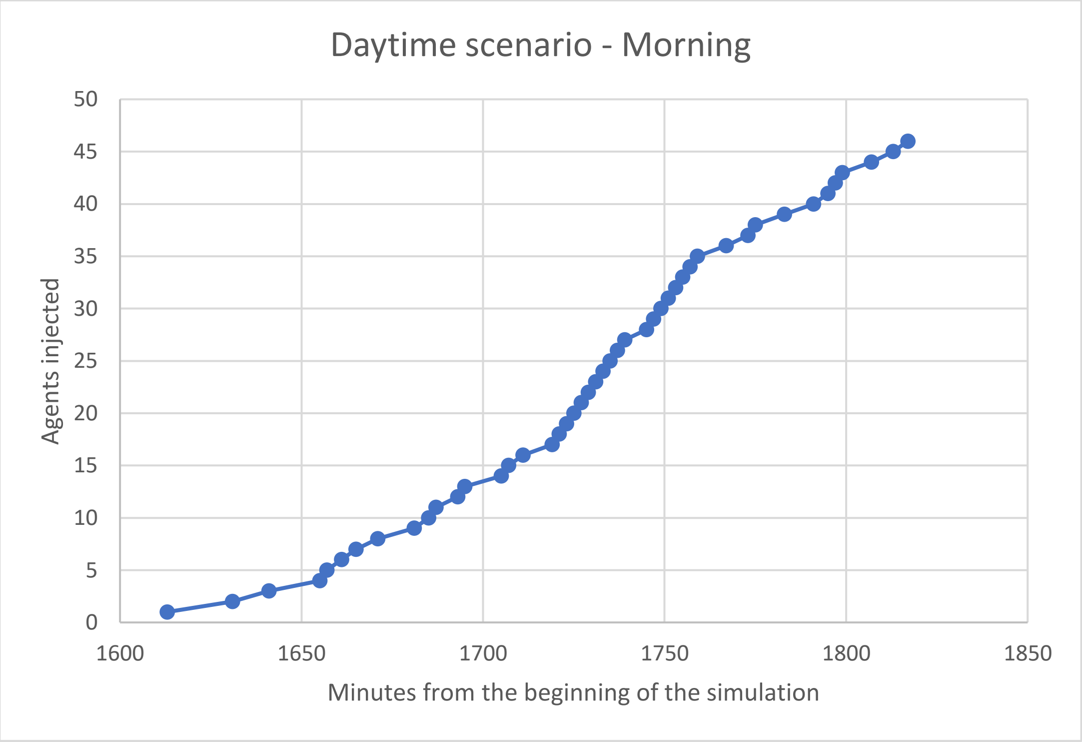


Figure 59 Emergency event - morning scenario

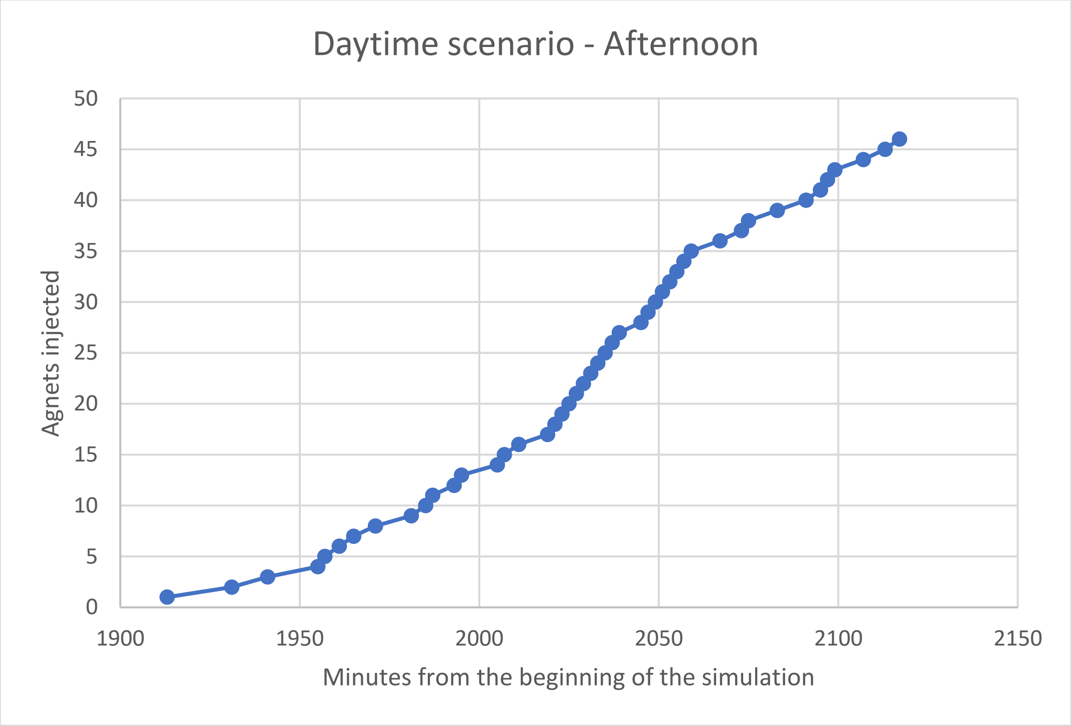


Figure 60 Emergency event - afternoon scenario

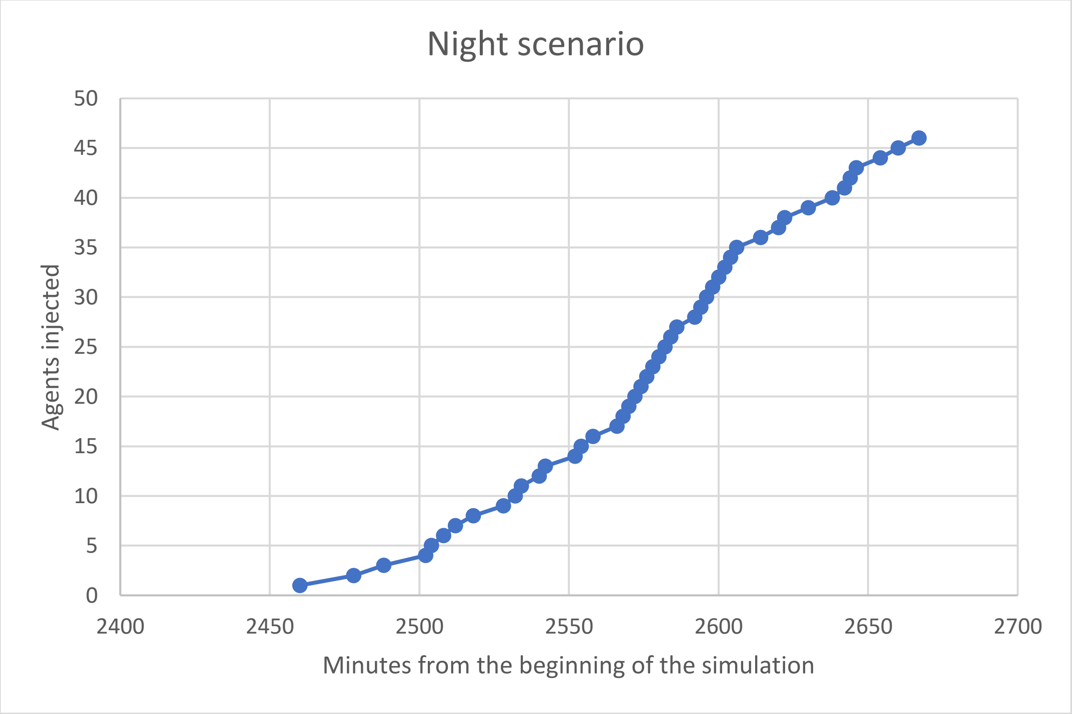


Figure 61 Emergency event - night scenario

It is now possible to move to point number three that is the deterministic representation of the emergency. Given the sequence of *agents* injection just recorded it is necessary to create a new *agent* according to the moment in time indicated into the excel sheet. To do so, it is modified "EmergencyPatientsArrival" *source* module, inducing *agents* arrival according to “inject()” function calls. In order to read the values contained in “EmergencyPatients” excel file, and call “inject()” function consequently, it is introduced a method named “InjectPT”. This method compares the model time with the value contained in the first cell of the sheet and, if the first is higher than the second, it is given the signal to inject a new *agent*. Anytime an *agent* in generated a variable named “Emergency” is updated. “InjectPT” function checks the line of the sheet corresponding to the value of “Emergency”. It is reported below the corresponding code:

```
if(time()>EmergencyPatients.getCellNumericValue(1,
Emergency, 1)){;
EmergencyPatientsArrival.inject(1);

}
```

“InjectPT” is activated by an e*vent* named “setParameters” repeated every minute, in order to compare continuously model time with the arrival patients sequence recorded into the excel sheet.

4.1.2 Scope of work

The overall scope of work, so the portion of hospital considered and represented within the model, has already been defined in simulation system design section. In this paragraph it is discussed not just the portion of hospital represented, but the one *evaluated* according to the KPIs which will be described in the following section. In facts, along the simulation system design process, it emerged clearly the relevance of some patients pathways with respect to others and, specifically, some steps of them. In particular it will be devoted particular attention to:

- Red patients in Shock Room;
- Yellow patients in ED;
- Green patients in ED;
- Red Patients in OR;
- Yellow patients in OR;
- Patients to be hospitalized;
- Ordinary patients in OR;

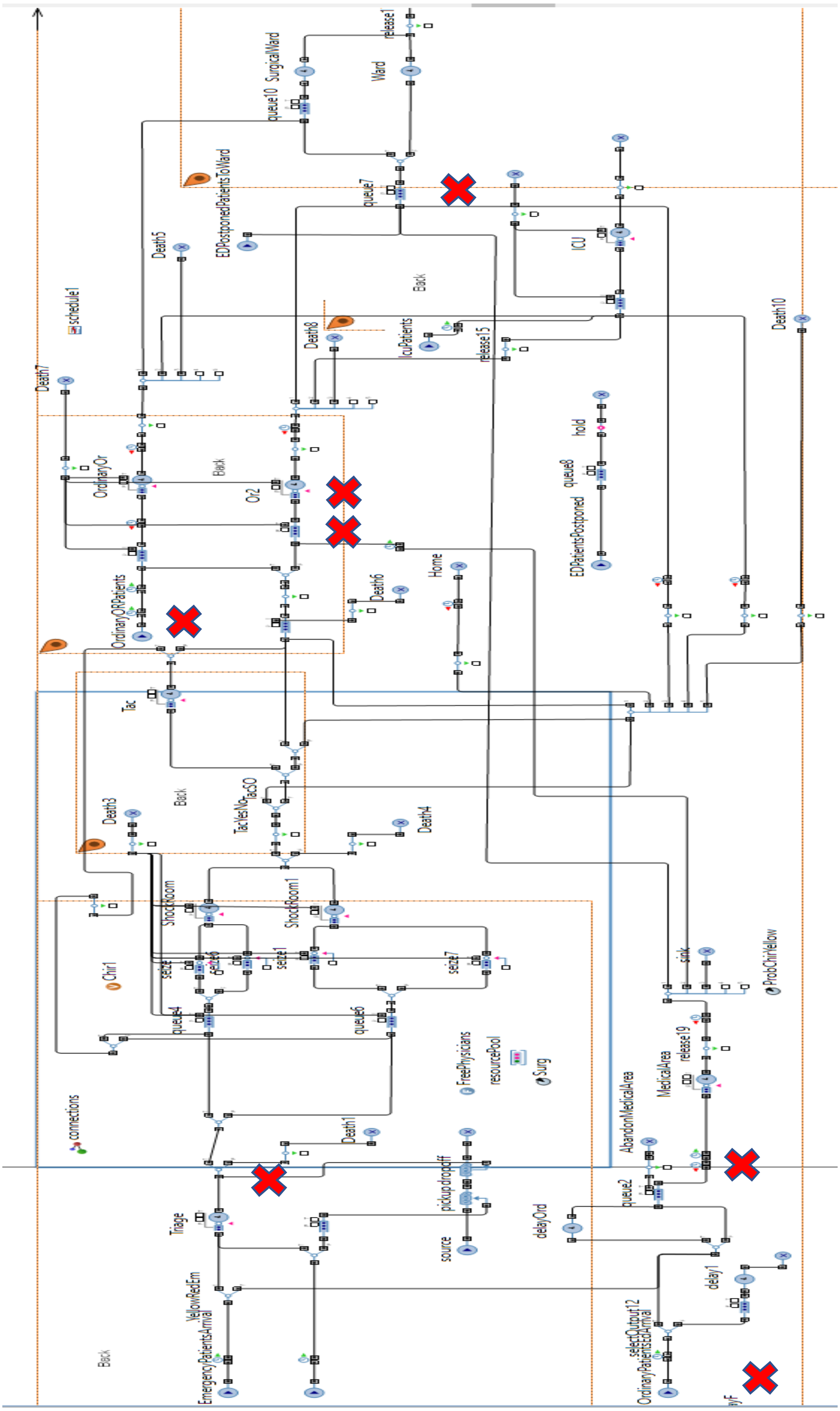


Figure 62 Waiting times collection

Some of the 7 different steps along patient pathways mentioned above represent the most important source of trade-off, as it has been presented along the simulation system design. It is possible to notice the presence of trade-offs having two different natures:

1. Trade-offs between urgent patients within ED.
2. Trade-offs between ordinary and urgent patients.

In particular those belonging to category 2 will be the main object of analysis through the simulator, in order to highlight the effect they have on hospital system resilience and essential medical services delivery continuity. The most important resources in trade-off are anesthesiologists, general surgeons, nurses, OSS, ORs and related staff, beds in wards, beds in ED.

It is important to notice the heterogeneity of the situations considered and, consequently, the necessity of finding a proper way to integrate them in a proper manner. This issue will be the topic deepened in the next section.

One last comment is dedicated to patients terminating their care process in ICU. Despite the relevance of the resource it was decided to exclude this sub group from the analysis to simplify the process of prioritization. As anticipated along the simulation system design process, this choice is expected not to induce any significative distortion to the results of the analysis considering the marginal amount of patients passing through this area with respect to the totality of patients simulated.

4.1.3 KPIs

To conclude the process of simulation campaigns construction it is now dedicated a section to the definition of the most appropriate set of KPIs to be evaluated to achieve the goal set for the thesis. A second driver taken into consideration is the data and information produced and actually collectable through Anylogic.

In order to evaluate hospital system resilience to disruptive events, and its capability to guarantee medical services in conditions of emergency, it has been taken into considerations the MCCER’s framework. The model represents the trend of a system’s relevant performance over time when facing a disruptive event. A system is considered resilient to the extent to which succeeds in being *robust* and *rapid* in recovering performances after a disruptive event. Robustness and rapidity are therefore the dimensions assessed in an integrated manner to evaluate different incident response strategies, in particular for what concerns the interaction between ordinary and urgent activity. These two dimensions can be viewed from different perspectives according to the performance to be evaluated. Each system may be characterized by a different set of performances considered as the most relevant ones. In this work it is given precedence to the hospital performance in terms of rapidity and quality of care. Since, of course, it is not the duty and the aim of this thesis to evaluate physicians competences and choices regarding patient care process, actually both dimensions can be reconducted to the time a patient has to wait before being treated. As it will be described in the next paragraphs, this parameter will be disentangled in two indicators more focused respectively on the rapidity and quality of care. Despite many of the considerations made can assume a different perspective if evaluated from an economical point of view, it is excluded any monetary analysis. This choice has been taken for the specificity of the system and the criticality of the situation analyzed.

Given these premises, it will be now described the process applied to establish an indicator able to represent hospital system performance in terms of time awaited by the patient before being treated. This process is moved by the purpose of defining a KPI representative of the hospital system resilience, so capturing robustness and rapidity of the overall system in responding to a maxi emergency, analyzing a performance considered as relevant for a system such as the hospital one. The first step to create a synthetic indicator refers to the collection of waiting times from the simulator. The procedure applied to accomplish this task has been largely described along the simulation system design process. In facts, through a series of system and entity specific variables it is recorded patients waiting times in each of the relevant areas of the model. In particular, according to the list of relevant patient pathways steps, an indicator “I” will be constructed integrating the following waiting times:

- Red patients waiting time before being admitted to shock room;
- Yellow patients waiting time before being admitted to ED rooms;
- Green patients waiting time before being admitted to ED rooms;
- Red patients waiting time before being admitted to OR;
- Yellow patients waiting time before being admitted to OR;

- General patients waiting time before being admitted to wards;
- elective patients waiting time before being admitted to OR.

For what concerns those steps regarding the ED, they simply refer to the time spent by the patient in the queue. Differently, items related to ORs deserve a more detailed definition. In particular, regarding red patients, it is considered the time awaited before being admitted to OR after leaving the shock room. Similarly it is recorded the time between yellow patients leaving ED and being admitted to OR. This value represents the delay between yellow patient showing the necessity of a surgery and the moment it is actually undertaken. In facts, referring to the data inserted into the model to simulate yellow patients length of stay and described in Annex1, it is included also those cases in which a patient awaits in ED for a free OR slot. In this way, those values collected through the simulator which are different from 0 represents those cases in which a patient, whose conditions worsened significantly, is not accepted in OR immediately. The basic assumption is that any value different from zero should be considered as an increase of the standard average waiting time. The same applies to patients awaiting for a bed in wards. To conclude, for what concerns elective patients scheduled for a surgery, it is recorded the delay with respect to the time the surgery was scheduled.

The second step consists in the integration of these values. In facts, as it is easy to understand, not all of them have the same relevance. Intuitively, a red patient waiting for a surgery in OR is much more relevant than a green patient in ED waiting room. It results necessary to prioritize the different waiting times, in order to have the possibility to integrate them coherently. To do so it is applied the AHP method (Analytical Hierarchical Process), in order to establish weights to be assigned to the different waiting times. The expert interviewed is dr. Faccincani, OSR ED SAD. The first step of the model consists in the creation of a hierarchy of objectives and criteria. Below it is reported the hierarchy representing the different elements considered, the way they are related among each other and with respect to the global goal. The global objective is the hospital system rapidity of care to all the patients, which is the performance identified as relevant at the beginning of this section. The categories of patients previously highlighted represent the intermediate criteria. For what concerns yellow patients, it is introduced a second level to compare yellow patients waiting time before being admitted to ED from the time awaited to have access to ORs. The same is done for red patients.

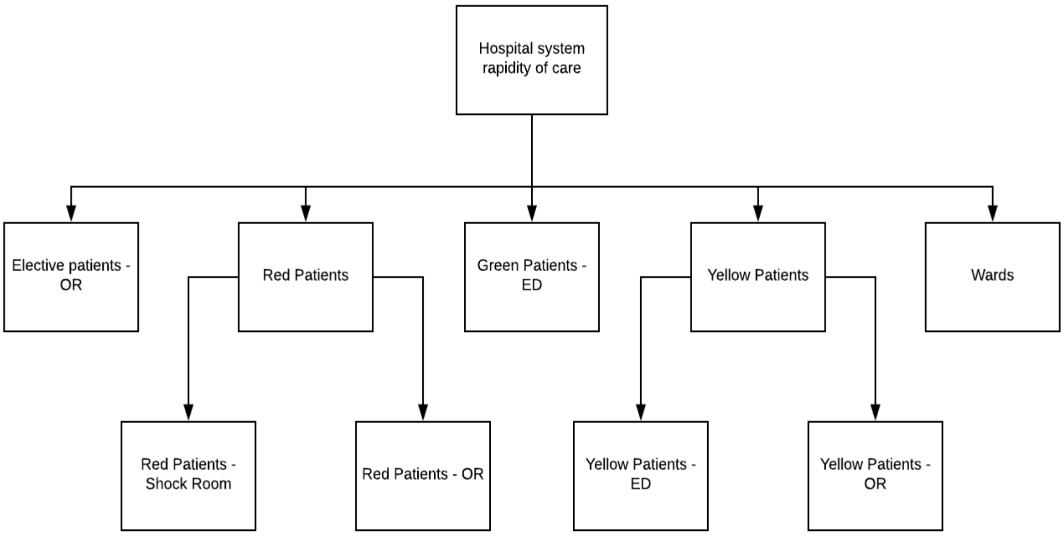


Figure 63 AHP hierarchy

Therefore, Dr. Faccincani has been asked to compare these items establishing a scale of priority. Along the interview with the expert it clearly emerged the incomparability between a red patient awaiting to be admitted in shock room and any other situation. In the simulation system design section, those patients who are not admitted in shock room in a sufficiently rapid manner have been considered as “at risk” and counted through specific variable PAR. This variable is updated anytime an *agent* leaves the system through the time out port exit of the shock rooms modules. In order to consider the indication provided by the expert, rather than comparing red patients waiting to be admitted in shock room with all the other categories, it has been introduced a *veto* regarding this portion of patients: any strategy increasing the number of patients at risk (PAR) must be considered as unacceptable, regardless its performance in any other term. Given this premise, through a series of pairwise comparisons, it is created the matrix reported below, related to the first level. Multiplying first level weights times second level weights, the weights to be assigned to each item have been established. The final vector of weights reported in Table39A. In Annex2 it is reported the computation of pairwise comparison matrix and the analysis on the consistency of the expert.

Yellow - ED	0.132
Yellow - OR	0.088
Green - ED	0.036
Red - OR	0.555
Ordinary - OR	0.153
Ward	0.036

Table 339A vector of weights

Interpreting these values, it is possible to affirm that red patients are almost 20 times more important than a green patient in ED or a patient awaiting to be hospitalized. Of course these kind of analysis represents a simplification of the overall complexity of the system. In addition it is necessary to remember the internal heterogeneity of the categories considered. As an example, patients scheduled for a surgery in OR may present very different conditions and degrees of urgency. On the other side the resulting weights provide a very relevant tool to integrate and compare in a consistent manner all the desired parameters. This is crucial to assume the systemic perspective considered as basic for the aim of the thesis and it represents the attempt to lever on KPIs to achieve the results set for the thesis.

