Combining methods for simulating and improving the Emergency Rescue Chain

Marta Barbas[1,2, *]

Thesis to obtain the Master of Science Degree in Biomedical Engineering – October 2017

Supervisors: Prof. Stefan Nickel [2] and Prof. Dr Prof. Mónica Oliveira[1]

[1]Instituto Superior Técnico, University of Lisbon, Portugal; [2]Karlsruhe Institute of Technology; *Email: marta.barbas@tecnico.ulisboa.pt

ABSTRACT: Emergency Rescue Chain (ERC) corresponds to the process activated by a sudden illness and that culminates in the arrival to the health care facility, being centred on occurrences outside hospital emergency systems. Out of hospital emergency medical systems hold three main actions: 112 calling, dispatching and ambulatory service. This thesis develops a methodology – based on computer simulation techniques – to explore and evaluate the ERC, researching whether computational simulation methods are worth being applied to monitor and improve the chain underlying processes. The methodology is developed and is specifically used to explore differences across ERCs from two European nations, Portugal and Germany. Portuguese and German ERC will be detailed, as well as the main challenges faced by them. Furthermore, the application of the methodology focuses on stroke ERC, a highly time-dependent rescue disturbance. The proposed approach corresponds to a set of ordered steps and combines discrete with agent based simulation. The results depict how the use of the methodology is flexible and useful for evaluation and analyse of distinct ERC's. Nevertheless, the obtained results are merely illustrations on how the methodology can be used in practice and generate useful insights. Overall, the main contribution of this thesis is the proposed methodology as well as the verification that computational simulation models can be used to evaluate EMS topics, such as the ERC.

KEYWORDS: Emergency Medical Service (EMS); Emergency Rescue Chain (ERC); Portugal; Germany; Simulation; Stroke;

1. INTRODUCTION

Emergency Medical Service (EMS) is a healthcare service that plays a key role in providing the correct facilities and equipment for a coordinated and effective delivery of health and safety services to victims of sudden illness/injury, including pre-hospital, in-hospital triage, resuscitation, initial assessment, management of unit, differentiated urgent and emergency cases until discharge or transfer to another physician/healthcare facility [1-3]

Rescue services are anchored in the emergency services. Actually, it is the task of the rescue service to ensure that people have access to the appropriate services of emergency rescue, as well as transportations to the most suitable healthcare facilities [4].

Amongst the available literature on EMS systems, several challenges can be highlighted. The demographic evolution (ageing society) will lead to the increase in cardiovascular, chronic diseases (ex. Diabetes) and morbidity, with a serious rise in health expenditure, namely in the rescue services. Consequently, it is imperative a more rational use of the available resources [4].

Thus, the goal of this study is to explore and evaluate the emergency rescue chain and analyse whether computational simulation methods are worth being applied to monitor and improve the chain underlying processes. Simulation models coupled with a set of common key performance indicators were built, allowing to mimic EMS operations in an accurate way. Two distinct European nations are being compared: Portugal and Germany. Their health care systems and, more precisely, their Emergency Medical Services are being studied.

This study contributes to the current literature in EMS because few studies have taken a broad view to analyse and evaluate rescue services, more precisely of the emergency rescue chain. Several studies have already covered and evaluated separately the different processes within the pre-hospital stage (ex. choosing station locations, allocating ambulance to stations, etc), but this dissertation tries to go further towards a complete coverage, taking into account different process and resources used by the rescue chain.

2. BACKGROUND

Initially, as a background to give a context to the problem at hand, a perspective of the perspective of the current state of the healthcare systems in Europe is given. Therefore, some of the challenges faced by the sector are addressed. Two European countries are described with a higher detail: Portugal and Germany. The current situation of their Health Care System (HCS) is outlined. Afterwards, Emergency Medical Services are presented. Moreover, a disease that shows a high impact on population morbidity is introduced: stroke.

The progressive ageing verified all across European countries, growing number of people living with chronic conditions, limited resources and rising costs addresses new challenges to health and welfare systems. [5-7].

Drawing comparisons between countries "offer the possibility of exploring new and different options", [7] and opens the possibility for learning. The interest for health systems comparison has risen from two different sides: "global social developments" and information technology, making easier the task of collect and process data [7].

Therefore, a comparison between two distinct European nations takes place in the following sections: Portugal and Germany [8]. Germany's has the oldest health care system is in Europe and according to OECD data is the EU country with the highest health spending per percentage of its GDP (11.9%). Contrasting with Germany, Portugal only spends 8.9% of its GDP in health [9].