The last step undertaken to create "I" is the application of the weights to the values generated by the simulator. After each simulation, thanks to the "add" function described in the simulation system design section, it is filled 6 different databases for each one of the waiting times described above. On each row it is recorded the moment in time a patient terminates its awaiting and the corresponding waiting time. In order to capture the overall hospital system performance in each moment of the simulation, the waiting time of the most *recent* patient leaving a queue is assumed as representative of the waiting time of an area of the model, until a new patient terminates its awaiting. To make an example, "patient1" (yellow) is admitted to the ED 600 minutes later than beginning of the simulation, after a waiting time equal to 60 minutes. "Patient2" (yellow) is admitted to the ED 640 minutes later than the beginning of the simulation, after a waiting time equal to 80 minutes. Given this data, it is assumed, for yellow patients in ED, a waiting time equal to 60 minutes between the 600th minute and 640th, while after the 640th it is assumed a waiting time equal to 80 minutes. The same approach is applied to each of the six waiting times object of the analysis. In this way it is created a timeline of the simulation. A portion of the overall results is reported, as an example, in table34.

Time()	Green - ED	Ord - OR	Ward	Yellow - ED	Yellow - OR	Red - OR
2099	180	109.194	0	272.016	0	6.063
2100	180	109.194	0	272.016	0	6.063
2101	180	109.194	0	272.016	0	6.063
2102	180	109.194	0	281.595	0	6.063
2103	180	109.194	0	281.595	0	6.063
2104	180	109.194	0	281.595	0	6.063
2105	180	109.194	0	281.595	0	6.063
2106	180	109.194	0	281.595	0	6.063
2107	180	109.194	0	281.595	0	6.063

Table 34 Example - sequence of waiting times

To each minute of the timeline, for each of the six items, it is assigned a value assumed as representative of the waiting time of the corresponding area of the hospital. The assumption just described is the only potential bias introduced by the indicator. As a matter of facts, in case of a long interval between two patients the resulting waiting times does not change. Conversely, in case of more than one patient terminating its awaiting period simultaneously they are recorder as just one. In the next chapter it will be discussed how to, eventually, overcome this limit.

Given this structure, it is now possible to move on in the description of "I" and its application. In facts, the weights identified through the AHP are applied to the waiting times associated to each minute of the simulation. In this way it is descripted the trend of "I" along the entire simulation. For each scenario, as it will be described more in detail, 9 simulations have been run and for each run it is developed the trend of "I". It is then computed the average curve among the 9 different curves resulting from the 9 simulations. This is done to exclude potential extreme situations from the analysis. The value achieved can be considered as representative of the hospital system waiting time. Since different weights are assigned to the waiting times characterizing the different area of the hospital, "I" can be useful to compare different strategies to face disruptive events. In particular, two parameters derived from this indicator will be evaluated:

> R' = integral of the curve described by the synthetic indicator "I" along the simulation from the moment the first maxi emergency patient arrives to when the indicator returns to the mean value under normal conditions.

$$R' = \int_{First\ ME\ patient}^{Return\ to\ normal\ operations} "I"$$

Formula1, R'

Of course, the lower the value, the better it is the performance. To compute this value it has been established the average value of “I” in the simulations representing the baseline. These simulations will be presented in the next section. Finally, it is now possible to present the KPI which will be analyzed to evaluate the different incident response strategies. In facts, it is necessary to turn the integral described above, into a resilience indicator. To do so it will be computed R defined as follows:

$$R = \frac{R'_{Baseline}}{R'_{Strategy}}$$

Formula2, R’

It is computed the ratio between the value of R’ for the baseline over the same lapse of time the value of R’ is computed in case of maxi emergency. This means that the closer the value of R to 1, the closer the performance of the hospital system, in case of maxi emergency, is to the performance in case of normal operations.

It is reasonable to affirm that this indicator is able to give a synthetic information on the level of resilience of the overall hospital system, considering both its robustness and its rapidity of recovery. Of course R will result to be lower in case of a significant increase of the overall waiting time. Similarly, the longer the time required by the system to return to normal operations the higher the value of R.

To conclude this section related to the KPIs which will be analyzed, it is worth to remember that, beside R, it will be kept into considerations also the number of red patients at risk (PAR). Over this second indicator it has been put a veto, in the sense that any strategy that induces an increase in the number of patients at risk (PAR) cannot be accepted. To clarify the definition of this index it is possible to make reference to the simulation system design. Along the different simulations campaigns it will be dedicated particular attention also to other indicators, such as, for example, the number of patients treated by an uncomplete team etc.

4.2 Results validation

Before moving to the presentation in details of the different simulation campaigns it is necessary to focus on the process undertaken to validate the simulator. Two different methods have been applied according to the available data:

- Analysis of the database;
- “Face validation”;

For what concerns green and yellow patients waiting time in ED, it has been possible to compare the results obtained through the simulator with the data stored in the database already mentioned, which contains information on all the patients treated in OSR ED in the last two years. Of course these are compared with the results of the baseline, so simulations regarding a scenario in which a maxi emergency does not occur. It is important to specify that the features of the simulated week (total number of patients, number of green patients, etc.) depend on the parameters introduced into the model and described in the simulation system design section. Given these features, simulations results will be compared with the data referring to a real week with similar features. For the remaining part of the data to be validated (“yellow – OR”, “Red – OR”, “Elective patients – OR”, Hospitalization) it is applied a “face validation” process. In this case it will be specified the correct way to interpret the different results. To do so it has been asked to the OSR ED SDA (dr. Faccincani) to evaluate the results and establish whether they are reasonable and realistic or not.

In table35 the features of the simulated week, in comparison with the real week considered for the validation, are presented

	Simulated week	Real week
Total number of patients	1400	1459
Green patient	1000	1110
Yellow patients	350	296
Red patients	50	53

Table 35 Simulated/real week parameters

Considering the overall volume of patients treated in OSR ED yearly (62000 on average) it is important to notice the fact that the simulated week represents a very *tough* one. According to the expert it represents the upper bound of the range, in terms of total number of patients acceptable in ED per week. This factor results from the discretization of the data contained in the database regarding patients arrival and introduced into the model.

Green, Yellow patients - ED

It is now possible to present the results of the simulations in normal operations for what concerns green and yellow patients waiting times in ED. These are reported and compared with the real data in the following table. In particular, in order to analyze waiting times distribution in the simulations and in the real data, it is assessed the percentage of patients awaiting less than 60 minutes, less than 120 minutes and the maximum waiting time.

Parameter	Green patients		Yellow patients	
	Simulation	Real	Simulation	Real
#pat WT < 60	55%	53%	35%	46%
#pat WT < 120	65%	71%	51%	65%
Max WT [min]	761	837	420	369

Table 36Simulated vs real week - green and yellow patients

Note that these data refer to the results contained in the databases produced by the simulations, while curves reported below are built with the same logic applied to create the trend of "I" (last patient waiting time as representative of the waiting time of the area). Considering the stochasticity of the simulations, the results reported above, according to the expert, can be considered as highly satisfying. In the Figure65 and 66 it is possible to see first the development along the simulated week of the waiting time for green patients, and then the same value as it emerges in the real week. It is reported the portion of simulation over which will be conducted the set of simulations described in the next section.

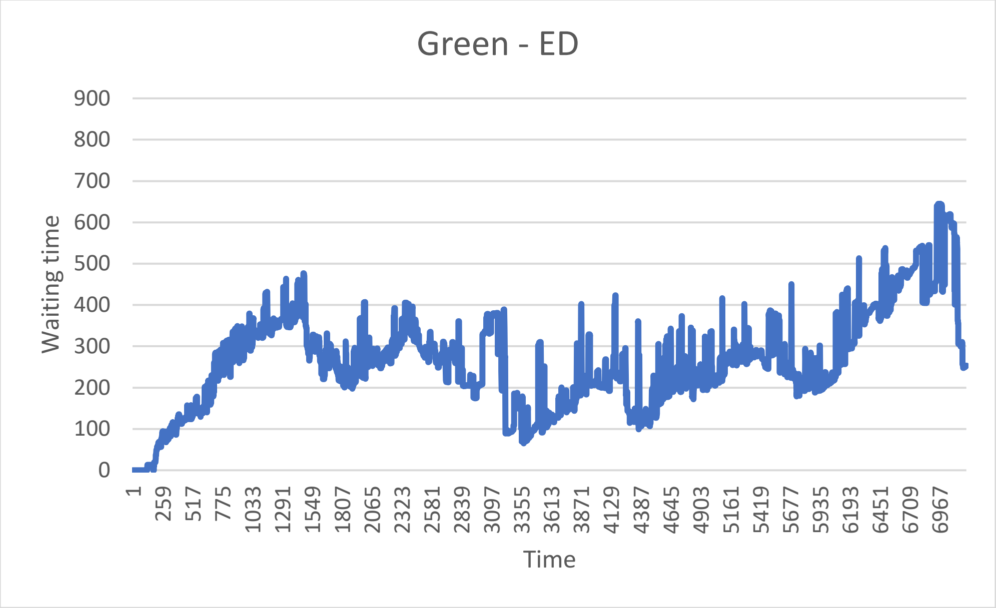


Figure 64 Green patients waiting times - simulated

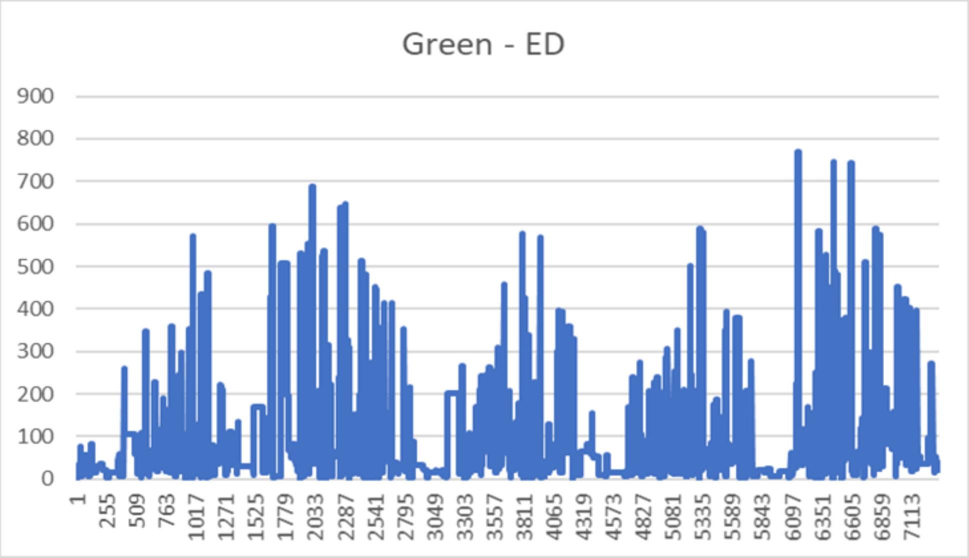


Figure 65 Green patients waiting times - real

Although less clearly, also in Figure65, it is possible to identify peaks and valleys related to the different days of the week, as a confirmation of the quality of the results.

The same kind of comparison is applicable also to yellow patients waiting time in ED.

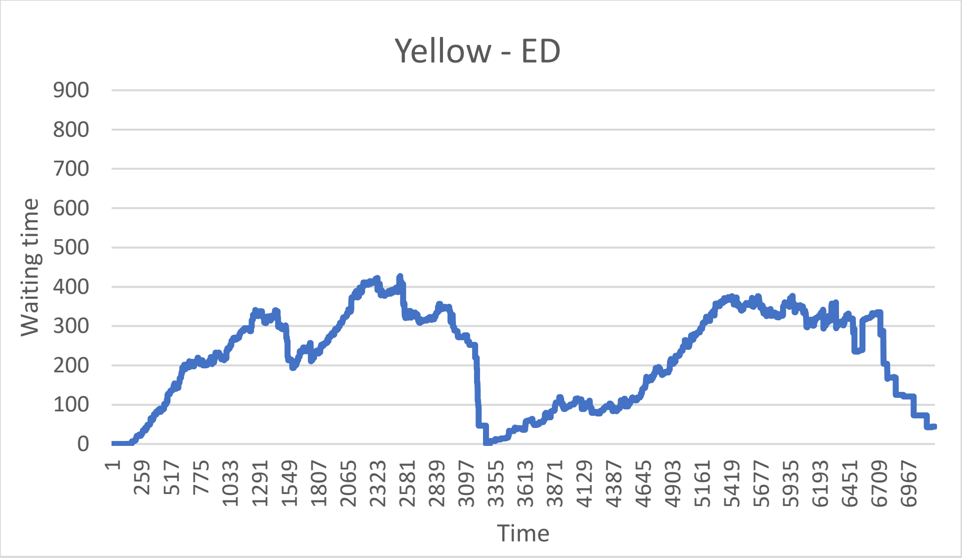


Figure 66 Yellow patients waiting times - simulated

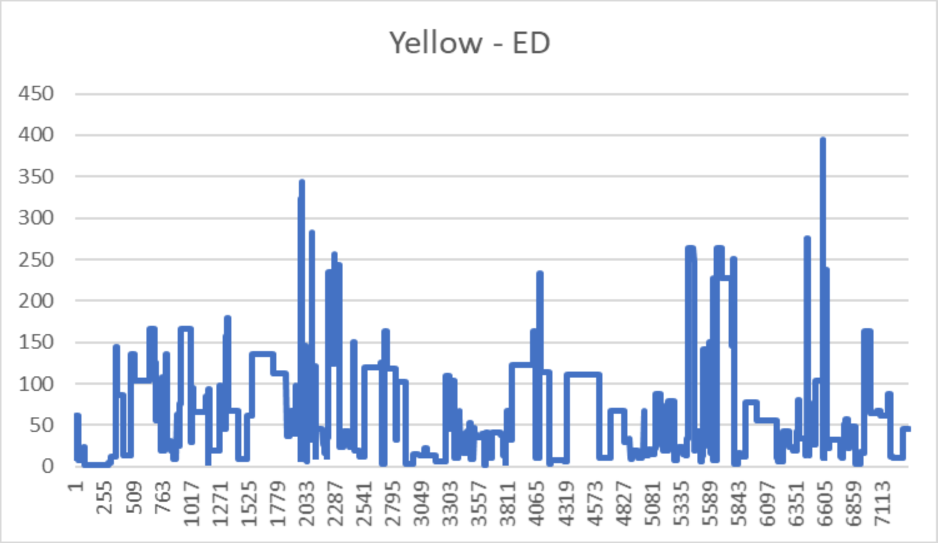


Figure 67 Yellow patients waiting times - real

The profile of the real curve presents some differences with respect to the one produced by the simulator. The basic reason is the significantly different number of yellow patients considered by the simulator (+20%). Keeping in mind this factor, according to the expert, the results suggested by the simulator can be considered as realistic.

Moving to the other items to be evaluated, so red patients in OR, yellow patients in OR, ordinary patients in OR and waiting time for hospitalizations, it is not possible to compare them with the real values since it is not available a database containing these values. In particular it is necessary to keep in mind the specific interpretation to be given to data and which will be proposed in the next paragraphs. Following, it is proposed a diagram showing the development of the waiting time along the simulation for each of the items. These are exactly the Figures evaluated by the expert during the process of “face validation”.

Ordinary - OR

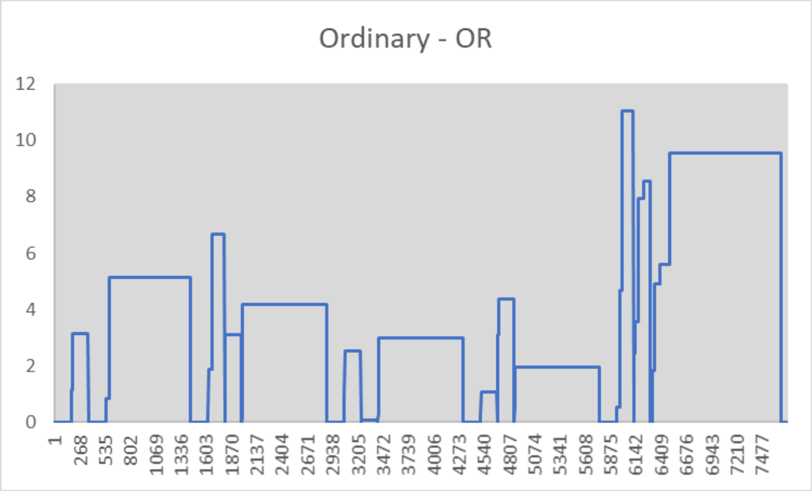


Figure 68 Ordinary ORs waiting times

As anticipated, regarding OR elective activity, Figure69 represents delays with respect to the schedule. These values can be considered as realistic.

Yellow - OR

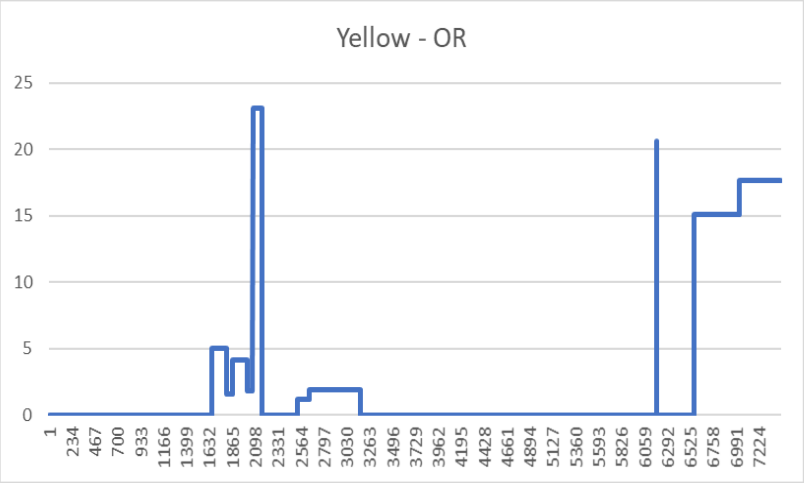


Figure 69 Yellow patients waiting times ORs

In Figure70 it is reported the trend of the time considered for the analysis which could be interpreted as the time between the moment in which a yellow patient shows the necessity of a surgery and the moment in which he/she is actually admitted to OR. As anticipated, those cases in which this value is not equal to zero represents situations in which a patients requires an OR immediately but it is not available. Considering the interpretation to be given to these data, and proposed in the previous section, according to the expert, this kind of situations are anyway slightly more frequent than what emerges from Figure70. Anyway this should not introduce particular distortion to the model.

Ward

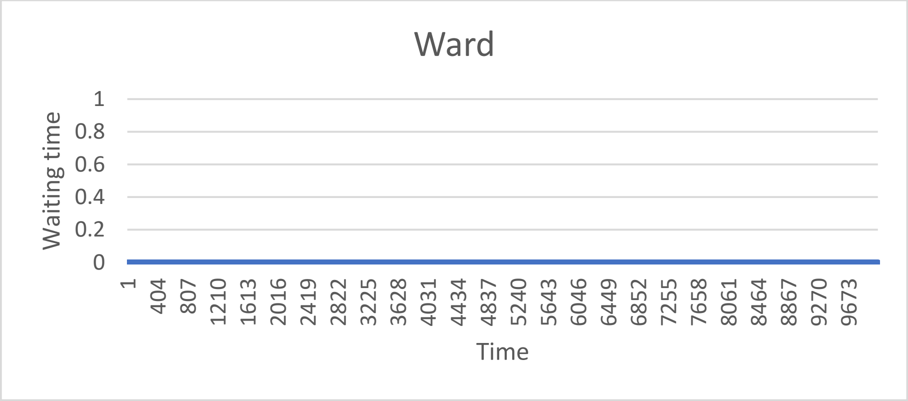


Figure 70 Hospitalization waiting times

Considerations reported above for “yellow – OR” are partially applicable also to patients awaiting to be hospitalized. In facts the value described in Figure71 does not represent the overall time a patient may await for a bed in wards, but it could be interpreted as the lapse of time between leaving a certain area and being assigned to a bed in ward. For what concerns patients leaving an OR, it is reasonable to expect this value equal to zero, as suggested by Figure71. On the other side, for what concerns patients leaving ED, it is expected a value different from zero more frequently. But, basing the analysis on the interpretation proposed above, and keeping in mind the specification on the nature of the data introduced into the model present in the previous paragraph, it is necessary to consider these data, similarly to what said for “yellow – OR”, as useful more in relative terms to compare emergency scenarios with the baseline, to identify any case of waiting time higher than the baseline. In facts, values of “ward” waiting time different from zero will be considered as worsening of the baseline scenario. This will be useful to evaluate emergency scenarios.

Red - OR

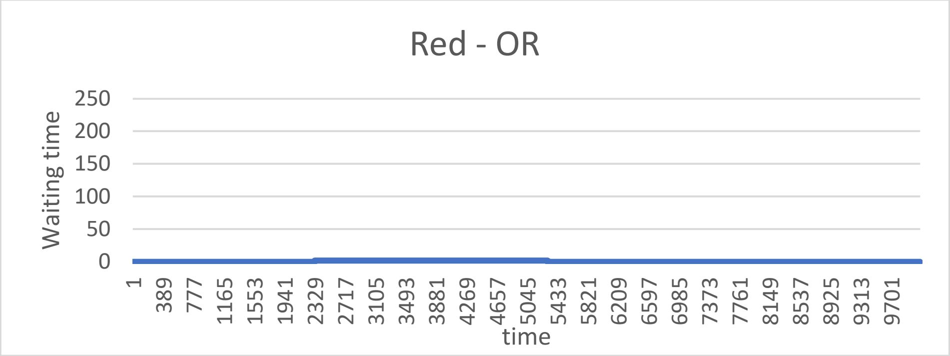


Figure 71 Red patients waiting times ORs

To conclude, for what concerns red patients awaiting for a slot in OR, it is reasonable to believe that the case of patient waiting more than 0 minutes is almost impossible, given the criticality of this class of patients. So the results produced by the model can be considered as realistic.

4.3 Simulation campaigns

It is now possible to present the different simulation campaigns the simulator has been applied to. The main areas investigated are the ones presented in the introduction of this chapter:

1. PEMAF rigidity in activation and deactivation;
2. Night scenario medical services delivery capability;

These areas of investigation will be addressed analyzing the baseline and other scenarios which could represent potentially an improvement for the system in relation to the three topics highlighted above. Basically, two different simulation campaigns will try to answer two questions:

1. Is it possible to reduce PEMAF rigidity in activation and deactivation, improving the overall hospital system performance in responding to a disruptive event without worsening ED urgent medical services delivery capability?
2. What is the most critical resource in defining the constrain to ED medical services delivery capability in the night scenario? What is the minimum set of

additional resources which could permit the maximum improvement in terms of medical services delivery capability.

As it is possible to understand, these objectives are coherent with the overarching goal of thesis. This was set at assessing and comparing possible strategies to guarantee continuity of medical services, improving and supporting the transition from security to resilience and so, to conclude, evaluating different strategies for essential medical services continuity in terms of resilience. In particular, this kind of work is expected to contribute to better integrate ordinary activity with urgent activity in case of maxi emergency, proposing an analysis focused on the overall hospital system.

The topic investigated through the simulation campaign number 1 is for sure the one dealt more in depth and for which, primarily, the simulator has been developed. As already anticipated, each campaign will be evaluated comparing the results with the current situation, which is, therefore, the starting point for every campaign.

In the following paragraphs it will be dedicated space to each of the campaigns, following the same approach applied in the simulation system design process. Of course, in case of scenarios simulating strategies alternative to the one applied currently, it will be proposed a qualitative description representing the logic behind them.

4.3.1 Simulation campaign 1 – PEMAF activation and deactivation transient

Three different scenarios representing three different emergency response strategies have been analyzed to deepen the topic of the PEMAF activation and deactivation transients:

- “As-is” strategy;
- “Steps On-Off” strategy;
- “Steps Off” strategy;

Each of these three strategies have been applied to a scenario including an emergency taking place entirely during the day (so beginning in the morning) and to a scenario including an emergency in the afternoon, so terminating in the night. For each scenario, 9 different simulations have been run in order to exclude potential outliers.

For what concerns the As-is strategy scenario, it refers to the simulation of the PEMAF application as it is currently. In particular it is made reference to the operative plan produced by OSR on the application of PEMAF in ED in case of maxi emergency. In section 3.2.3.1. ("Resource reconfiguration") qualitative description, rationalization and translation into Anylogic of the plan are reported. As anticipated in the introduction of this section, one of the main criticalities emerging from the analysis of the plan regards the interruption of ORs elective activity as well as ordinary admissions to wards. In particular, it is highlighted the low level of flexibility allowed by the plan, considering the development of the demand of medical services. In facts, ordinary activity is immediately interrupted in order to allow the highest possible increase in ED emergency response capability. The same applies to the deactivation of the plan, which consists in the re-allocation of resources to ordinary activities in the moment in which the emergency is declared concluded.

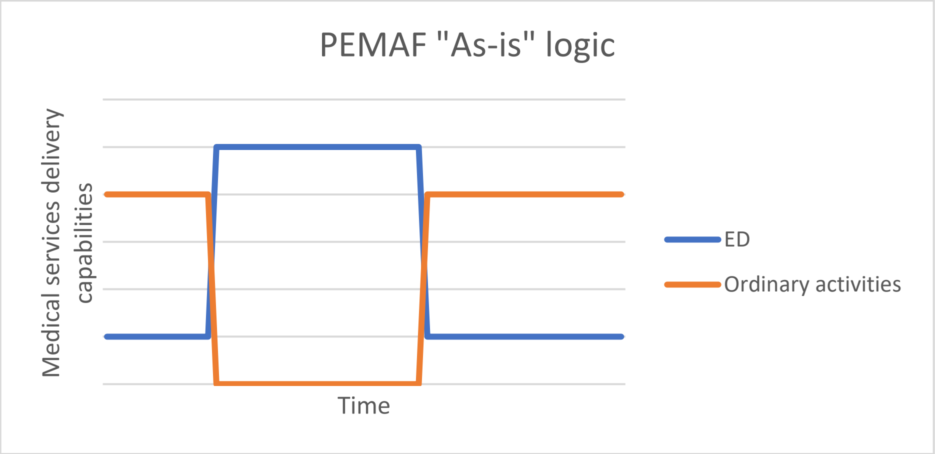


Figure 72 medical services delivery capability PEMAF distribution

Scenario 2 and scenario 3 are proposed to imagine and test strategies developed with the purpose of making the transient between the two configurations more flexible and fitting the demand in ED and of elective patients. Considering, as an example, the maxi emergency event described in previous paragraphs, and representing the one simulated, it is possible to understand that patients arrival in ED is not constant, but it assumes a belt shape.

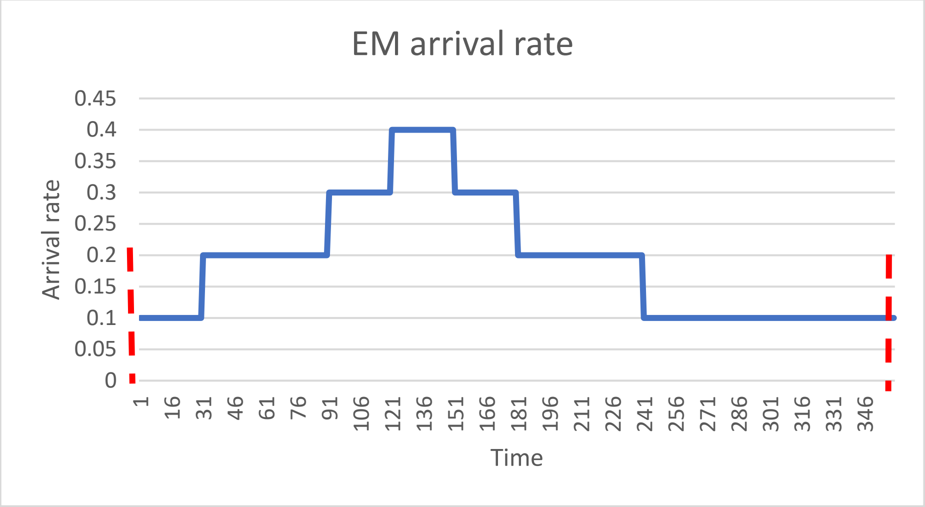


Figure 73 Emergency arrival rates

Despite the event considered represents just an example, it is reasonable to expect a patients arrival rate development similar to the one depicted in Figure73. On the other side, ordinary patients demand can be considered as constant. For these reasons, scenario 1 and scenario 2 will propose two different strategies – named “Steps On-Off” and “Steps Off” – that could potentially make resources allocation more coherent with the emergency development as well as with the steadiness of the ordinary medical services demand in OR and wards. The two strategies and the way they are translated into Anylogic are presented in the following paragraphs. Conversely, results will be discussed in the next chapter.

Scenario ”Steps On-Off” strategy

In this scenario it is imagined and simulated a different resources allocation strategy both in the activation and deactivation transient (“On” refers to the activation transient, “Off” to the deactivation one). The logic behind this strategy is to allocate resources to ED emergency patients and to elective patients in ORs and wards in a way more coherent with the emergency and ordinary demand. The rationale sustaining this logic is reported in Figure74.

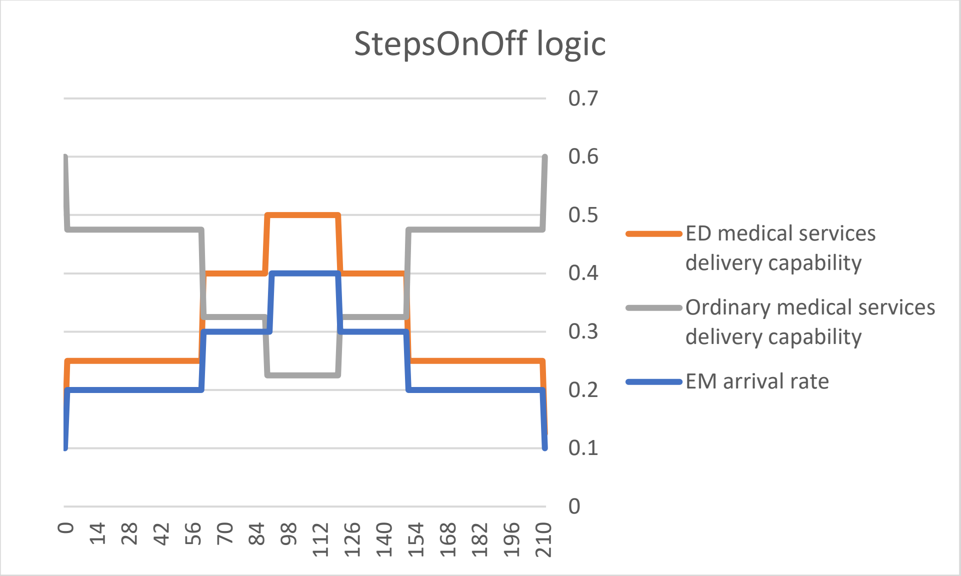


Figure 74 Steps On-Off strategy

The elements of the strategy are basically two:

1. Ordinary activity (in particular ORs activity and admissions to wards) is interrupted gradually, in more than on step. Consequently, resources, in particular medical staff, are moved from ordinary activity to ED in a gradual manner.
2. Ordinary activity (ORs and admissions to wards) is resumed gradually, as long as the amount of patients arriving in ED decreases in time. Consequently, resources, in particular medical staff, is re-allocated to ordinary activities in ORs and wards in a gradual manner, rather than in one single moment.

"Steps On-Off" strategy is expected to reduce the disservice to ordinary patients (reducing the lapse of time in which ordinary activities are interrupted) without worsening ED response to emergency capability. It is clear that the one depicted in Figure74 represents the best scenario, so the one in which the resources shifting steps manage to follow the demand increase.

Scenario "Steps On-Off" strategy in Anylogic

To represent this strategy in Anylogic it is possible to make partially reference to the section dedicated to the "As-is" resource reconfiguration section. The description of the activities carried out before first patient arrival, in particular those focusing on ED resources liberation, can be assumed as valid also in this context. The same applies to patient pathway reconfiguration (no Cat scan, Triage etc.). Conversely, it changes the set of additional resources moved to the ED and the timing of this process. To describe the differences with respect to the "As-is" strategy it is necessary to focus on the sequence of *events* triggered by "EmergencyAlert" and prosecuted by "ResourceReconfiguration". In the "As-is" scenario the following *event* triggered is directly the one simulating the return to normal operations resources configuration. On the other case, in the "Steps On-Off" scenario it is triggered a series of e*vents* necessary to simulate the different steps in resources allocation. These *events* are based on the same sequence described in the section related to the representation of emergency patients arrival ("Em1", "Em2"…). In this context, these are coded in order to simulate the different steps in resources allocation. The delay between one e*vent* and the following based is obtained through a system of variables and conditions. In table37 it is summarized the sequence, the time-related variable updated and the triggering condition of each *event.*

Event	Triggering condition	Action
"ResourceReconfiguration"	Time()>TimeLev0+30	TimeLev1=time()
"Em2"	Time()>TimeLev1+60	TimeLev2=time()
"Em3"	Time()>TimeLev2+30	TimeLev3=time()
"Em4"	Time()>TimeLev3+30	TimeLev4=time()
"Em5"	Time()>TimeLev4+30	TimeLev5=time()
"Em6"	Time()>TimeLev5+60	TimeLev6=time()
"Em7"	Time()>TimeLev6+120	

Table 37 StepsOnOff events

In particular, as it will be described in the next paragraph, along the time, a bigger amount of ORs (and related staff) is dedicated to emergency urgent patients, as well as the intensity to patients discharging from wards is increased. The "height" of the steps, so the number of ORs, surgeons, anesthesiologists to be moved to ED in each step is decided a priori. Of course the sequence of steps proposed is just an example, and many others could be developed with an higher degree of flexibility and precision. The calibration of this strategy in relation to the features of the *event* to be faced could be an interesting development of this model. In the following tables it summarized the sequence of steps applied, in the morning scenario. It is reported the way resources (spaces and staff) are shifted from ordinary activities to the ED and reverse, once the influx of patients start decreasing, and the way it is translated in Anylogic. Just those resources in trade-off between two areas of the hospital and managed gradually are reported, while for the rest of the code it is possible to make reference to Figure73 in which it is reported the As-is strategy. A particular focus is dedicated to those resources determining a trade-off between urgent and ordinary patients, so for those trade-offs belonging to category 2 (referring to the distinction reported in section 4.1.2). For what concerns trade-offs belonging to category 2 (nurses, beds, Oss etc.) these are not the object of this strategy.

“ResourceReconfiguration”	Anesthetists in ED = 5;	Anesthesiologists.set_capacity(5);
	General surgeons in ED = 5;	GeneralSurgeons.set_capacity(5);
	Anesthetists in OR = 24;	AnesthesiologistsOR.set_capacity(24);
	General surgeons in OR = 24	GeneralSurgeonsOR.set_capacity(24);
	ORs for elective patients = 24;	OrdOperatingRooms.set_capacity (24);
	ORs for urgent patients = 4;	OperatingRoomEd.set_capacity(4);
	OR equipe for eurgent = 4	EquipeOperatingRoomEd.set_capacity(4)
	OR equipe for ordinary = 24	EquipeOperatingRoom.set_capacity(24);
“Em2”	Anesthetists in ED = 7;	Anesthesiologists.set_capacity(7);
	General surgeons in ED = 7;	GeneralSurgeons.set_capacity(7);
	Anesthetists in OR = 22;	AnesthesiologistsOR.set_capacity(22);
	General surgeons in OR = 22;	GeneralSurgeonsOR.set_capacity(22);
	ORs for elective patients = 22;	OrdOperatingRooms.set_capacity (22);
	ORs for urgent patients = 6;	OperatingRoomEd.set_capacity(6);
	OR equipe for urgent = 6;	EquipeOperatingRoomEd.set_capacity(6);
	OR equipe for ordinary = 22;	EquipeOperatingRoom.set_capacity(22);
		AdditionalOutgoingPatients = 0.00005;
		AdditionalOutgoingPatients1= 0.00005;

Table 38 Resource reconfiguration, EM2

For what concerns the intensity of patients discharge from wards, in this case it is quantified in 0.05% of the overall capacity in surgical and non-surgical wards per minute.

“Em3”	Anesthetists in ED = 15;	Anesthesiologists.set_capacity(15);
	General surgeons in ED = 15;	GeneralSurgeons.set_capacity(15);
	Anesthetists in OR = 14;	AnesthesiologistsOR.set_capacity(14);
	General surgeons in OR = 14;	GeneralSurgeonsOR.set_capacity(14);
	ORs for elective patients = 14;	OrdOperatingRooms.set_capacity (14);
	ORs for urgent patients = 14;	OperatingRoomEd.set_capacity(14);
	OR equipe for urgent = 14;	EquipeOperatingRoomEd.set_capacity(14);
	OR equipe for ordinary = 14;	EquipeOperatingRoom.set_capacity(14);
		AdditionalOutgoingPatients = 0.0001;
		AdditionalOutgoingPatients1 = 0.0001;
“Em5”	Anesthetists in ED = 24;	Anesthesiologists.set_capacity(24);
	General surgeons in ED = 24;	GeneralSurgeons.set_capacity(24);
	Anesthetists in OR = 5;	AnesthesiologistsOR.set_capacity(5);
	General surgeons in OR = 5;	GeneralSurgeonsOR.set_capacity(5);
	ORs for elective patients = 5;	OrdOperatingRooms.set_capacity (5);
	ORs for urgent patients = 23;	OperatingRoomEd.set_capacity(23);
	OR equipe for urgent = 23;	EquipeOperatingRoomEd.set_capacity(23);
	OR equipe for ordinary = 5;	EquipeOperatingRoom.set_capacity(5);

Table 39Em3, Em5

Starting from “Em6” event it starts the process of resources reallocation from ED to ordinary activities.

“Em6”	Anesthetists in ED = 15;	Anesthesiologists.set_capacity(15);
	General surgeons in ED = 15;	GeneralSurgeons.set_capacity(15);
	Anesthetists in OR = 14;	AnesthesiologistsOR.set_capacity(14);
	General surgeons in OR = 14;	GeneralSurgeonsOR.set_capacity(14);
	ORs for elective patients= 14;	OrdOperatingRooms.set_capacity (14);
	ORs for urgent patients = 14;	OperatingRoomEd.set_capacity(14);
	OR equipe for urgent = 14;	EquipeOperatingRoom.set_capacity(14);
	OR equipe for ordinary = 14;	EquipeOperatingRoomEd.set_capacity(14);

“Em7”	Anesthetists in ED = 2;	Anesthesiologists.set_capacity(2);
	General surgeons in ED = 2;	GeneralSurgeons.set_capacity(2);
	Anesthetists in OR = 28;	AnesthesiologistsOR.set_capacity(28);
	General surgeons in OR = 28;	GeneralSurgeonsOR.set_capacity(28);
	ORs for elective patients= 27;	OrdOperatingRooms.set_capacity (27);
	ORs for urgent patients = 1;	OperatingRoomEd.set_capacity(1);
	OR equipe for urgent = 1;	EquipeOperatingRoomEd.set_capacity(1);
	OR equipe for ordinary = 27;	EquipeOperatingRoom.set_capacity(27);
		AdditionalOutgoingPatients = 0;
		AdditionalOutgoingPatients1 = 0;

Table 40 Em6, Em7

In the following Table41 the allocation of resources to ED and ordinary activities is summarized. The number of ORs available for ordinary or urgent patients refers also the number of anesthesiologists and surgeons devoted to ordinary or urgent patients. Similarly ED medical services delivery capability refers mainly to the number of anesthesiologists and surgeons moved to ED. Since the team assigned to a patient in ED follows him/her also in OR, this number determines also the number of ORs dedicated to urgent patients. As anticipated, for what concerns all the other parameters, it is possible to make reference to the section regarding As-is resource reconfiguration.

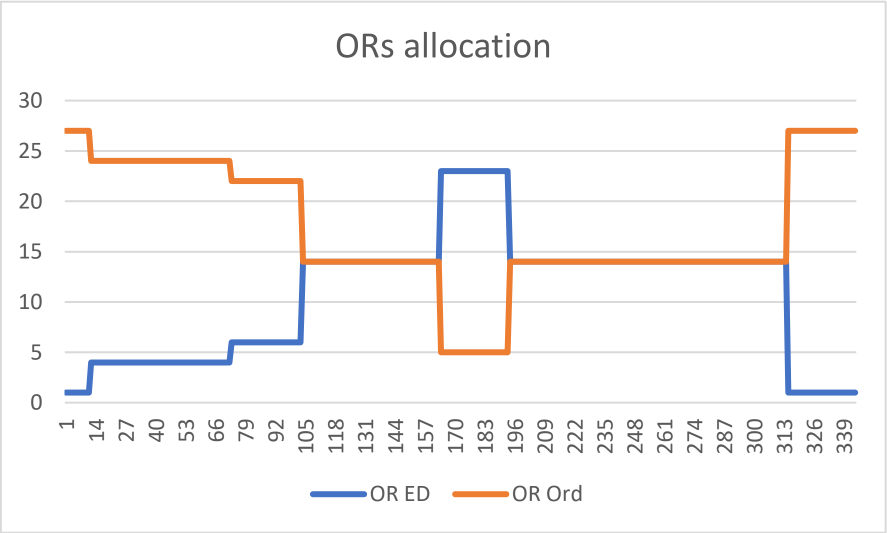


Table 41 ORs steps on off allocation

The structure of the “Steps On-Off” strategy applied in the afternoon scenario is similar to the one just presented in particular for what concerns the “On” transient. It changes the “Off” side of the scenario since it is not possible to completely reactivate the ordinary activity. Anyway, differently from the case of the As-is scenario, it is assumed the possibility to undertake at least one shift of surgeries scheduled for the day and delayed because of the maxi emergency. To do that, "Em5" *event* is triggered 30 minutes before as well as "Em6". To simulate the interruption of the activities for the night it is introduced an *event* named "night" triggered by the following condition:

```
isWorkingHour()==false && time()>TimeLev0
```

The *event* sets the capacity of "OrdOperatingRooms", "EquipeOperatingRoom", "AnesthesiologistsOR" and "GeneralSurgeonsOR" to 0. Through the *event* "Day" described in section x, ordinary activity is reactivated in the morning.

Scenario "Steps Off" strategy

In this scenario it is imagined and simulated a different resources allocation strategy just in the plan deactivation transient ("Off"). The logic behind this strategy is to allocate the maximum amount of resources to ED as soon as possible, in order to respond to the sudden influx of patients from the emergency and converging there. Once the peak of arrivals is passed and the demand of medical services in ED starts reducing it is possible to reallocate, step by step, some resources to the ordinary activity. The aim of this strategy is that of guaranteeing the maximum medical services delivery capability to ED, and reduce it just when the development of the emergency and the way it evolves is clearer.

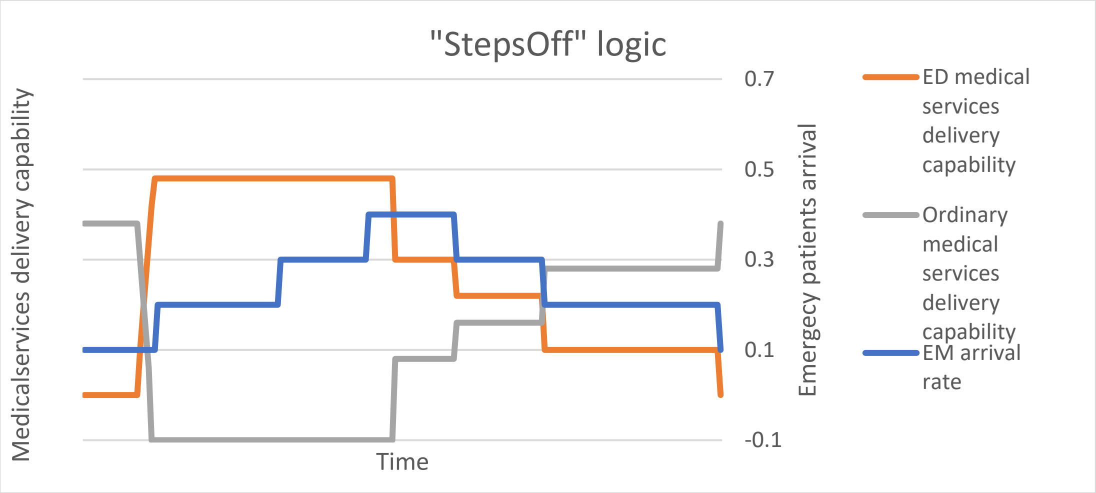


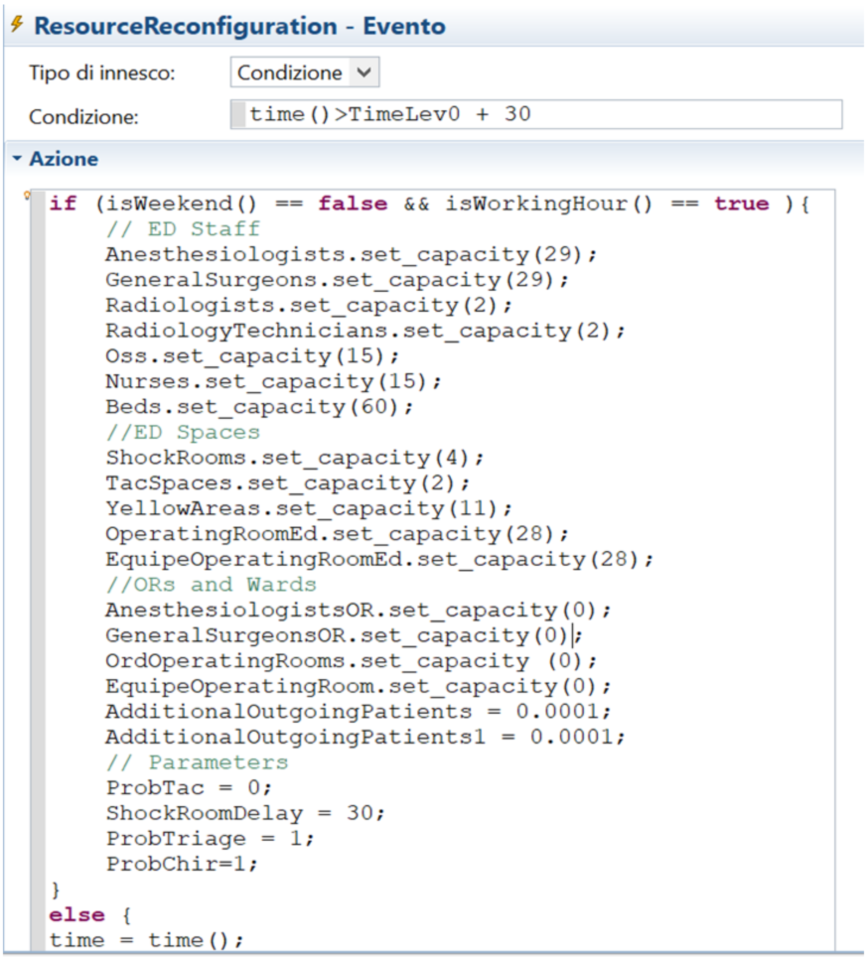
Table 42 Steps off logic

The elements of the strategy are basically two:

1. Ordinary activity (in particular ORs activity and admissions to wards) is interrupted immediately, in just one step. Consequently, resources, in particular medical staff, are moved from ordinary activities to ED as soon as it given the alert signal.
2. Ordinary activity (ORs and admissions to wards) is resumed gradually, as long as the amount of patients arriving in ED decreases in time. Consequently, resources, in particular medical staff, is re-allocated to ordinary activities in ORs and wards earlier in a gradual manner, rather than in one single moment.

Scenario "Steps Off" strategy in Anylogic

"Steps Off" strategy translation in Anylogic is an integration of the "As-is" strategy and the "Steps On-Off" strategy. Also in this case it is possible to make reference to the section dedicated to "As-is" resource reconfiguration strategy for what concerns the activities carried out before first patient arrival, patient pathway reconfiguration etc. Differently from "Steps On-Off" strategy, it is possible to replicate in this context also the "ResourceReconfiguration" *event* and it's triggering condition. 30 minutes later than "EmergencyAlert" *event* it is triggered "ResourceReconfiguration" *event* which represents the choice of activating the plan. It is reported in Figure75 the entire code composing "ResourceReconfiguration" *event.* To clarify the different statements they have been subdivided into different categories according to the object of reconfiguration: ED staff, ED spaces, ORs, Wards and parameters.



ResourceReconfiguration - Evento

Tipo di innesco: Condizione

Condizione: `time()>TimeLev0 + 30`

Azione

```
if (isWeekend() == false && isWorkingHour() == true ){
    // ED Staff
    Anesthesiologists.set_capacity(29);
    GeneralSurgeons.set_capacity(29);
    Radiologists.set_capacity(2);
    RadiologyTechnicians.set_capacity(2);
    Oss.set_capacity(15);
    Nurses.set_capacity(15);
    Beds.set_capacity(60);
    //ED Spaces
    ShockRooms.set_capacity(4);
    TacSpaces.set_capacity(2);
    YellowAreas.set_capacity(11);
    OperatingRoomEd.set_capacity(28);
    EquipeOperatingRoomEd.set_capacity(28);
    //ORs and Wards
    AnesthesiologistsOR.set_capacity(0);
    GeneralSurgeonsOR.set_capacity(0);
    OrdOperatingRooms.set_capacity (0);
    EquipeOperatingRoom.set_capacity(0);
    AdditionalOutgoingPatients = 0.0001;
    AdditionalOutgoingPatients1 = 0.0001;
    // Parameters
    ProbTac = 0;
    ShockRoomDelay = 30;
    ProbTriage = 1;
    ProbChir=1;
}
else {
time = time();
```

Figure 75, Resource Reconfiguration

This *event* simulates ordinary activities interruption and the immediate reallocation of resources to ED. For what concerns ordinary activities resuming, this is simulated through a series of *events* analogous to the one described in the previous paragraph. In the following tables the main features of the *events* simulating a gradual deactivation of the plan are summarized. In this scenario, just the portion starting with "Em4" will actually introduce a modification in the system.

Event	Triggering condition	Action
"ResourceReconfiguration"	Time()>TimeLev0+30	TimeLev1=time()
"Em2"	Time()>TimeLev1+60	TimeLev2=time()
"Em3"	Time()>TimeLev2+30	TimeLev3=time()
"Em4"	Time()>TimeLev3+30	TimeLev4=time()
"Em5"	Time()>TimeLev4+30	TimeLev5=time()
"Em6"	Time()>TimeLev5+60	TimeLev6=time()
"Em7"	Time()>TimeLev6+120	

Table 43 StepsOff events

“Em4”	Anesthetists in ED = 26;	Anesthesiologists.set_capacity(26);
	General surgeons in ED = 26;	GeneralSurgeons.set_capacity(26);
	Anesthetists in OR = 3;	AnesthesiologistsOR.set_capacity(3);
	General surgeons in OR = 3	GeneralSurgeonsOR.set_capacity(3);
	ORs for elective patients = 3;	OrdOperatingRooms.set_capacity (3);
	ORs for urgent patients = 25;	OperatingRoomEd.set_capacity(25);
	OR equipe for urgent = 25;	EquipeOperatingRoomEd.set_capacity(25);
	OR equipe for ordinary = 3;	EquipeOperatingRoom.set_capacity(3);
“Em5”	Anesthetists in ED = 24;	Anesthesiologists.set_capacity(24);
	General surgeons in ED = 24;	GeneralSurgeons.set_capacity(24);
	Anesthetists in OR = 5;	AnesthesiologistsOR.set_capacity(5);
	General surgeons in OR = 5;	GeneralSurgeonsOR.set_capacity(5);
	ORs for elective patients = 5;	OrdOperatingRooms.set_capacity (5);
	ORs for urgent patients = 23;	OperatingRoomEd.set_capacity(23);
	OR equipe for elective = 23;	EquipeOperatingRoomEd.set_capacity(23);
	OR equipe for ordinary = 5;	EquipeOperatingRoom.set_capacity(5);
		AdditionalOutgoingPatients = 0.00005;
		AdditionalOutgoingPatients1= 0.00005;
“Em6”	Anesthetists in ED = 14;	Anesthesiologists.set_capacity(14);
	General surgeons in ED = 14;	GeneralSurgeons.set_capacity(14);
	Anesthetists in OR = 15;	AnesthesiologistsOR.set_capacity(15);
	General surgeons in OR = 15;	GeneralSurgeonsOR.set_capacity(15);
	ORs for elective patients = 15;	OrdOperatingRooms.set_capacity (15);
	ORs for urgent patients = 13;	OperatingRoomEd.set_capacity(13);
	OR equipe for urgent = 13;	EquipeOperatingRoomEd.set_capacity(13);
	OR equipe for ordinary = 15;	EquipeOperatingRoom.set_capacity(15);

“Em7”	Anesthetists in ED = 2;	Anesthesiologists.set_capacity(2);
	General surgeons in ED = 2;	GeneralSurgeons.set_capacity(2);
	Anesthetists in OR = 28;	AnesthesiologistsOR.set_capacity(28);
	General surgeons in OR = 28;	GeneralSurgeonsOR.set_capacity(28);
	ORs for elective patients = 27;	OrdOperatingRooms.set_capacity (27);
	ORs for urgent patients = 1;	OperatingRoomEd.set_capacity(1);
	OR equipe for urgent = 1;	EquipeOperatingRoomEd.set_capacity(1);
	OR equipe for ordinary = 27;	EquipeOperatingRoom.set_capacity(27);
		AdditionalOutgoingPatients = 0;
		AdditionalOutgoingPatients1 = 0;

Table 44 Em4, Em5, Em6, Em7

It is now worth to specify one feature of the software which is relevant for all the strategies described up to now, in particular in relation to the “*resourcePool*.set_capacity()” function. When *resourcePool* capacity is increased through this function, new units are added as soon as “*resourcePool*.set_capacity()” is called. On the other side, when this function is called to reduce a *resourcePool* capacity, the number of available units is reduced just as long as tasks occupying them as terminated. This is crucial to simulate the shift of resources from ordinary to urgent activities and reverse, in particular for what concerns ORs. In facts, before making available an OR unit (and the related units of staff) occupied by an ordinary/urgent *agent* to an urgent/ordinary *agent*, the surgery previously began is terminated, making this process very similar to the real one. Considering this delay is crucial in analyzing the interaction between ordinary and urgent activities.

It is now concluded the presentation of the scenarios composing the first simulations campaign. These will be evaluated through the logic described in the section dedicated to KPIs. The two main indicators analyzed will be, in facts, “R”(as it has been defined before) and the average number of red patients at risks (PAR). Performances will be assessed for each strategy (“As-is”, “Steps On-Off’, “Steps Off”) in the morning scenario and in the afternoon scenario. The analysis is summarized by the following synoptic

	Morning scenario		Afternoon scenario	
	“R”	PAR	“R”	PAR
“As-Is”				
“Steps On-Off”				
“Steps Off”				

Table 45 Final synoptic campaign1

4.3.2 Simulation campaign2 - Night scenario, Critical Resources analysis

The second simulations campaign is focused on the night scenario. As anticipated in the introduction, this set of simulations, as well as the one described in the following section, is developed in order to get insights on the topic investigated. As it will emerge, in facts, the level of detail is lower with respect to simulation campaign 1.

It has been chosen to separate night scenario from the ones describing a maxi emergency in the morning or in the afternoon since it would have very poor meaning to analyze the integration between ordinary and urgent patients during the night. In this context, as it will emerge from the description of the results, the most critical topic is for sure the identification of the ED medical service delivery capability. In facts, during the night shift or the weekend, resources are much more constrained with respect to the working hours shift. In this context, the most critical issue is that of quantifying, as precisely as possible, the number of patients the ED is able to receive and guarantee a care process to. In the document produced by OSR to describe the application of the PEMAF in the hospital, it is proposed a detailed analysis on the combination of red, yellow and green patients the ED is able to accept without reducing the level of care to the patient. In order to continue the logic proposed by this document, the simulator will be applied to identify the most efficient way to improve ED medical service delivery capability in case of a maxi emergency event during the night. With respect to the current approach, it is proposed a time based analysis, to analyze ED medical services delivery capability along all the time of the simulation.

To achieve the goal it is simulated the same event described for the morning and afternoon scenario, but triggered at 2:00 a.m. Of course it represents a dramatic scenario, with an influx of patients significantly above the ED capacity of response. On the other side this choice is useful to strongly stress the system and making it very sensible to the increase or reduction of resources. It is important to specify that in such a scenario it would be activated, for sure, the second level of the plan. In this way, staff defined "available", so autonomously self-declared as willing to be contacted in case of need, is called to the hospital. This has been excluded from the analysis since it does not really exist a true codification describing processes. On the other side, as it will be described, the work, as it has been structured, can be helpful in identifying those resources to be absolutely activated among the ones "available". In particular it will be proposed a series of simulations presenting the same event but, each one, a different combination of resources added to ones made available by the activation of the plan (first level). The simulations characterizing this campaign are summarized in table46. "+1" and "+2" refer to number of additional resource units.

Resource added and quantity added.	Shock Room	Anesthesiologists and General surgeon	Trauma team	Nurse and Oss
+1				
+2				

Table 46 Logic simulation campaign2

The scenario simulating the creation of 1 or 2 more shock rooms considers the possibility of equipping spaces with all the instruments characterizing a shock room. This is to say that the aim is that of understanding whether spaces and instruments may introduce a constrain in ED medical services delivery capability. On the other side, the three last simulations are focused on the staff. The logic of having three different configurations of staff is that of understanding whether the creation of a new entire Trauma team is actually the best alternative, or it may be more efficient to increase the number of just a portion of the staff composing it. It is simulated both the scenario with just 1 unit added and also that with 2 units to highlight, in case, the effect of the diminishing returns principle. In facts, it is not taken for granted that adding 2 units gives the same improvement than adding just one of the same resource. The performance of the system considering the different resources configuration will be evaluated according to three different parameters:

- Red patients at risk (PAR)
- Patients assigned to an uncomplete team, so resulting in a lower level of care ("LLC")
- Maximum red patients waiting time to be admitted in shock room ("Max)

As it is possible to notice, the focus is moved exclusively on red patients, since they represent for sure the most critical agents. The analysis proposed through this simulation campaign can be summarized by the following synoptic:

	Shock Room		Anest+Gen.Surg.		Trauma Team		Nurse+OSS	
	+1	+2	+1	+2	+1	+2	+1	+2
PAR								
LLC								
Max								

Table 47 Final synoptic simulation campaign2

The synoptic will be completed with the average value resulting from the 10 different simulations.

In Anylogic the night scenario does not present any particular difference with respect to the others. In facts, as anticipated, in the scenario considered, the maxi emergency is declared concluded around 8:00 so ordinary activities can restart in that moment. In order to modify the availability of resources, it is modified, in each simulation, the capacity of a different *resourcePool.*

CHAPTER5

SIMULATION CAMPAIGNS – RESULTS

This chapter is aimed at presenting the results of the simulation campaigns and structuring a discussion about them. The chapter is structured in 2 main blocks, each one dedicated to one of the simulation campaigns described in the previous chapter. Each block follows the same logic, presenting first the results deriving from the analysis of the “As-is” strategy. “As-is” scenario simulates the strategy currently put in place to face maxi emergency events, and its effects on the 2 streams of analysis highlighted in the previous chapter. Subsequently, for each simulation campaign, it is proposed the scenario resulting from the application of the alternative strategies identified and structured for each topic. The analysis is conducted over the KPIs described in chapter4, but also on indicators useful to identify the root causes of the different performances. These will be proposed as a conclusion of the chapter as well as some considerations to link the results with the overall objective of the thesis. The considerations made starting from the results produced by the simulator will be analyzed in order to derive indications that could be useful to the HDM at the moment of a maxi emergency.

5.1 Simulation campaign 1 - PEMAF activation and deactivation transient

The results related to the first simulation campaign are presented in this section. Each scenario will be briefly described in terms of number of patients for each color code, event simulated and activation/deactivation of the resources reconfiguration plan. Subsequently, it is depicted the development of the "I" indicator along the time of the simulation, and the computation of the indicator "R". Propaedeutically to the computation of "R", it is highlighted the moment in time in which the hospital performance ("I") returns to the average value characterizing normal operations. Lastly, the number of patients at risk (PAR) is reported. The results related to two different scenarios, morning and afternoon, for each strategy will be presented. For what concerns simulations presenting a disruptive event, the duration of the simulation is reduced to concentrate it around the event. Comments and considerations on the results will be reported once completed the final synoptic.

5.1.1 Baseline

Green patients	1000
Yellow patients (baseline)	350
Red patients (baseline)	50
Maxi emergency	No emergency
Duration of the simulation	10000 minutes

Table 48, Baseline scenario

The results related to the baseline scenario are mainly reported in the previous chapter. Integrating them it is possible to compute the trend of the "I" indicator and its average value which will be useful to compute "R". It is reported a reduced frame with respect to the entire simulation, in order to focus on the lapse of time in which the disruptive will occur in the subsequent scenarios.

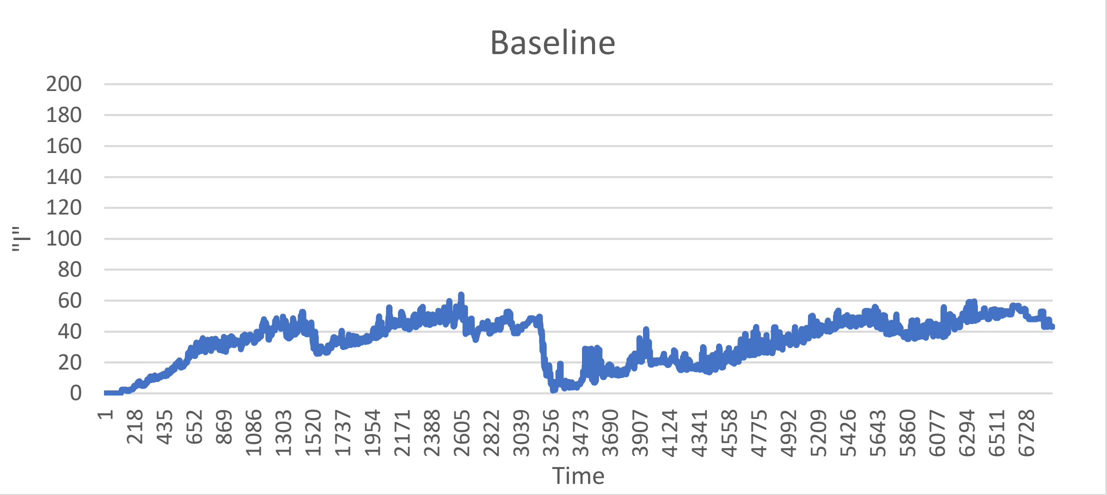


Figure 76, Baseline, "I" trend

For the computation of the average value of "I" it is excluded the lapse of time referring to the weekend, since it would introduce a significant distortion. During the weekend, as it is possible to understand from the description of the baseline in the previous chapter, the pression over the system is significantly different as well as the resulting performance with respect to the working day. It is excluded also the value of "I" in the first 400 minutes, representing the time needed by the simulator to "warm up" and to create a realistic workload on the hospital system.

Average value of "I"	32.109

To conclude it is now presented the results related to number of patients at risk (PAR) according to the definition provided in the previous sections.

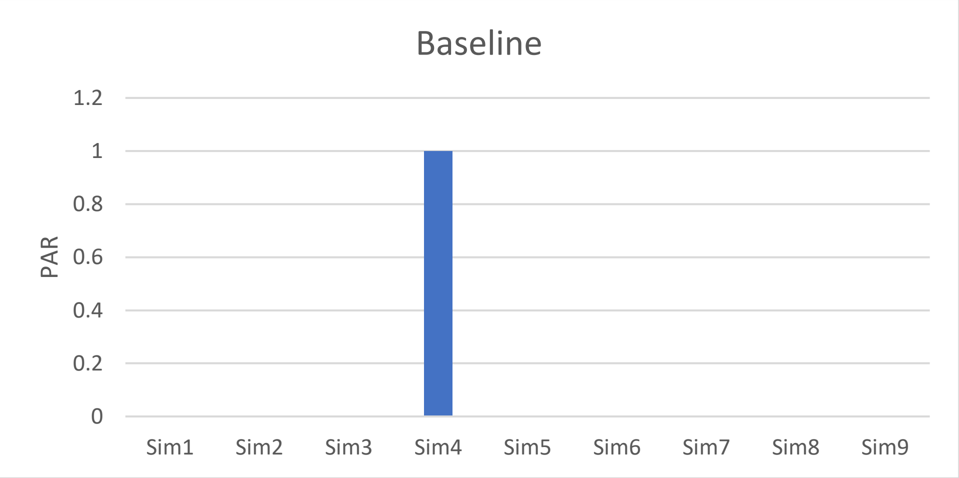


Figure 77, Baseline, PAR

It is possible to consider a number of patients at risk equal to 0.11 per simulation.

5.1.2 “As-is” scenario

The “As-is” scenario simulates the application of the current strategy to manage maxi emergency event, the one proposed in the PEMAF. It is presented first the results related to the morning scenario, and then to the afternoon scenario.

Morning scenario

Green patients (baseline)	800
Yellow patients (baseline)	230
Red patients (baseline)	30
Red Patients (emergency)	18
Yellow Patients (emergency)	27
Emergency alert	Min: 1600 – Tuesday, 10:30 ca.
PEMAF deactivation	Min: 1960 – Tuesday, 16:00 ca.
Duration of the simulation	7200 minutes

Table 49, As-is scenario

“I” indicator trend

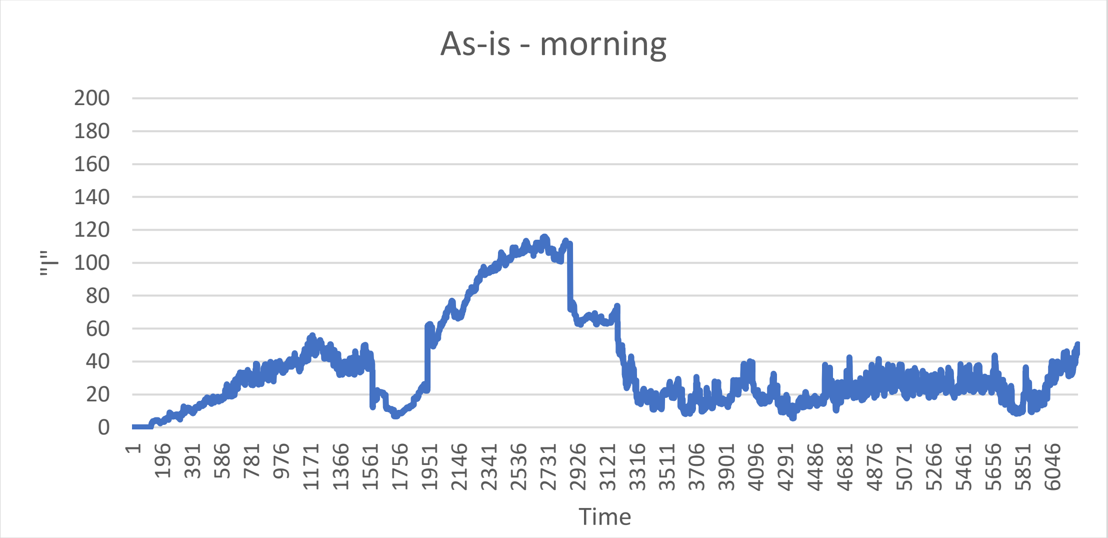


Figure 78, As-is morning, "I" trend

From min 1600 it is possible the see a drop in “I” and then a sudden increase. Waiting times are significantly decreased at the beginning of the emergency considering the effort put to desaturate the ED. After the emergency, the performance of the system returns to the average value in normal operations at 3291 (Wednesday, 15:00 ca.). The peak of “I”, so the most critical moment, arrives at 2721 (05:00 a.m. ca., Tuesday) with a value of “I” equal to 114. Given these values it is possible to compute the value of “R” as the ratio between the integral of “I” in the baseline scenario between 1600 and 3291 and the integral of “I” in the “As-is” scenario in the same lapse of time. The integral is computed summing up the value of “I” for each minute in the interval considered.

“R’ “ and “R” computation

Given the values presented above it is possible to compute the value of “R’ “ and “R” over the same lapse of time (1600-3291).

	“R’ “	“R”
Baseline	69829.986	0.601
“As-is”	116123.81	

Table 50, "As-is" morning, R computation

Number of patients at risk

It is now reported the analysis on the number of patients at risk per simulation. As it is possible to see, the performance does not vary significantly with respect to the baseline scenario.

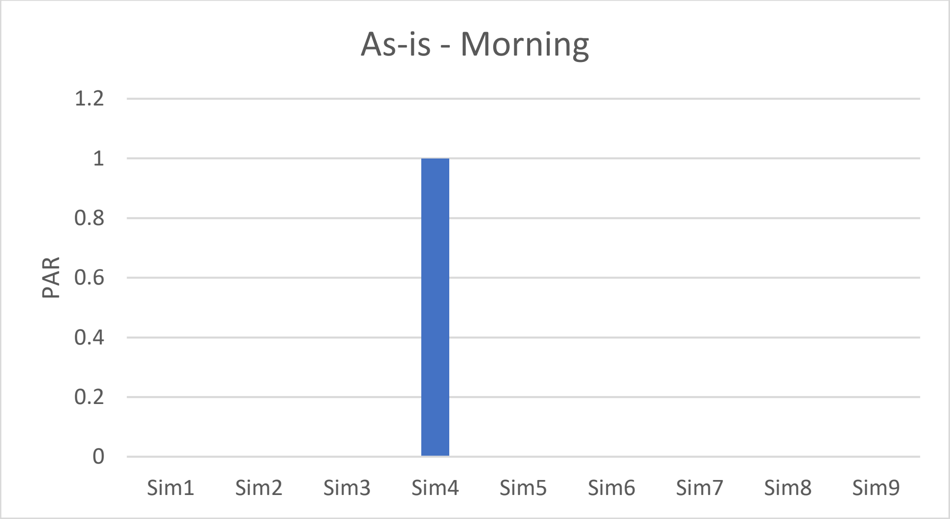


Figure 79, "As-is" morning, PAR

To compile the final synoptic it will be considered a value of patients at risk equal to 0.11 per simulation.

Afternoon scenario

Green patients (baseline)	800
Yellow patients (baseline)	230
Red patients (baseline)	30
Red Patients (emergency)	18
Yellow Patients (emergency)	27
Emergency alert	Min: 1883 – Tuesday, 16:00 ca.
PEMAF deactivation	Min: 2243 – Tuesday, 21:00 ca.
Duration of the simulation	7200 min

Table 51, "As-is" afternoon, scenario

It is considered a scenario in which an emergency alert arrives around 16:00. This means that one "shift" of ordinary surgeries is missed, while the previous one is considered to begin at 15:00. This means that ORs are allocated to urgent patients just once ordinary surgeries are completed.

"I" indicator trend

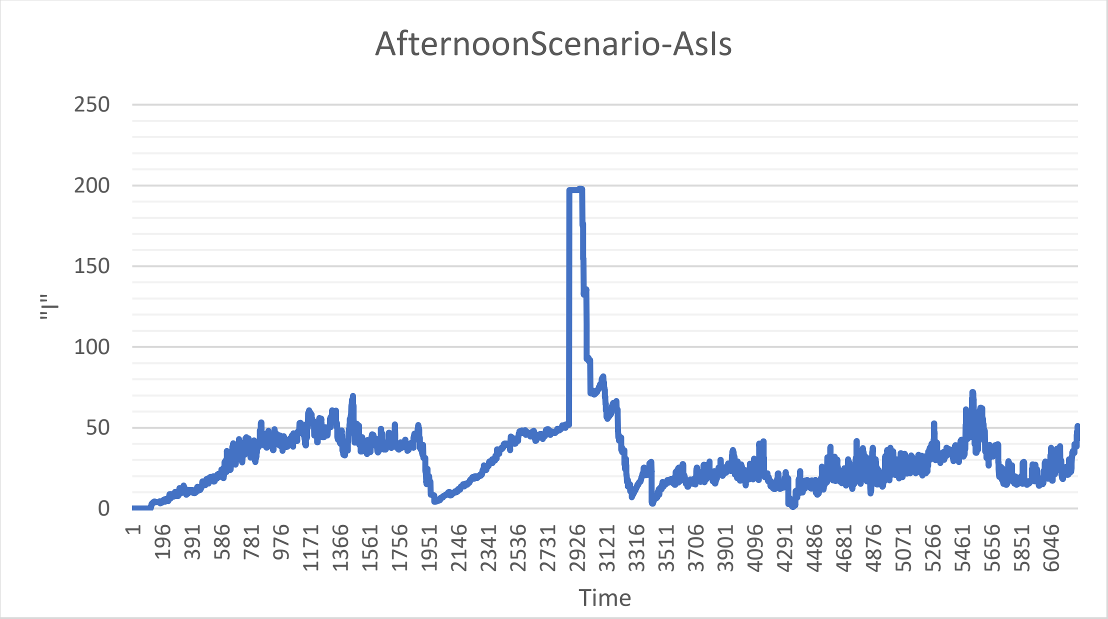


Table 52, "As-is" afternoon, "I" trend

In this case it is possible to see a very significant peak ("I" = 197) around 2880 minutes (8:00 a.m. ca, Wednesday) that corresponds to the moment in time in which delayed surgeries are completed the following day. The system returns to normal operations – so “I” passes *through* 32.109 – at 3240 (Wednesday, 14.00 p.m ca.). Given these values it is possible to compute “R’ “ and “R”.

“R’ “ and “R” computation

Given the values presented above it is possible to compute the value of “R’ “ and “R” over the same lapse of time (1883-3239).

	“R’ “	“R”
Baseline	59068.95	0.87
“As-is”	67857.69	

Table 53, "As-is" afternoon, "R" computation

These results suggest a lower level of criticality in the afternoon scenario compared with the morning one: as a matter of fact, the length of time necessary by the system to recover performances as they are in normal operations is shorter than the one necessary in the morning scenario and the value of “R” is significantly higher. In the final paragraph of this section it will be proposed an analysis on the causes of this result. This conclusion, as it will be explained, seems to be reasonable according to some relevant factors, but on the other side it shows some issues related to the way indicator “I” has been constructed for this kind of analysis. In facts waiting times are recorded just when *agents* leave the queue, so at the end of the time awaited and, in case more than one *agent* leaves the queue simultaneously, this is not recorded. In the afternoon scenario, these two factors may have both an effect on the result potentially introucing a limitation to the effectiveness of the indicator “I”, which is sensible to the two factors just highlighted. For sake of coherence the final synoptic will be compiled with the value reported in table53, but, in the next section it will be dedicated a paragraph to some proposals to overcome these issues. These are excluded from the analysis carried out now since they probably go beyond the basic logic applied to build the indicator “I” and “R”,

Number of patients at risk

In this scenario, no patients resulted to be at risk in the simulations run

5.1.3 “Steps On-Off” scenario

The “Steps On-Off” scenario simulates the application of a strategy to manage maxi emergency events different from the one proposed by the PEMAF. In particular it is proposed a different approach towards the management both of the activation and deactivation transient. It is presented first the results related to the morning scenario, and then to the afternoon scenario.

Morning scenario

Green patients (baseline)	800
Yellow patients (baseline)	230
Red patients (baseline)	30
Red Patients (emergency)	18
Yellow Patients (emergency)	27
Emergency alert*	Min: 1600 – Tuesday, 10:30 ca.
PEMAF deactivation**	Min: 1810 – Tuesday, 14:00 ca.
Duration of the simulation	7200 minutes

Table 54, "StepsOnOff" morning scenario

*, ** in this case, the values reported in the table indicate the beginning of the gradual resources shifting from ordinary to urgent activities and reverse, according to the sequence of events reported in the previous chapter.

“I” indicator trend

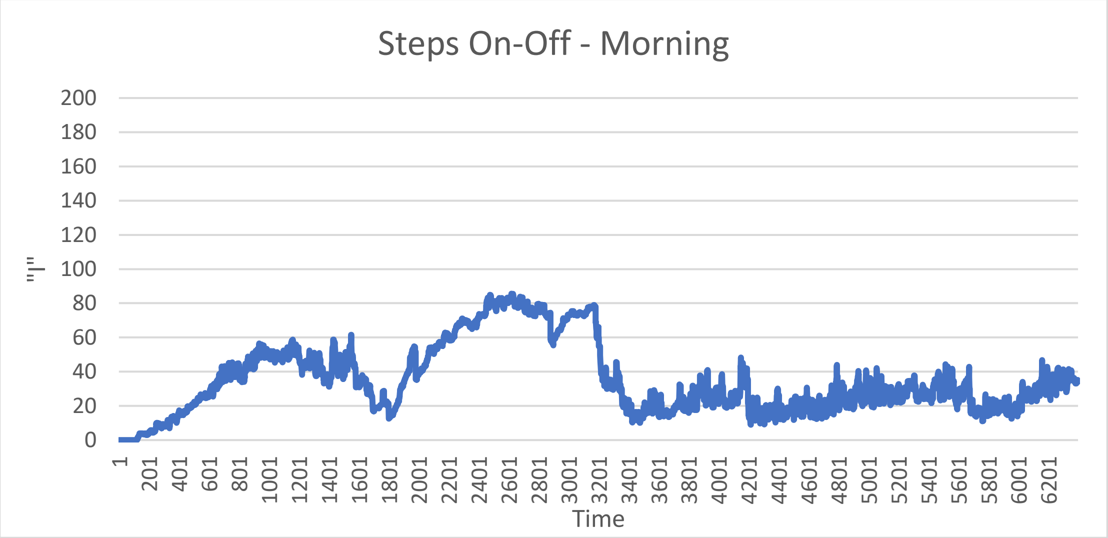


Figure 80, "StepsOnOff" morning, "I" trend

In this scenario there is a drop in the value of “I” around minute 1600 as described in the “As-is” scenario. The performance of the hospital system is worsened by the occurrence of the maxi emergency, but, in a lower level with respect to the “As-is” scenario. In facts, the peak of “I” occurs at 2480 (00:30 ca, Wednesday) with a value equal to 85, significantly lower than the one in the previous scenario (114). The system returns to normal operations at 3240 (14:00 ca, Wednesday).

“R’ “ and “R” computation

Given the values reported above it is possible to compute the value of “R’ “ and subsequently the value of “R” computing the value of “R’ “ for the baseline in the same lapse of time.

	“R’ “	“R”
Baseline	69389.3	0.71
“Steps On-Off”	96916.9	

Table 55, "StepsOnOff" morning "R" computation

With respect to the “As-is” scenario this kind of strategy permits almost a 17% improvement of “R” (so in terms of hospital system waiting times). It is now necessary to analyze the number of patients at risk

Number of patients at risk

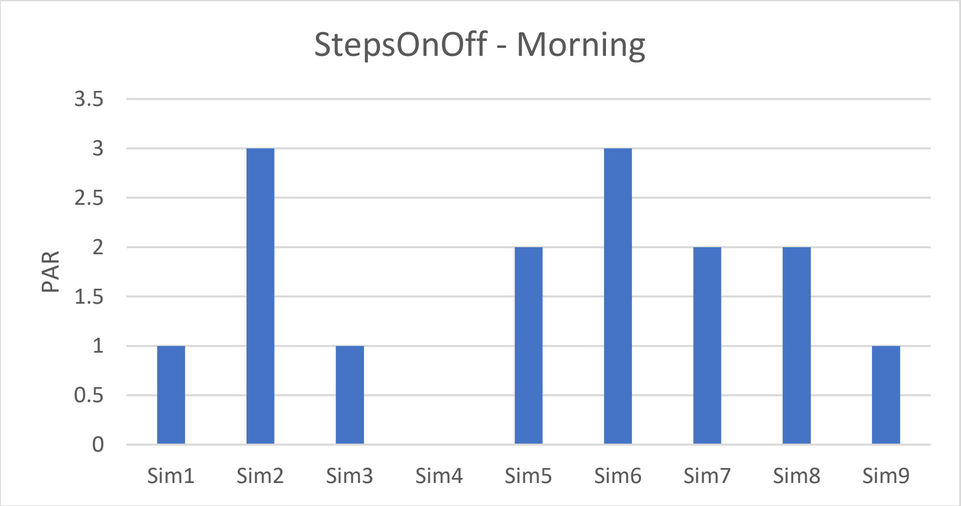


Figure 81, "StepsOnOff" morning, PAR

As it is possible to see from Figure81, the number of patients at risk is significantly increased with respect to the other scenarios. The average number of patients at risk among the simulations is 1,7 patient/simulation. In general this means that, given the emergency event simulated and the structure of the strategy as it was described in the previous chapter, much more pression is put on the ED, in particular on shock rooms and related staff. Given the structure of the indicator “I”, specifically regarding the number of patients at risk, this strategy has to be considered unacceptable. In facts, despite the overall performance of the hospital is improved in terms of waiting times, it is significantly higher the risk of not being able to take care of patients in ED. This imposes to refuse the “steps On-Off” strategy.

Afternoon scenario

Green patients (baseline)	800
Yellow patients (baseline)	230
Red patients (baseline)	30
Red Patients (emergency)	18
Yellow Patients (emergency)	27
Emergency alert	Min: 1880 – Tuesday, 16:00 ca.
PEMAF deactivation	Min: 2240 – Tuesday, 21:00 ca.
Duration of the simulation	7200 min

Table 56, "StepsOnOff" afternoon scenario

“I” indicator trend

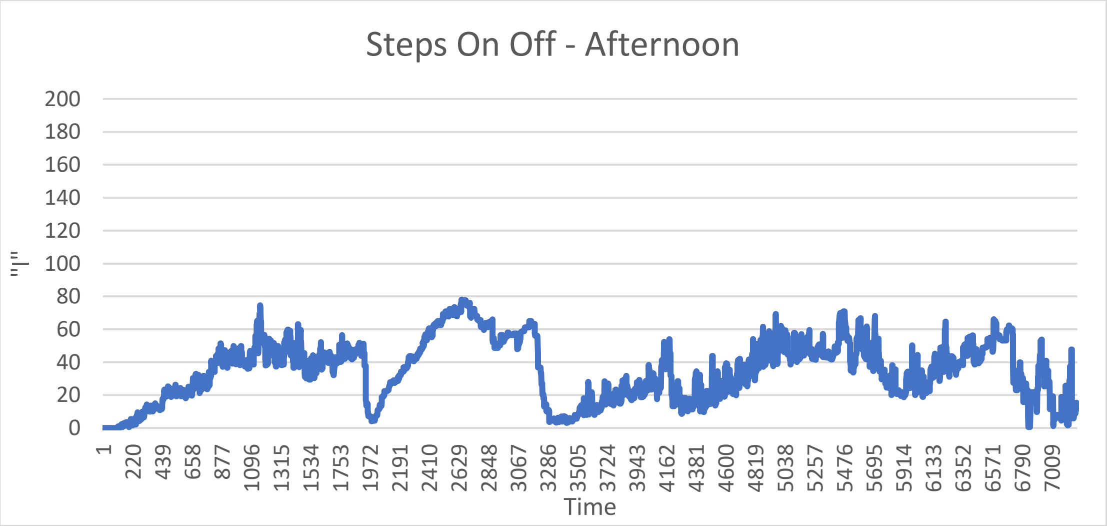


Figure 82, "StepsOnOff" afternoon "I" trend

The emergency begins, as indicated in table56, at minute 1880, and it can be considered concluded, so the hospital system performance returns to the average value in normal operations, after 3240 minutes from the beginning of the simulation, so Wednesday, 14:00 ca. The peak is I=78.02

"R' " and "R" computation

Given the values presented above it is possible to compute "R' " and "R".

	"R' "	"R"
Baseline	61145.45	0.89
"Steps On-Off"	68435.364	

Table 57, "StepsOnOff" morning, "R" computation

Number of patients at risk

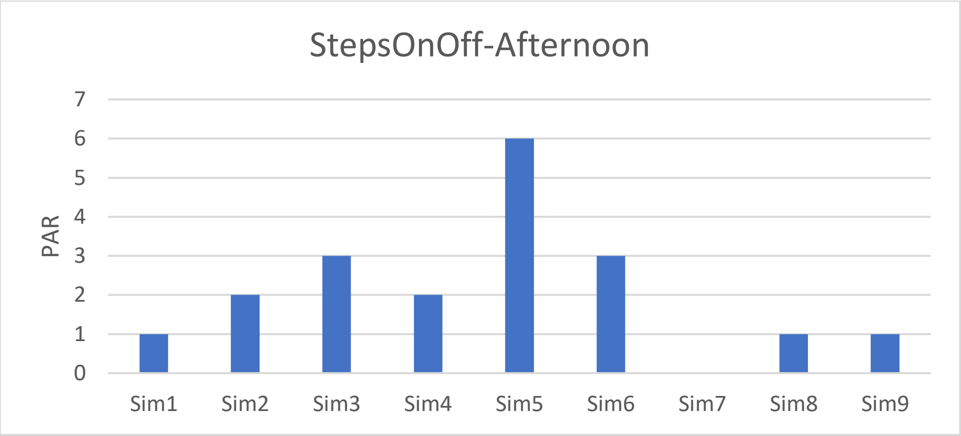


Table 58StepsOnOff afternoon, PAR

Also for what concerns the application of the "StepsOnOff" strategy in the application scenario it is evident how the number of patients at risk increases significantly with respect to the baseline and also the "As-is" strategy. The average value of patients at risk is 2.1

5.1.4 “Steps Off” scenario

The “Steps Off” scenario simulates the application of a strategy to manage maxi emergency events different from the one proposed by the PEMAF but also from the one described in the previous paragraphs. In particular it is dedicated particular attention to the deactivation transient, which is gradual as the one proposed by the “StepsOnOff” strategy, while the activation of the plan remains similar to the one proposed by the PEMAF . It is presented first the results related to the morning scenario, and then to the afternoon scenario.

Morning scenario

Green patients (baseline)	800
Yellow patients (baseline)	230
Red patients (baseline)	30
Red Patients (emergency)	18
Yellow Patients (emergency)	27
Emergency alert*	Min: 1600 – Tuesday, 10:30 ca.
PEMAF deactivation**	Min: 1790 – Tuesday, 13:30 ca.
Duration of the simulation	7200 minutes

Table 59 "StepsOff" morning scenario

*,** in this case, the values reported in the table indicate the complete resources shifting from ordinary to urgent activities (one step) and reverse, but in a gradual manner, according to the sequence of events reported in the previous chapter. It is worth to notice that in this case it is considered viable to anticipate 30 minutes, with respect to the “stepsOnOff” scenario, resources shifting from urgent to ordinary activities thanks to the prior allocation of the entire amount of staff, spaces etc. to urgent activities.

“I” indicator trend

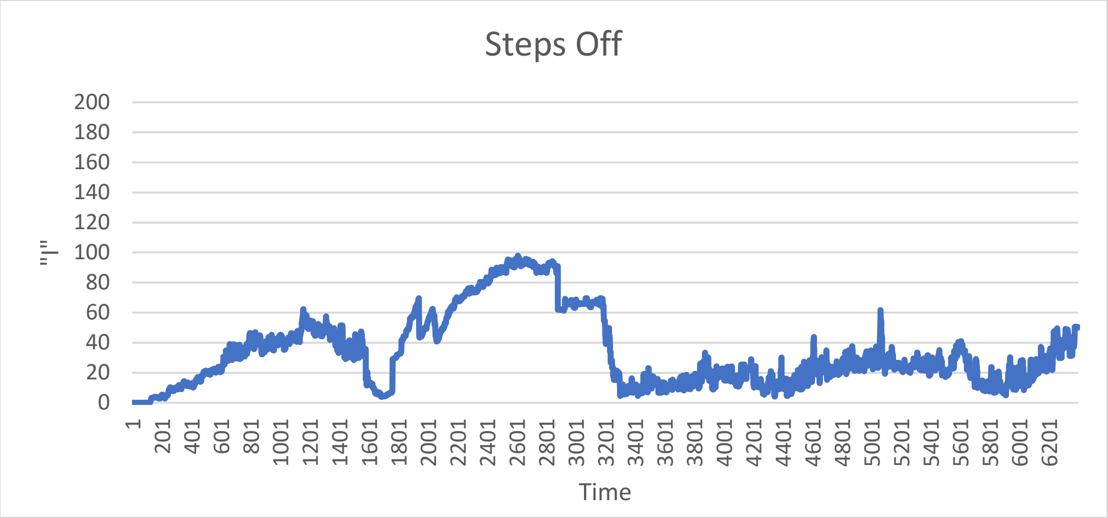


Table 60 "StepsOff" morning, "I" trend

As reported in table59, emergency begins at the 1600th minute. The worst performance of the system occurs at the 2614th minute from the beginning of the simulation (3:30 a.m. Wednesday) with a value of I = 97.34. The system returns to normal operations at the minute number 3230 (14:00 ca, Wednesday). Given these values it is possible to compute “R’” and “R”.

“R’ “ and “R” computation

	“R’ “	“R”
Baseline	69372.58	0.66
“Steps On-Off”	104309.7	

Table 61, "StepsOff" morning, "R" computation

The performance of the hospital system resulting from the application of this strategy permits an 11% improvement with respect to the scenario in which it is simulated the application of the “As-is” strategy.

Number of patients at risk

Analyzing the number of patients at risk applying the “StepsOff” strategy it is possible to affirm that this strategy does not present any particular difference with respect to the baseline and the “As-is” scenario. Also for what concerns this scenario, just 1 simulation presents a case of patient at risk, so the average value considered is 0.11.

Afternoon scenario

Green patients (baseline)	800
Yellow patients (baseline)	230
Red patients (baseline)	30
Red Patients (emergency)	18
Yellow Patients (emergency)	27
Emergency alert	Min: 1880 – Tuesday, 16:00 ca.
PEMAF deactivation	Min: 2240 – Tuesday, 21:00 ca.
Duration of the simulation	7200 min

Table 62, "StepsOff" afternoon scenario

“I” indicator trend

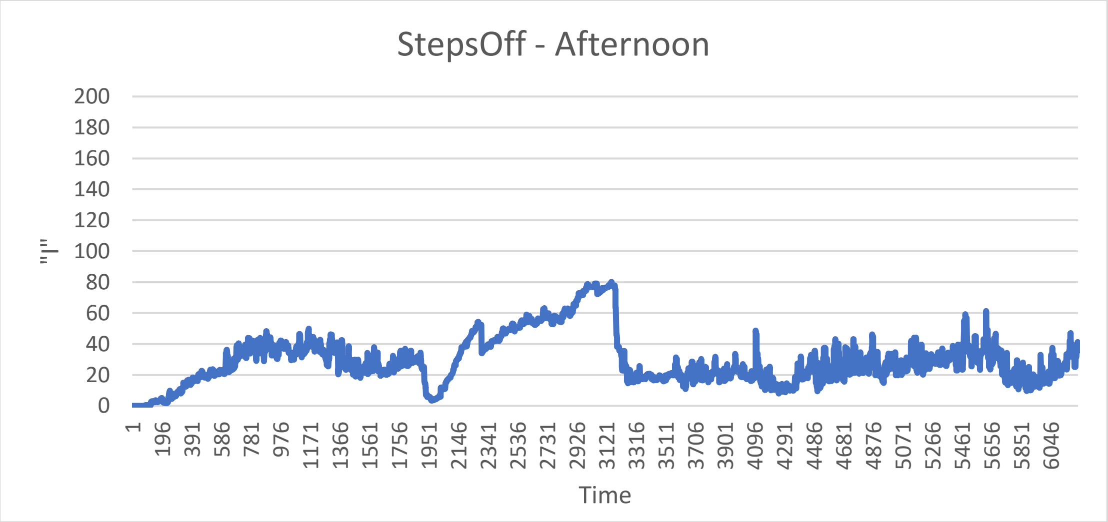


Figure 83, "StepsOff" afternoon, "I" trend

The emergency starts at the 1880th minute, and the value of “I” *passes* back through 32.109 at 3225 minutes. The peak of “I” is 80.1. given these values it is possible to compute “R’ “ and “R”

“R’ “ and “R” computation

	“R’ “	“R”
Baseline	59456.1	0.91
“Steps On-Off”	64680.09	

Figure 84, "StepsOff" afternoon, "R" computation

Number of patients at risk

This scenario presents the same results highlighted in the morning scenario applying the same strategy. It is possible to assume 0.11 patients at risk as the average value.

5.1.5 Analysis of the results

It is now presented a summary of the results by compiling the synoptic presented in Chapter4. Starting from these results it will be conducted the discussion on the simulations run focusing on the goals set for the thesis.

	Morning scenario		Afternoon scenario	
	“R”	PAR [pt/sim]	“R”	PAR
“As-Is”	0.60	0.11	0.87	0
“Steps On-Off”	0.72	1.7	0.89	2.1
“Steps Off”	0.66	0.11	0.91	0.11

Table 63, Simulation1, final synoptic

The analysis will be conducted comparing strategies applied to the same scenario (morning, or afternoon). Finally it will be proposed some considerations on the differences between the two scenarios.

Morning scenario

From the data reported in table63 it is possible to have a some indications on the strategy that better may foster hospital system resilience in case of maxi emergency. Of course these are to be interpreted mainly as insights on the topic, but, at the same time, as it will be described in the paragraph, it is possible to derive some interesting clues sustaining the decision process of the HDM in case of maxi emergency. “StepsOnOff” strategy could appear to be the best strategy to manage a maxi emergency, improving hospital system performance in terms of waiting times: “R” in “StepsOnOff” strategy results to be closer to 1 than the scenarios simulating the “As-is” strategy and the “StepsOff” strategy. This suggests that shifting resources gradually from ordinary activities to urgent and reverse should permit to reduce hospital system performance worsening in case of maxi emergency. With respect to the “As-is” strategy it also reduces the time necessary by the system to return to normal operations performances. On the other side it is significantly increased the number of patients risking not to receive the necessary care process in ED, in particular red patients. As it is possible to understand from the results reported in table63, “StepsOff” strategy seems to be able to improve the way the trade-off between ED urgent medical services delivery capability and ordinary medical services provision, evaluated in terms of waiting times and patients at risk, is solved. In facts it is not recorded an increase of patients at risk in ED, while the overall system performance, as suggested by the “R” indicator, is improved with respect to the “As-is” scenario. In the next paragraphs it will be proposed a brief investigation on the root causes of these results. It is worth to specify that those parameters that will not be commented are the ones that do not present particular differences from one scenario to the other.

First of all it is interesting to focus on the waiting time of ordinary patients in OR. Below it is reported a summary on the performance of the system with respect to this parameter – ordinary patients waiting time for OR– referring to the three scenarios (“As-is”, “StepsOnOff”, “StepsOff”).

OROrd	Morning		
	As-is	OnOff	Off
MaxWT [min]	343.40	147.00	272.00
AVG WT [min]	131.96	15.51	100.93
#Pat delayed [pat/sim]	82.00	39.00	80.00

Table 64, "OR Ordinary"

In the "As-is" scenario ordinary patients scheduled for a surgery in ORs are penalized to maximize ED medical services delivery capability. On average, during the lapse of time considered to compute "R", ordinary surgeries are delayed more than 2 hours and almost 80 surgeries are affected by this delay. In facts, two entire shifts of surgeries are delayed, affecting also the following ones as a consequence. It is important to notice that these data cannot be interpreted as predictions, since scenarios are affected by a multitude of factors not considered by the model. On the other side, it is interesting to evaluate the relative performance of the system in a certain scenario with respect to the others, since the assumptions made are the same for all the scenarios. Following this logic, from table64 it results evident the way the "StepsOnOff" strategy significantly reduces the delay to ordinary surgeries: the average waiting time is 88% reduced and the number of surgeries suffering for a delay is half than the ones in the "As-is" scenario. In any case, the maximum waiting time is significantly lower applying the "StepsOnOff" strategy. Conversely, in the "StepsOff" scenario, the number of surgeries suffering a delay is similar to the one applying the "As-is" strategy, since ordinary activities are immediately interrupted, but it is reasonable to expect a reduction in the average waiting time thanks to an early reactivation of ordinary activities.

The results related to ordinary surgeries delays compared with those, that will be now presented, focusing on the waiting times of urgent patients needing a ORs time slot (yellow and red), show the way different strategies solve differently the trade-off between elective and urgent patients sent in ORs. It is important to notice that no one of the three strategies creates constraints on the availability of ORs slots for red patients. Considering the 9 simulations run for each of the three scenarios, the cases of red patients not assigned to an OR immediately are extremely rare. On the other side, the three different strategies determine different performances of the system in terms of yellow patients waiting time before being admitted to an OR. These are reported in table65

Yellow - OR	Morning		
	As-is	OnOff	Off
MaxWT [min]	16.30	109.89	38.67
AVG WT [min]	3.67	34.11	3.59
#Pat delayed [pat/sim]	0.56	2.90	1.33

Table 65, Yellow OR

With respect to the “As-is” and the “StepsOff” scenario, the “StepsOnOff” strategy introduces a significant reduction in the availability of resources devoted to urgent patients needing a surgery. In this last scenario it is significantly increased the number of urgent patients not assigned to an OR as soon as the necessity of it emerges, and the waiting time is almost 10 times higher than the time a yellow patients awaits for a slot in OR applying the “As-is” strategy. It is important to remember the interpretation given to the “yellow – OR” waiting time recorded by Anylogic, which is described in chapter4. According to that interpretation, each case of yellow patient waiting for a surgery a significant amount of time, represents a severe reduction in the quality of care. In these terms, the “As-is” strategy seems to be the best, since all the resources are made available for urgent patients. Also in this case, the simulations considering the “StepsOff” strategy suggest intermediate results, with slightly more frequent cases of yellow patients surgeries delayed, but for a very short lapse of time. The results proposed in table65 suggest that applying the “As-is” or the “StepsOff” strategy, the average delay to yellow patients surgeries should be absolutely acceptable.

Continuing in this section dedicated to the interpretation of the simulations in the morning scenario, it is worth to comment the results related to the time for hospitalization. These are reported in table66

Ward	Morning					
	As-is		OnOff		Off	
Max WT [min]	228.67		911.67		245.33	
AVG WT [min]	15.88		27.67		18.88	
#Pat delayed [pat/sim]	5.56		44.71		6.89	
Beds freed	Surg	Non-surg	Surg	Non-surg	Surg	Non-surg
	11	37	6	20	9	31

Table 66, Hospitalization

“StepsOnOff” strategy seems to be the strategy that determines the higher risk for patients not to find an available bed at the end of the care process. In facts the number of patients for which it occurs this condition is significantly higher than that in “As-is” and “StepsOff” scenario. For what concerns these last two scenarios, it is possible to see how comparable they are, with a very low difference between them in the parameters computed. Differently, applying the “StepsOnOff” strategy, beside increasing the frequency of delayed hospitalizations, the average awaiting is increased as well. Anyway, to evaluate these results, it is important to keep into considerations, in an integrated manner, the *intensity* of wards ordinary activities interruption. In all the cases, in facts, no additional patients are admitted to wards in case of emergency, but it changes the amount of beds which are freed speeding up discharge procedures. The data related to this dimension are reported in table66

To conclude this section focused on to the morning scenario it is possible to extract some insights that could be useful to sustain HDM decision process when an emergency alarm arrives from the 118 operative center. First of all simulations seem to suggest that it is worth to apply a prudence principle when determining resources allocation strategy in the response plan activation transient. Even in a controlled space, as the one of a simulation model, in which the simulated emergency event is almost entirely known, it is not possible to forecast the magnitude of the impact on the ED, and in particular on shock rooms. It is worth to specify that it would have been possible to tailor a resources allocation strategy perfectly fitting patients arrival, which, as described, was determined a priori. In some ways, this is what has been done considering an emergency characterized by a belt shaped patients arrival rate. Anyway it has not been possible to avoid cases of patients not beginning the care process in a sufficiently rapid manner, since Shock Rooms occupation remains a completely aleatory variable in the model (following the distribution described in Annex1). This is something absolutely reasonable, since, if by one side it may be possible to make a forecast, at least on the number of incoming patients, it is not possible to foresee what kind of treatments they may need, how long they will occupy shock rooms etc. Given these considerations, the results of the simulations can be considered as a confirmation of the suitability of basing the *early* allocation of resources on a prudence principle. Trying to interpret the results, it seems reasonable to claim that the "StepsOnOff" strategy cannot be considered the best one since the allocation of resources is unbalanced on the side of ordinary patients. As presented in table65, ordinary patients waiting time is extraordinarily reduced with respect to the "As-is" strategy, and this is probably, considering also the weights assigned through eh AHP method, the reason why the "R" value results to be the highest one in the morning scenario. On the other side this puts an unacceptable pression on the ED.

Focusing on the "Off" transient, so the one to return to normal operations resources configuration, simulations seem to suggest a possible improvement, with respect to the "As-is" strategy, shifting gradually resources from the urgent to the ordinary activities. Considering indicator "R", "StepsOff" strategy permits an 11% improvement with respect to the "As-is" scenario. The possibility of reducing ordinary surgeries delays, as well as the time awaited by a certain amount of patients for hospitalization, without worsening the capability of the system to absorb the shock provoked by the emergency is coherent with the objective set for the thesis. Overall, there are clues suggesting the system to be more robust, reducing the impact of the emergency on the medical services delivery capability (evaluated in terms of waiting times), favoring a faster return to normal operations.

Afternoon scenario

The results of the simulations focusing on the afternoon scenario are more ambiguous with respect to the ones described in the previous paragraphs. In facts the application of the different strategies to the afternoon scenario has the effect of reducing the differences, in terms of hospital system response to the emergency, between them, determining similar values of "R". On the other side it is confirmed the considerations made on the "StepsOnOff" strategy: also in the afternoon scenario it increases significantly the risk of making the ED unable to receive all the incoming red patients.

This is the reason why, also for what concerns the afternoon scenario, excluding this kind of strategy seems to be the most reasonable choice. Given this premise, it is interesting to comment and compare the “As-is” strategy and the “StepsOff” strategy, since it is possible to extract some insights useful to structure the most appropriate strategy and sustain the HDM in case of emergency. Before moving to these considerations it is worth to specify that in this context it seems reasonable to keep into considerations the value of “R” as it comes out from the simulations, despite the issues highlighted in the previous section. This choice is made to conduct a coherent analysis over the results considering that, very likely, relative results are anyway robust with respect to these issues.

Focusing on the analysis of the “As-is” and the “StepsOff” scenarios, it is interesting to notice the way the improvement allowed by the application of the second strategy is thinner than the one introduced in the morning scenario. The “StepsOff” one remains the strategy generating the highest value of “R”, so potentially the best one, excluding the “StepsOnOff” strategy. However, the value of “R” in the “StepsOff” scenario is just 6% higher than the one in the “As-is” one, while in the morning scenario the improvement was almost double. A significant portion of the explanation that can be given to these results revolves around the interpretation given to the delay induced in the scheduled surgeries. As it is possible to understand from the data reported in table67, anticipating the shift of ORs from urgent to ordinary activities permits to significantly improve the quality of the service towards elective patients, since no surgeries are postponed to the following day. In facts, the average number of patients delayed in the “StepsOff” scenario is almost 20% lower, and in any case not superior than 4 hours. On the other side, in the “As-is” scenario the delay is significantly higher.

OR Ord	Afternoon	
	As-is	StepsOff
MaxWT [min]	900.00	228.38
Avg WT [min]	248.00	34.57
#Pat delayed [pat/sim]	81.10	66.00
Shifts lost	1	0

Table 67, "OR Ord"

Furthermore, it is important to notice that, as already anticipated, it is assumed that the waiting list, in case of patients postponed, keeps the same queuing logic, so FIFO, while it is reasonable to expect to have some patients to be postponed even later than the following day. Given these premises, keeping aside for a second the value of “R”, it is possible to affirm that a gradual return to ordinary activities in the afternoon scenario actually permits an improvement in the service provided to the amount of patients that would be postponed because of the maxi emergency. In facts, analyzing the development of the “ORs – Ord” waiting times, it is possible to notice the way the results are significantly conditioned by the approach selected to base this work, in particular the construction of the “I” indicator. In Figure85 and Figure86 it is possible to compare the results related to the ordinary surgeries delays applying the “As-is” strategy first, and then the “StepsOff” strategy.

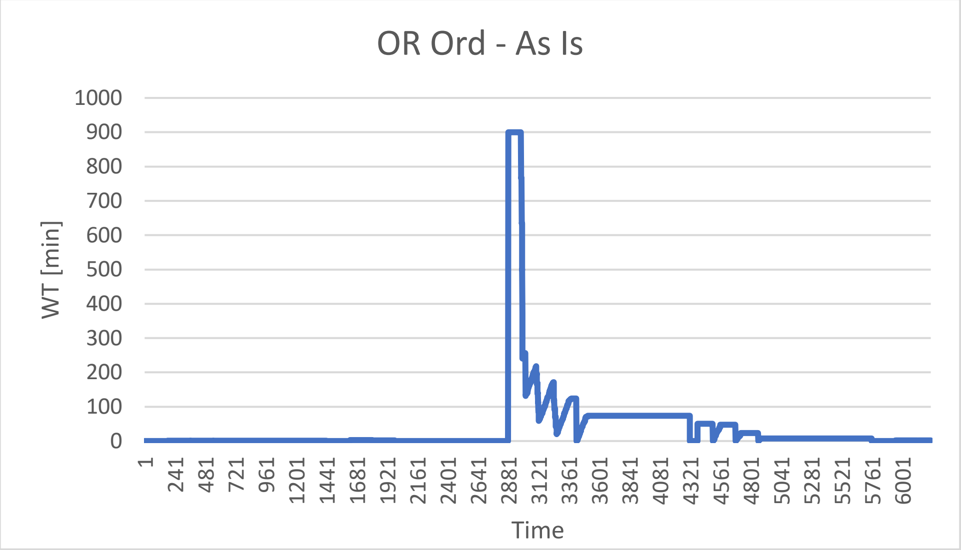


Figure 85, OR Ord waiting time trend, "As is" scenario

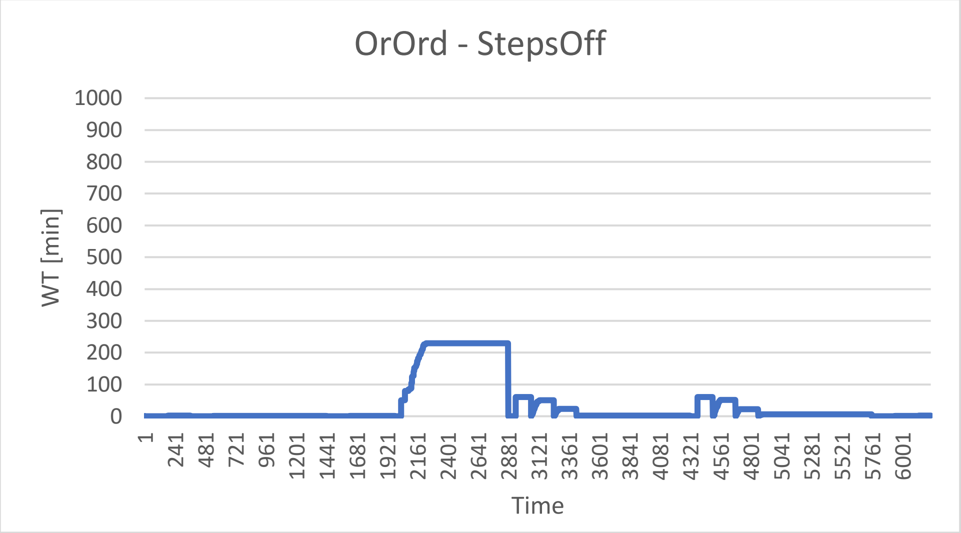


Figure 86, "OR Ord" waiting time trend, "StepsOff" scenario

As it is possible to understand, beside the issue related to the cases of many patients simultaneously leaving the queue and so recorded as one, this scenario highlights also the sensibility of the indicator to long lapses of time between two following patients leaving a queue. To clarify this issue, it is possible to see in figure86 the way the “OR – Ord” waiting time remains equal to the waiting time of the last patient leaving the queue before the night. Despite this is completely in line with the approach selected to base this work on, it is possible to challenge the assumption leading to this representation of this parameter, considering it too penalizing for the “StepsOff” scenario. For example it would be possible to simply consider the waiting time during the night equal to 0. Despite this approach could apparently solve the issue, it would be non-coherent with the underlying logic of the indicator. Another possibility could be to focus on the representation of the “As-is” scenario, considering for example a sort of penalization to be introduced into the computation of “R”, to keep into consideration the fact that surgeries are postponed to a different day. In facts it is basically different to postpone a surgery, but still within the same day, with respect to look for a OR slot in a different day. In the second case it is necessary to keep into considerations many different aspects, such as the additional hospitalization costs for the hospital, due to the nights a patient should spend in hospital beyond the expected ones, the disservice towards the patients itself, but also its family etc. and, even more important than what just mentioned, there could be cases of patients suffering for a significant worsening of the health conditions for these kind of delays. To conclude it would be reasonable not to consider ordinary surgeries delays weight as linear, but introducing a penalty in the computation of the “R” indicator to keep into consideration the shift to a different day. Quantifying the penalty to be considered could an interesting development of this work with many different applications beside the simple improvement of the analysis proposed in this thesis. That of the integration between elective and urgent patients in OR, in facts, is a crucial topic also in normal operations, not just in case of maxi emergency, and therefore it would be interesting to give an estimation of the effects of postponing surgeries.

Passing over, it is probably possible to extract some useful insights for what concerns the afternoon scenario, despite the limitations just highlighted. It seems evident, in facts, that the afternoon scenario results, in general, less critical than the morning one. In all the three cases considered the value of “R” is closer to 1 than the respective simulations in the morning scenario. This is probably attributable to the lower overall pression over the system, in terms of incoming patients, as it suggests a rapid analysis on the 6 dimensions considered to structure the "R" indicator. In Figure87 it is reported an attempt to estimate the pression over the 6 different areas of the system in the baseline scenario, comparing the lapses of time in which the PEMAF is active in the scenarios simulating a maxi emergency.

	Morning	Afternoon
Green patients arrival rate [pat/min]	0.14	0.106
Yellow patients arrival rate [pat/min]	0.14	0.106
OR – ordinary [#shifts within the interval]	2 shifts	1 shift
Yellow – OR [AVG #pat/simulation]	4	3
Red – OR [AVG #pat/simulation]	2	2
Ward [AVG #pat/simulation]	58	56

Figure 87, Analysis of the pression, afternoon scenario

Just as a brief comment to the table, for what concerns green and yellow patients, it is made reference to the data reported in chapter 3. Arrival rates are the same since *agents* are subdivided into green and yellow according a probability: 17% of the incoming patients is yellow.

Data in Figure87 may also suggest an interpretation to the relative results of "R" in the afternoon scenario for the three different strategies with respect to the morning one. Despite the effects on "R" introduced by the methodology applied to structure "I", and already largely described in the previous paragraph, it seems reasonable to affirm that the lower the pression over the hospital, the lower the effectiveness of *flexible* strategies such as the "StepsOff" or the "StepsOnOff" ones. In facts also the discarded strategy "StepsOnOff" results less performant in the afternoon scenario compared to the morning one. This can be considered as reasonable thinking to the basic logic of these strategies, so to favor the integration of ordinary and urgent activity in case of maxi emergency. A summary of the comparisons between "As-is" and the two other strategies in the two scenarios is reported in table68

	Morning	Afternoon
ΔR “StepsOnOff’ – “As-is”	+17%	+4%
ΔR “StepsOff’ – “As-is”	+11%	+6%

Table 68, Afternoon morning comparison, "R"

A further indication of this insight can be found in the time necessary by the system to return to normal operations in the two different scenarios. Note that this indicator does not suffer the limitations highlighted for “R” in the afternoon scenario, since it does not depend on the integral of “I”. In table69 it is summarized the time necessary by the system to return to normal operations in the different scenarios.

Time to NO	Morning	Afternoon	ΔMorning - afternoon
"As-is"	1691	1360	+24%
"StepsOnOff"	1640	1347	+22%
"StepsOff"	1630	1345	+21%

Table 69, Afternoon morning comparison, time for recovery

It seems reasonable to affirm that the same maxi emergency event triggered in the morning requires a significantly higher amount of time for the system to return to normal operations with respect to an event in the afternoon. This gives an indication on the system resilience in terms of rapidity.

To conclude and summarize some of the consideration made in this section, it is possible to affirm that the simulator seems to suggest a lower effectiveness of flexible strategies in the afternoon scenario. Anyway it is necessary to further investigate and detail the topic related to the relevance of surgeries postponement to a different day with respect to the schedule. This means that it would be necessary not to keep on considering just “surgeries” generically, but case by case the criticality of the different patients. By one side it may result particularly helpful to reactivate some ORs for scheduled surgeries, in order not to delay the most critical ones, while on the other side it may be considered not that relevant for the most standard ones. To conclude it seems possible to affirm that the afternoon scenario can be considered as less critical than the morning one.

5.2 Simulation campaign 2 – Night scenario, critical resource analysis

The second simulation campaign is focused on the night scenario, so that considering an emergency which occurs not during the working hours. Simulations characterizing this campaign are carried out during the night but the results are applicable also to analyze medical services delivery capability of the ED in the weekend. As anticipated in chapter4, the logic and the aim of this simulation campaign is different from the ones characterizing simulation campaign1. In facts, it would have poor meaning to investigate the trade-offs between ordinary and urgent activity in the scenarios considered. On the other side, given the limitations in terms of staff, it is much more interesting to try to estimate the capability of the hospital to receive and treat patients. In particular it has been conducted a set of simulations useful to analyze the "As-is" situation, so the one considering the resources as established by the PEMAF activation during the night. Subsequently the results of a series of experiments will be conducted to try to have insights on the most critical resource, so the one constraining ED medical services delivery capability the most. This is done in order to suggest the minimal increase of resources that could permit the highest gain in terms of red patients potentially acceptable and treated by the ED. In particular it is proposed a focus on red patients since they are the ones consuming the highest amount of resources.

First of all it is reported the analysis on the "As-is" scenario. The results related to these simulations are reported in table70. Three different parameters are analyzed:

- Average number of red patients at risk. Red patients at risk are evaluated according to the definition provided in the previous chapter
- Average maximum waiting time before being admitted to shock room
- Average number of patients who are treated according to a standard of care lower than expected. This parameters counts the number of cases in which patients are assigned to a team that does not present all the expected members. In particular, it may emerge the necessity of creating teams without a general surgeon, but just a specialist one, or anesthesiologists taking care of more than one patient at the same time.

Scenario	PAR [#patients]	Max WT [min]	Lower LOC [# patients]
As-is	8.2	37.7	5.4

Table 70, "As-is" night scenario analysis

The data reported in table70 refer to the entire emergency lapse of time. In figure88 it is summarized the temporal development of the emergency in the night scenario.

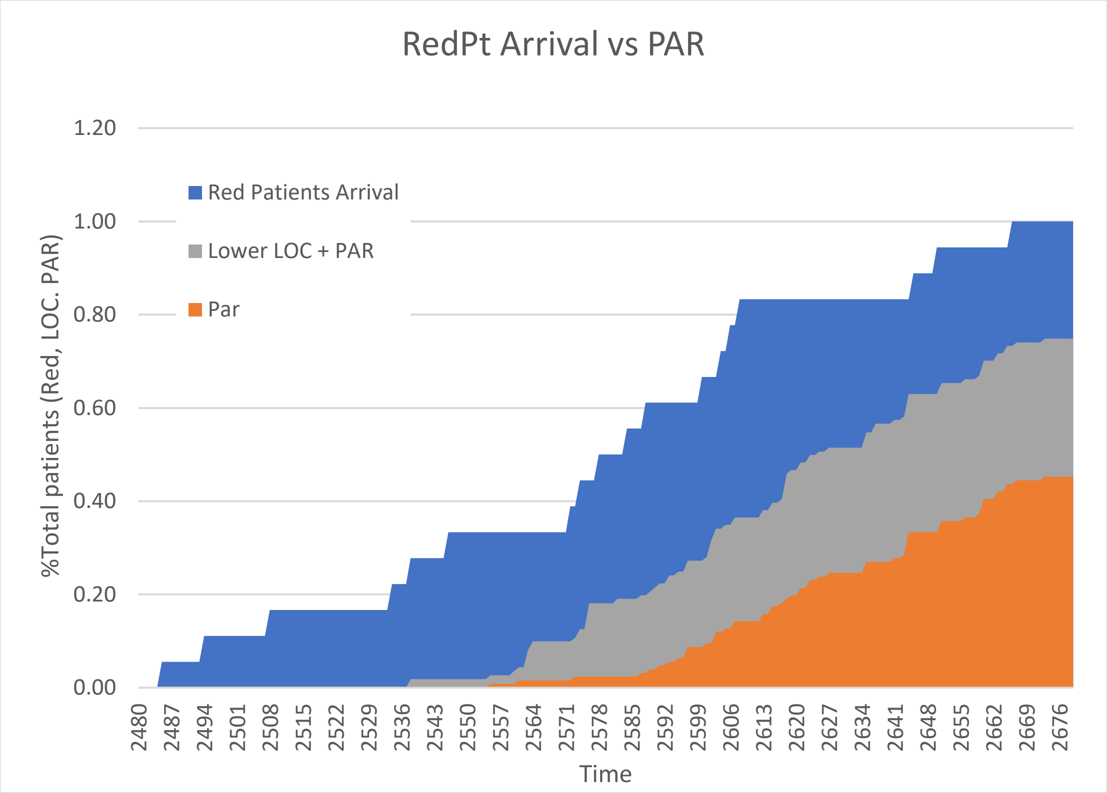


Figure 88, Emergency temporal development, "As-is" scenario

The blue area represents the cumulative arrival of red patients while the grey and the orange areas represent, respectively, the average cumulate number of patients treated at a level of care lower than the standard and the average cumulate number of patients “at risk”, according to the definition provided in chapter3. Analyzing the waiting time of each of the patients at risk, it emerges the interval of time the ED succeeds in receiving patients, although considering the possibility of assigning them not to a full team. In table71 this will be named “T”. To assume a different perspective, given the data reported in picture, “T” provides an indication on the time once passed the ED is no longer able to deliver medical services to red patients. As it is possible to see, the necessity of reducing the quality of care emerges almost in any case soon after the arrival of the 4th patient, while the exposition of patients to risk occurs, on average, later. In table71 it is reported the computation of “T”.

Average time - first patient at risk (A)	2598 min +/- 30 min
Average waiting time first patient at risk (B)	20 min
First red patient arrival (C)	2484
“T” (=A-B-C)	95 minutes +/- 30 min

Table 71, "T" computation, “As-is” scenario

From the computation reported in table71 it is possible to have an indication on the robustness of the ED, and in particular shock rooms, with respect to the impact provoked by the sudden influx of red patients. Considering the delay necessary to actually increase the available staff during the night shift, in facing an event as the one simulated, the simulator indicates the ED to be able to receive patients for, indicatively, the first hour and a half. Of course, this is specifically referring to the emergency simulated, and it strongly depends on the aleatory patients length of stay in shock and process of care, but it is still probably possible to derive the consideration just reported. Keeping into considerations the entire development of the emergency simulated, ED staff can be considered as sufficient to deal with red patients arrival for, indicatively, the first hour and a half, that corresponds to the arrival of the first 7/8 red patients. This gives an indication, in case, on the necessity to activate further additional staff and the timing for doing it.

It is now possible to move to the results of a set of experiments run to have an indication on the most critical resource and on how to improve ED medical services delivery capability to red patients. These are reported in table72 in which the value of the three parameters described above are analyzed for 4 different scenarios. For each scenario it is considered the possibility to add one or two units (last column) of the resource mentioned in the first column. This is done to highlight the way resources actually constrain the performance of the system, while some other don’t. Increasing the availability of the firsts may improve the overall performance of the system. For each scenario 10 simulations have been run, and in table72 it is reported the average value of three parameters.

Resource increased	PAR [#patients]	Max WT [min]	Lower LOC [# patients]	Quantity
ShockRoom	8.40	35.80	4.90	+1
	6.67	35.35	5.26	+2
Anesthesiologist and general Surgeon	3.90	28.10	3.00	+1
	3.63	29.10	1.09	+2
Nurse and Oss	7.20	38.30	3.20	+1
	7.20	44.90	3.70	+2
Trauma Team	3.50	33.60	3.20	+1
	2.20	30.40	3.70	+2

Table 72, additional resources analysis

Comparing the results with the ones characterizing the “As-is” scenario, it seems evident how increasing simply the number of shock rooms, so in general spaces, instruments and technology, does not improve the capability of the ED to receive red patients. In general this can be considered as a confirmation of one of the basic assumptions made in developing the PEMAF, so that the most critical resource is for sure the human one. According to the surgical activities director of OSR’s ED, this is particularly true for the exceptional flexibility of the human resource, which is able to perform many different tasks. Analyzing the results related to the last three scenarios it emerges how adding units of staff improves the performance of the ED. In particular it is taken into consideration the possibility of adding one/two entire teams or just some units of it, to try to highlight the minimum set of additional resources determining the best improvement. Results are clear enough to affirm that, very likely, adding 1 anesthesiologist and 1 general surgeon is sufficient to reduce significantly the number of patients at risk as well as the number of patients treated at a level of care lower than the standard. In facts, adding one entire team or just 1 anesthesiologist and 1 general surgeon determines similar results. Furthermore it is interesting to notice the way adding two units of the same resources do not introduce a linear improvement. This indicates the way, despite anesthesiologists and general surgeons are probably the most critical resource, it is necessary to consider them within the ED system and not in isolation. In Figure89 it is reported a summary of the simulations run adding 1 anesthesiologist and 1 general surgeon. Over these simulations it is conducted an analysis similar to the one reported in table71 to give an estimation of the ED robustness.

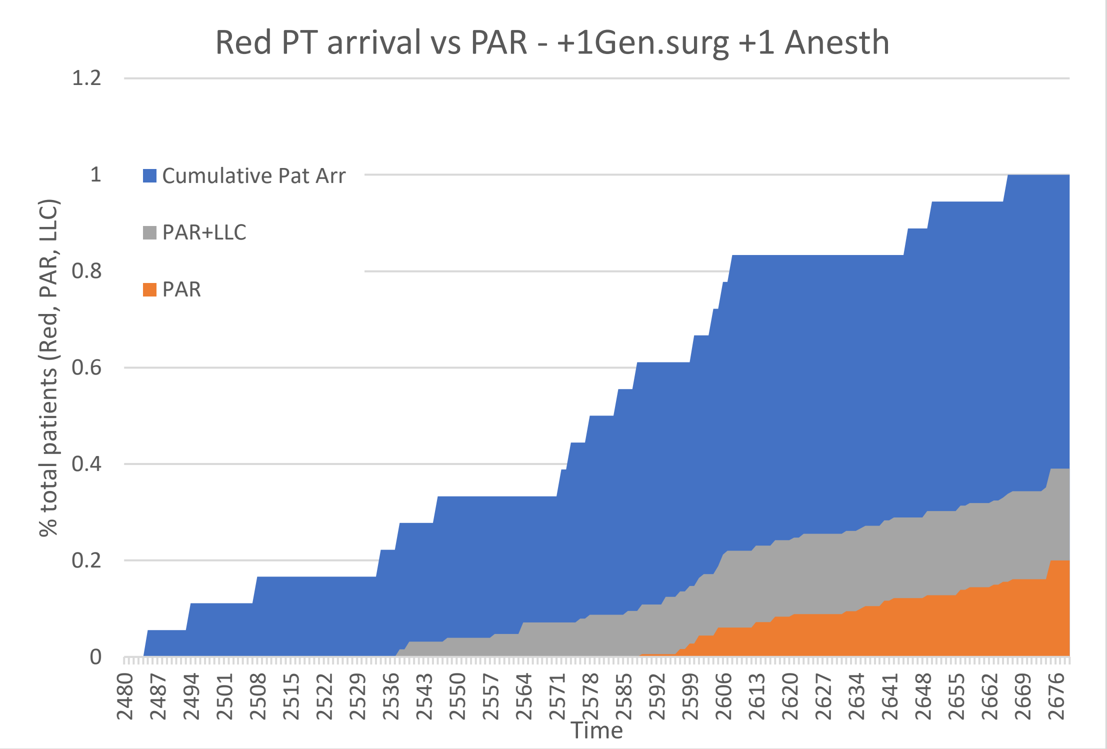


Figure 89, Emergency temporal development, scenario +1gen surg, +1 anesth

Average time - first patient at risk	2628 min +/- 32 min
Average waiting time first patient at risk	24 min
First red patient arrival	2484
“T”	120 minutes +/- 32 min

Table 73, "T" computation, +1gen surg, +1 anesth scenario

As it is possible to understand from table73, adding 1 anesthesiologist and 1 general surgeon, beyond reducing the number of patients at risk, seems to permit to extend the length of time in which the ED is able to serve incoming red patients.

It is now concluded the section related to the second simulation campaign. Two different kinds of analysis have been run, one related to the “As-is” ED capacity, and one to the improvement of it. Despite the specificity of the event simulated it has been possible to derive some interesting insights on the ED actual medical services delivery capability, going beyond the simple consideration of the available staff, and on how to improve it in the most efficient and effective way.

CHAPTER 6
CONCLUSIONS

The final chapter of the thesis is dedicated to conclusions. Passing through and summarizing the research steps and the work flow described in previous chapters, the most relevant results are presented. It is addressed the most valuable contribution to the academic knowledge and for professionals interested by the topic dealt by the thesis. It is underlined the potentials for generalization of the findings and the limitations emerged during the analysis. Lastly, some suggestions for future research are offered.

The literature review revealed current knowledge gap in a structured and systematic approach towards the development of business continuity plans and resilience capabilities in hospitals to face maxi emergencies. In particular, it was highlighted the necessity to deepen the comprehension of the trade-offs emerging between the demand arising from an emergency itself and the provision of medical services to elective patients. Despite the topic related to the identification of critical resources and to the optimal allocation of them is present in literature, it emerged a gap in the approaches to evaluate them. As highlighted by the section focusing on the most frequent KPIs developed and assessed, in facts, it seems reasonable to affirm that a systemic approach is still lacking. If by one side the analysis on the capacity of the ED to deal with maxi emergency is a widespread topic, it is very rare to find contributions on the interaction between ED and the ordinary activities of the hospital. It was interesting to notice the way some of the topics resulting to be lacking in literature still find difficulties to be dealt also by practitioners, determining areas of improvement interesting also for professionals. As a matter of facts, analyzing the practices and the procedures developed by OSR to deal with maxi emergency, some emerging food for thoughts and potential improvements resulted to be in line with the gaps identified in literature. The research main focus was thus set on assessing, through a multi-method simulation approach, the suitability of resilient resources allocation strategies in case of maxi emergency at an hospital-system level. In addition, thanks to the interaction with OSR ED surgical activities director, dr. Faccincani, it turned out to be particularly critical the identification of hospital medical services delivery capability in the scenarios characterized by a low level of available staff. In particular, it was set the objective to develop a dynamic analysis, able to address the entire temporal development of an emergency, triggered during the night period, rather than a static one where hospital capacity is assessed considering the available staff only.

Given the abovementioned premises, two different simulation campaigns were run to analyze specific scenarios: an emergency occurring during the day and during the night shifts respectively. A specific set of KPIs was developed to evaluate hospital system performances in the different scenarios, according to the objectives set for the thesis. Particular attention was dedicated to the integration in a unique indicator of different parameters useful to evaluate the performance of the hospital in a systemic perspective (named "I" index). To conclude, it was defined a synthetic parameter useful to evaluate the resilience of the hospital system (named "R" index) to compare the performance of the system in case of a maxi emergency with the hospital baseline performance (under normal operating conditions).

6.1 Summary of main results

Summarizing the results, the simulations run for assessing the hospital system performances in facing a maxi emergency through the PEMAF in OSR highlighted potential room for improvement. In particular, starting from the analysis of the activation and deactivation transients as they are planned to be managed, two different strategies were studied. Both are developed to *sustain* the provision of medical services to ordinary patients without reducing the capability of the ED to serve urgent patients. The results suggest that in the transient from normal operations to the emergency configuration of resources, the most appropriate strategy is that allowing to allocate immediately all the available resources in ED, to deal with the sudden influx of patients.

In this case it has been found confirmation on the validity of the strategy currently applied in OSR. In facts, patients’ needs and all the other factors determining the occupation of resources are entirely unforeseeable and it is not possible to think to tailor an allocation of resources strategy trying to fit the rate of arrival of patients.

The second finding regards the transient from the emergency configuration of resources to normal operations. In this case the simulator suggested a potential improvement with respect to the PEMAF produced by OSR. In facts there are evidences highlighting the suitability of a gradual resources shifting from ED to ordinary activities. The main advantages are realized in a reduction of the disservice to elective patients and of unwanted effects on the system. In facts it is reasonable to believe that this kind of strategy should not introduce interferences between the provision of medical services to the demand arising from the emergency and the ordinary one. Particularly relevant is the possibility to reallocate ORs to the most urgent scheduled surgeries. Last, the analysis carried out on the first simulation campaign consisted in comparing the two different scenarios, one in which the emergency is triggered during the morning and one during the afternoon. The results suggest a higher improvement in hospital system performance due to resilient strategies when the pression over the system is higher. Referring to the two scenarios, it seems reasonable to claim that the afternoon scenario is less critical than the morning one.

For what concerns the second simulation campaign it is worth to briefly highlight two considerations emerged along the discussion of the results. First of all, from the analysis related to the resources available in the night scenario and on the most effective way to improve them, it turned out clearly the relevance of the human resource. In facts, although in a simplified manner, it’s the staff available in ED determining the medical services delivery capability, and not the availability of instruments, machineries and spaces. Second, what permits to enlarge significantly the lapse of time in which patients are not exposed to risk is the capability of medical staff to compensate and fulfills gaps and shortages. In the simulator, this is represented by possibility of specialist surgeons to take the place of a general surgeon and anesthesiologists to take care of more than one patient per time. This flexibility is for sure a fundamental characteristic of the ED staff in case of maxi emergency.

6.2 Implications and improvement on scientific state-of-the-art knowledge and usefulness for hospital administrators.

The present work thesis involves implications and elements of novelty both regarding the state of the art of the scientific knowledge and the activity of hospital managers to deal with maxi emergency scenarios in a more efficient and effective way. Beside the findings described in the previous paragraphs, it is worth to highlight the relevance of the methodology applied and the tool selected to sustain the analysis. In facts, the process developed for this work thesis is an evidence of the suitability of *events based* simulation approach integrated with a *system dynamics* one to obtain a quantitative assessment of the impact of an emergency on the overall hospital system processes. With respect to the most diffused application of simulation tools and software to deal with this topic, which is, as highlighted in Chapter2, the analysis of interconnectedness and cascading effects over the system of nodes and supplies failures, the application of a *discrete events* approach allows to focus on the care processes more in detail. As highlighted in Chapter3, this requires a significant effort on the conceptualization of processes, activities and available resources in normal operations, but most of all on the way they are reconfigured in case of maxi emergency. In this context it has been recognized as particularly relevant the possibility to sustain *discrete events* simulation modelling technique with a *system dynamics* one, in order to integrate different areas of the hospital. The methodology presented in this work study overcomes some limitations of the existing approaches towards the application of quantitative methods to evaluate the response of hospitals facing maxi emergency. In particular it suggests the possibility to maintain a systemic approach towards the overall hospital system. This is obtained both through a proper conceptualization and translation into the software of the care processes, but also through a rational definition of KPIs able to integrate different dimensions of the hospital performance in serving patients in case of maxi emergency (Indexes named “I”, “R”, “PAR”). Potential applications of this approach are multiple, as it will be described in the next paragraph. In particular, for this work thesis, it was proposed the application of the methodology described towards the evaluation of different resources allocation strategies highlighting the way resilience enabling strategies permit to improve the performance of the hospital system. This represents a contribution to fulfill the gap highlighted in Chapter2, in the development of resilience capabilities in hospital, in particular to support the definition of business continuity plans. To summarize the main findings highlighted in the previous paragraphs, it is possible to affirm that the simulator confirmed the suitability and generalizability of the current OSR approach towards the emergency reconfiguration of resources, based on the intention to guarantee immediately the maximum medical services delivery capability in ED. On the other side it suggested the rationality of introducing into the PEMAF procedures to return to normal operations in a gradual manner, reallocating resources to ordinary activities progressively in time. Both indications permit to reduce the gap with respect to the performance in normal operations, fostering the resilience of the system as suggested by the values of the indicator named “R”. According to dr. Faccincani , OSR ED Surgical activities director, these indications are particularly relevant for the entire network of actors entitled to manage a maxi emergency scenario. In facts it has been clearly pointed out the relevance of a proper management of the emergency in the deactivation phase not just by the hospital managers but most of all by the 118 operative center. As a matter of facts, it’s the 118 operative center which first is able to establish the magnitude of the emergency event. A timely communication of the real medical services demand would permit hospitals managers to gradually reallocate resources to ordinary activities reducing this way the disservice to elective patients, as stated by the first simulation campaign. An improvement of the work proposed for this thesis could be the one of identifying a numerical and objective threshold below which hospitals, such as the OSR, can have the indication of starting reallocating resources gradually to ordinary activities. In this way, as it will be highlighted in the next paragraph, the tool developed could actually assume the role of an objective tool for decision support.

It is important to notice that the findings highlighted in the previous paragraphs can be viewed from two different perspectives, both helpful to fuel a more conscious resilient approach towards the resource management in hospitals in case of maxi emergency. First of all, understanding and experimenting ways to reconfigure existing assets in order to determine the most appropriate one to face disruptive events is a resilience enabling practice. Tools like the simulation permit to establish proactively relevant capabilities that can be used both in proactive and reactive mode. In this case it suggested relevant insights on the best way to manage transients in order to make the system more robust (reduction of the number of patients at risk and of the overall hospital system worsening) and faster to recover. Introducing the results derived from the simulator within a formal plan to face disruptive events makes them a predetermined procedure and favors the awareness over them of the actors involved. In facts, the second interpretation that could be given to the findings mentioned above, is the creation of a set of explicit knowledges that can sustain the HDM in the decision processes in case of emergency. As anticipated along the simulation system design, in maxi emergency situations it is necessary to establish a clear line of command. In OSR PEMAF, the chief surgeon on duty is assigned the role of HDM and therefore to manage all the available resources. Tools like the simulations and findings such as the ones derived from the simulator put in place for this thesis may be helpful to clarify the effects that a decision taken by the HDM can have over the system.

Similarly, simulation campaign2 represents a contribution towards the improvement of ED medical services delivery capability robustness. Also in this case it is particularly important to highlight the relevance of the topic not just from an academic point of view but also for professionals and practitioners. According to dr. Faccincani, a tool like the one developed for this work thesis, beside the application mentioned above, may have also at a strategic level. First of all, the application of the simulator to normal operating conditions may be extremely helpful in sustaining processes, like the one currently carried out in OSR in which the ED is planned to be moved in a different area, of structural changes or personnel dimensioning. A tool able to highlight the effects on the ED performance of the different alternative choices may permit to size properly the investment. Second, in conditions of health economics extremely bounded, in which resources are always saturated, the management of the peak of demand is critical. An objective tool able to sustain the decision process of resources allocation keeping a systemic and integrated approach, like the one proposed for this work thesis, is helpful in achieving a more efficient and effective system not just in day by day routine but also in managing the risks an hospital system faces.

6.3 Limitations and avenues for further developments

At the end of the thesis some questions and several ideas concerning the obtained results arise, starting from the limitations and the assumptions made in this work which can be the starting point for further improvement. Given the degree of novelty of the approach assumed towards the problem, it is in facts fair to highlight issues still to be solved but also the strong potential for development, opening the way to deeper and, to the extent of the writer, promising analysis.

First of all, it is possible to see a weakness of the model in the representation of the medical area of the ED. As anticipated along the simulation system design process, in facts, a lower level of detail has been achieved in describing this area with respect to the one achieved in representing the flow of red patients; for the aim of this work thesis it has been considered non-necessary to deepen and enrich the model in this sense. Anyway it represents an area of improvement since it presents dynamics determining resources trade-offs between ED patients which are not completely caught by the present work, focused, on the other side, on the trade-offs between ordinary and ED patients. In addition, it could open a further stream of analysis, which is the one related to the best practices to be put in place to favor the process of ED immediate emptying in case of emergency.

One of the most interesting aspects of the simulator produced is the possibility to consider it as a platform, as the core of a wider model potentially developable by expanding the modules considered. In the present work the ordinary activity of the hospital is represented mainly by ORs and wards, but it could be, of course, included many other areas of the hospital, or disentangled the ones considered in sub-areas according to the different specialties. This possibility is particularly relevant considering the enormous potentialities of the software selected, Anylogic. Offering a multi-method simulation modelling approach allows to work at different levels of analysis (both tactical and strategic) and to make the model scalable. In particular, investigating more in detail the potentiality of the software in integrating the hospital systemic level with the operative level of the different departments by integrating *system dynamics* and *discrete events* simulation modelling is for sure one of the most promising streams of analysis. In addition, even considering the same structure of the simulator presented in this model, the analysis could be expanded by modifying the event simulated, both in terms of intensity and nature. Simulating different scenarios according to the magnitude of the sudden influx of patients generated by the emergency would permit to test the sensitivity of the robustness of the system towards different conditions. On the other side considering also events of a different nature, in particular internal emergencies reducing internally the medical services delivery capability is surely one of the most unexplored domains in literature.

Annex1 - Data processing

In this annex the considerations and computations carried out to define some of the most important parameters of the model are proposed.

Distribution1:

Distribution1 is intended to represent green and yellow patients frequency of arrival along the different days of the week.

Through *database1* it has been possible to identify patterns in patients arrival along the day and along the week. This is necessary in order to make the simulation as realistic as possible since ordinary patients determine the saturation of resources in normal conditions. As it possible to see from Figure91 and Figure92, patients arrival is highly variable along the day but apparently constant comparing the overall number of patients admitted the different days of the week.

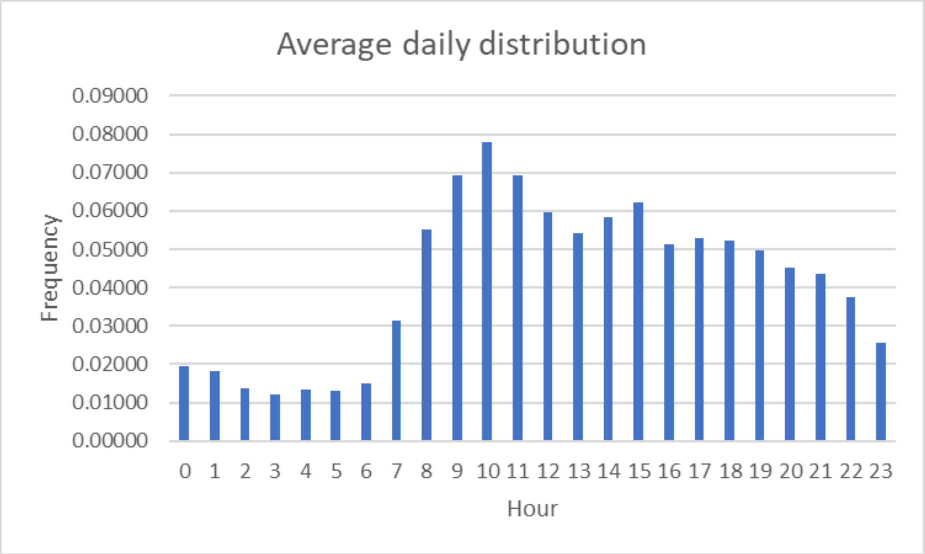


Figure 90 Average patients arrival frequency along the day

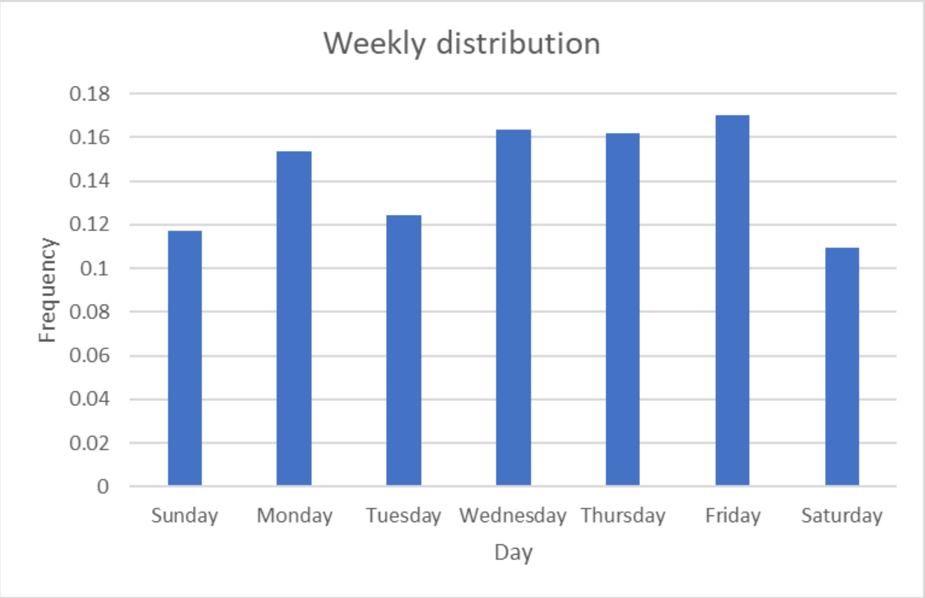


Figure 91 Patients arrival frequency along the week

Actually, despite the average volume does not differ significantly from one day to the other, patients arrival distribution along the day changes from one day to another: as it is possible to see from Figure93 there are peaks and valleys that necessarily makes the volume of work in ED very different, and that do not occur in the same way every day. To make some examples, if by one side it is reasonable to expect a peak of demand around 10:00 a.m every day, night shifts are very different comparing Saturday night with Thursday night.

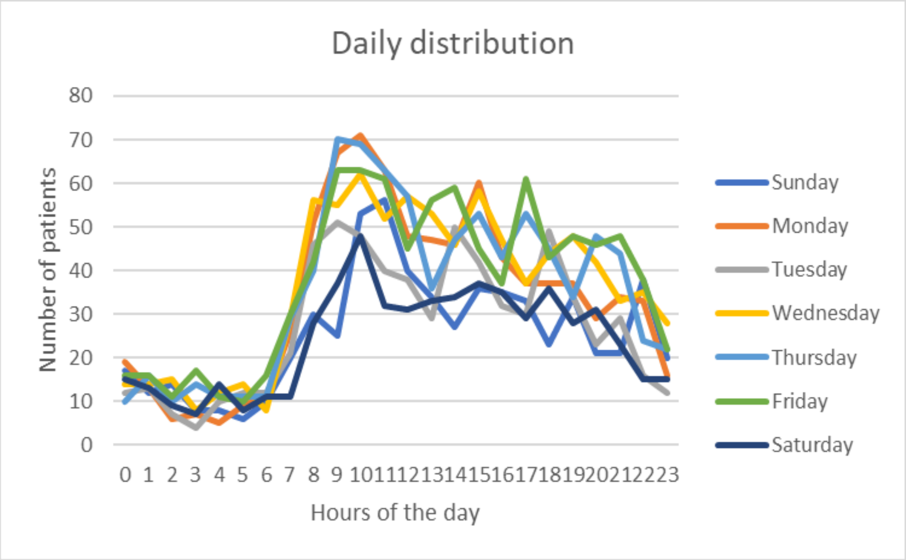


Figure 92 Patients arrival along the days

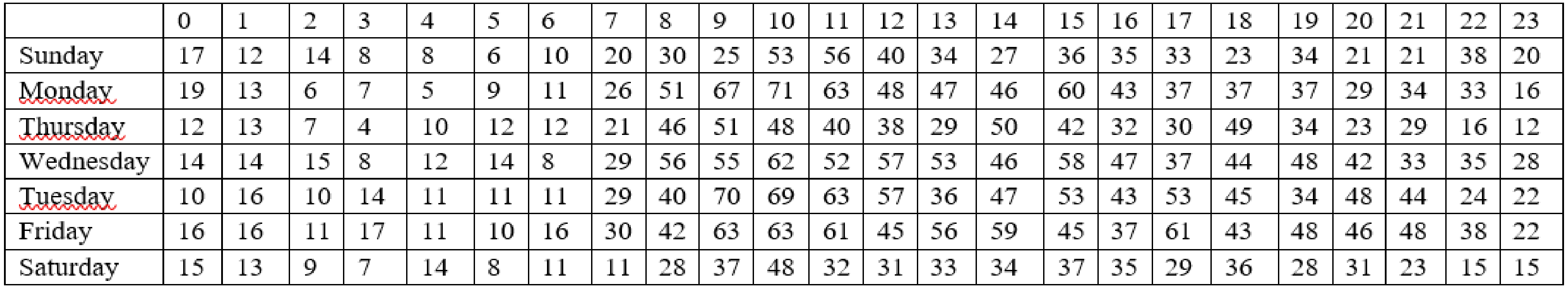
To catch this kind of variability related to two different dimensions (hour of the day and day of the week) it has been defined a discrete empirical distribution based on the number of patients recorder in ED. This kind of information has been turned into an arrival rate in terms of [patients/minute]. Data and results are available in tables 75,76,77

Distribution2

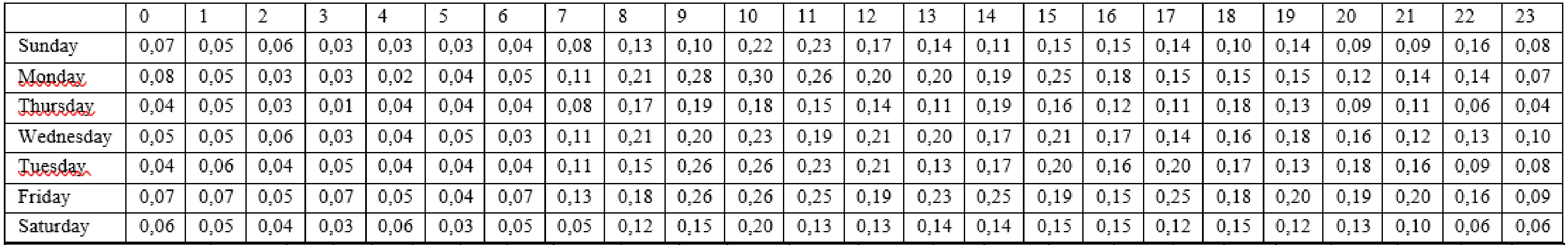
Regarding red patients, it has been established a schedule of arrivals based on the trends extracted from database1. In particular it has been necessary to build that in such a way to avoid two red patients simultaneously in ED during the week. On Friday and Saturday night the intensity of arrivals has been increased with 2 red patients arriving at the same time. In table4 it is reported the schedule of arrivals as it will be introduced in Anylogic

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1:00	1		1		1		1
2:00		1		1		1	
4:00	1		1		1		
6:00		1		1			1
9:00	1		1		1		
12:00		1		1		1	
14:00	1		1		1		1
17:00		1		1		1	
19:00	1		1		1		1
22:00		1		1	2	2	

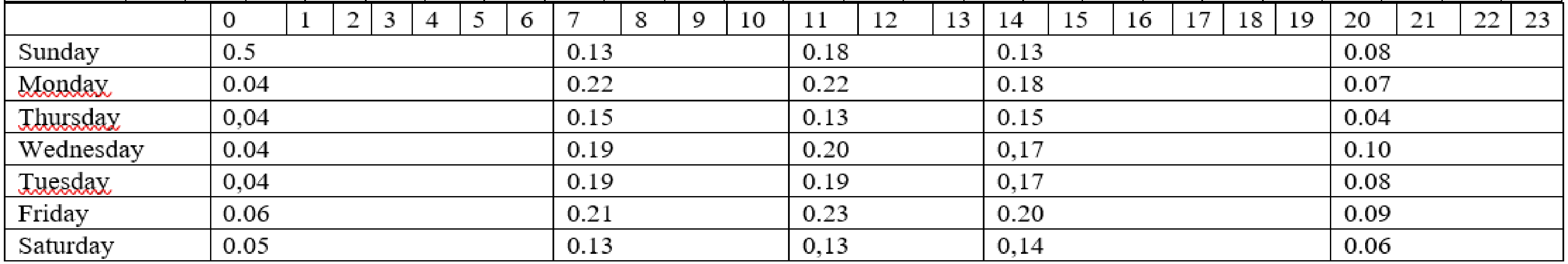
Table4 Red patients weekly "schedule"



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	17	12	14	8	8	6	10	20	30	25	53	56	40	34	27	36	35	33	23	34	21	21	38	20
Monday	19	13	6	7	5	9	11	26	51	67	71	63	48	47	46	60	43	37	37	37	29	34	33	16
Thursday	12	13	7	4	10	12	12	21	46	51	48	40	38	29	50	42	32	30	49	34	23	29	16	12
Wednesday	14	14	15	8	12	14	8	29	56	55	62	52	57	53	46	58	47	37	44	48	42	33	35	28
Tuesday	10	16	10	14	11	11	11	29	40	70	69	63	57	36	47	53	43	53	45	34	48	44	24	22
Friday	16	16	11	17	11	10	16	30	42	63	63	61	45	56	59	45	37	61	43	48	46	48	38	22
Saturday	15	13	9	7	14	8	11	11	28	37	48	32	31	33	34	37	35	29	36	28	31	23	15	15



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	0,07	0,05	0,06	0,03	0,03	0,03	0,04	0,08	0,13	0,10	0,22	0,23	0,17	0,14	0,11	0,15	0,15	0,14	0,10	0,14	0,09	0,09	0,16	0,08
Monday	0,08	0,05	0,03	0,03	0,02	0,04	0,05	0,11	0,21	0,28	0,30	0,26	0,20	0,20	0,19	0,25	0,18	0,15	0,15	0,15	0,12	0,14	0,14	0,07
Thursday	0,04	0,05	0,03	0,01	0,04	0,04	0,04	0,08	0,17	0,19	0,18	0,15	0,14	0,11	0,19	0,16	0,12	0,11	0,18	0,13	0,09	0,11	0,06	0,04
Wednesday	0,05	0,05	0,06	0,03	0,04	0,05	0,03	0,11	0,21	0,20	0,23	0,19	0,21	0,20	0,17	0,21	0,17	0,14	0,16	0,18	0,16	0,12	0,13	0,10
Tuesday	0,04	0,06	0,04	0,05	0,04	0,04	0,04	0,11	0,15	0,26	0,26	0,23	0,21	0,13	0,17	0,20	0,16	0,20	0,17	0,13	0,18	0,16	0,09	0,08
Friday	0,07	0,07	0,05	0,07	0,05	0,04	0,07	0,13	0,18	0,26	0,26	0,25	0,19	0,23	0,25	0,19	0,15	0,25	0,18	0,20	0,19	0,20	0,16	0,09
Saturday	0,06	0,05	0,04	0,03	0,06	0,03	0,05	0,05	0,12	0,15	0,20	0,13	0,13	0,14	0,14	0,15	0,15	0,12	0,15	0,12	0,13	0,10	0,06	0,06



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	0.5							0.13				0.18			0.13						0.08			
Monday	0.04							0.22				0.22			0.18						0.07			
Thursday	0,04							0.15				0.13			0.15						0.04			
Wednesday	0.04							0.19				0.20			0,17						0.10			
Tuesday	0,04							0.19				0.19			0,17						0.08			
Friday	0.06							0.21				0.23			0.20						0.09			
Saturday	0.05							0.13				0,13			0,14						0.06			

Table 74,76,77 Patients arrival rate along the week

Yellow patients length of stay in ED

For what concerns yellow patients' length of stay in medical area, it is necessary to remind this area lower level of detail compared with the one achieved for the description of red patients pathway. In particular, as a result of the synthetic schematization described in previous paragraphs, it was decided to focus not on the durations of the different activities carried out on yellow patient, but on its overall length of stay in ED medical area, from the taken over to discharge. This is of course a limit in the descriptive power of the model, but this is considered negligible. Furthermore database1 allows to develop a significative analysis, since it is available for each yellow patient the overall length of stay in ED, considering the sum of the times during which the patients is visited and in which awaits for responses.

Lengths of stay in ED are very heterogeneous. The range is between the minimum (1h) recorded duration and the maximum one (23h) is very wide, with values comprised between 1h and 5h as the most frequent. The maximum value is set equal to 23h to consider the indication provided by the SDA of OSR ED. In this way it is excluded a portion of those patients moving to ORs and recorded as in ED. To represent these kind of data it was selected a beta distribution with lower shape value equal to 1.2 and higher shape value equal to 3.4.

It is reported now the test of fitting conduced to evaluate the choice made on the distribution to represent yellow patients' length of stay. It has been conducted a chi-squared test. The results of the test have been exploited to determine the most suitable distribution. In facts, the resulting distribution is just the last of a series of tests made to identify the most appropriate distribution. To run the test the expected values of the distribution have been generated in excel, and then compared with the real ones according to the values of the Chi-squared variable.

$$X^2 = \frac{\sum_{i=1}^{23}(Observed - HP)^2}{HP} = 15{,}24$$

The distribution presents 23 independent categories (22 degree of freedom) and chi-squared value equal to 15,24 considering a beta(1.2;3.4;0;23) theoretical distribution. The result of the test suggests that the deviation is not significant with an 85% degree of confidence

Annex2

In the following pages it is reported the application of the AHP model

vs	WT yellow ED	WT green ED	WT red Em OR	WT Ord OR	WT ward
WT yellow ED	1.00	7.00	0.14	4.00	7.00
WT green ED	0.14	1.00	0.11	0.14	1.00
WT red Em OR	7.00	9.00	1.00	7.00	9.00
WT Red Ord OR	0.25	7.00	0.14	1.00	7.00
WT ward	0.14	1.00	0.11	0.14	1.00

Table 75 Pairwise comparison matrix

ED	0.6
OR	0.4

Table 76 yellow patients in ED/OR weights

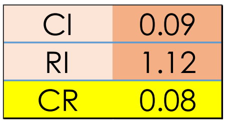
Below it is reported the analysis to assess the consistency of the decision maker. It consists in the normalization of the matrix produced by the expert and in the computation of the consistency ratio. A consistency ratio below 0.1 suggests a good degree of consistency.

	Normalized matrix				
vs	**A**	**B**	**C**	**D**	**E**
WT yellow ED	0.12	0.28	0.09	0.33	0.28
WT green ED	0.02	0.04	0.07	0.01	0.04
WT red Em OR	0.82	0.36	0.66	0.57	0.36
WT Red Ord OR	0.03	0.28	0.09	0.08	0.28
WT ward	0.02	0.04	0.07	0.01	0.04

Table 77 Normalized matrix

Ave	C.Measure
0.219	5.465
0.036	5.754
0.555	5.194
0.153	5.150
0.036	5.156

Table 78 first level vector of weights



CI	0.09
RI	1.12
CR	0.08

Table 79 Computation of the consistency ratio

In yellow it is highlighted the resulting consistency ratio, while in green it is reported the vector of weights resulting from the pairwise comparison of the first level criteria with respect to the global objective.

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Ringrazio la vane, perché solo *dentro le sue misteriose equazioni ho trovato ogni forma di logica,*

Ringrazio i miei genitori, mia sorella e i nonni, perché la casa costruita sulla roccia non cade, anche se straripano i fiumi e soffiano i venti,

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Bianche sponde, ed al di là di queste,

Un verde paesaggio

Sotto una lesta aurora

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