German health care system, as well as its emergency medical care, enjoy high national and international prestige, being used as a template for several European nations, namely Portugal. The progressing growing of technological infrastructures and use of highly specialized care associated with the demographic and economic evolution faced by Germany, make this country interesting case for study [10]. Understanding their health systems is important to comprehend the challenges that these countries are facing and evaluating possible solutions [9].

2.1 Emergency Medical Systems

All public health care systems integrate a sector called Emergency Medical Service (EMS) [11].

Pre-hospital emergency medical services are the main topic in this study. Usually, they are referred as out of hospital emergency services and cover three main actions: 112 calls, dispatching and ambulatory service [11].

At the present time, emergency medical services are facing several challenges. Considering the focus of this dissertation, it is important to understand that prehospital EMS cannot be isolated. An interconnectivity between dispatch centres and coordination between the emergency rescue service team and emergency medical service team is imperative. Furthermore, investments in equipment and training of professionals.

In the following paragraphs, Portuguese and German EMS are summarized.

In Portugal the success of the emergency network is due to the articulation, integration and guarantee of continuous care, that is guaranteed by having medical professionals with different levels of differentiation and training in this field (physicians, nurses, emergency technicians [12].

It is known that a fast transport to the appropriate health facility is a key factor for a positive medical outcome. Though, this is not always possible. Therefore, pre-hospital emergency team must have an adequate training focused on victim stabilization and transport. The transport must be ensured either to the most suitable health unit or by an execution of a "rendezvous" process [13].

The concept of having an Integrated system for medical Emergency (SIEM) has risen in 1981. SIEM is similar to a pool of entities working for a common goal: provide assistance to the victims of accidents or sudden illness. [14]

INEM is an acronym for National Institute for Medical Emergency and is in charge of coordinating SIEM in Portugal (excluding islands). INEM is a governmental organization and is responsible for the Ministry of health [15].

Germany is organised in 16 federal states. Each state has its own EMS law organization, regulations and is divided into several EMS regions. There is a coordination centre per region and sometimes they are combined with the fire brigade. In some regions, the German Red Cross or the Workers' Samaritan Federation Germany are organizing the services [16].

2.2. Stroke as a Challenge

The general EMS characteristics have already been described, and a detailed description of the current EMS in Portugal and Germany has been given.

Furthermore, demographic and epidemiological shifts were introduced as a challenge for HCS, more precisely to the EMS [6]. An ageing society will lead to the increase in cardiovascular diseases and it is known that vascular diseases are one of the main cause of death worldwide. Actually, in Portugal, it is the number one cause, being responsible for 40% of mortality [17]. The same happens in Germany, where, according to the statistics shown by the Federal Statistical Office, it still is one of the major causes of death and of a lifelong disability [18].

According to the definition given by the WHO, a stroke is a cerebrovascular disease (CVD) "caused by the interruption of the blood supply to the brain, usually, because a blood vessel bursts [haemorrhagic stroke] or is blocked by a clot [ischemic stroke]"[17].

Ischemic stroke occurs due to a lack of perfusion in a certain brain area, usually due to thrombosis, embolism or small vessel disease, leading to the death of tissues in the surrounding areas. Haemorrhagic stroke results from the rupture of an intracranial vessel that induces a hematoma that destroys and compress the cerebral structures, leading to a malfunction [19].

As strokes have a narrow treatment time window, according to Vaz [19], the severity of neurological damage

is intrinsically connected to the time that elapses until the end of the treatment process. While, in Portugal, EMS services show a special treatment process when it comes to rescuing stroke patients, in Germany there is no treatment protocol exclusively directed to stroke patients.

3. LITERATURE REVIEW

A literature review was conducted with the purpose of identifying and structuring concepts concerning the Emergency Rescue Chain (ERC) and offers the possibility of using simulation methods as evaluating tools. Simulation modelling techniques will allow a simple and objective problem analysis by mimicking the behaviour of a "system, phenomenon or process" [20] through the application of a model [20].

3.1. Emergency Rescue Chain

Globally, ERC corresponds to the process activated by a sudden illness and that culminates in the arrival to the healthcare facility. Actually, ERC is the process that occurs during out of hospital emergency systems. Out of hospital emergency medical systems hold three main actions: 112 calls, dispatching and ambulatory service [11].

Rescue chain is a sequence of chronologically and qualitatively successive sub-processes within emergency rescue that must ensure a total coordination between the rescue service team and the hospital [4].

In addition to patient considerations, several other factors affect prehospital care: personnel, environment, resources and logistics [21].

The Portuguese and German ERC will now be detailed as well as the main challenges faced by them. Furthermore, a deeper focus on stroke, a highly time-dependent rescue disturbance will take place.

3.1.1. Portuguese Emergency Rescue Chain

In Portugal, according to SIEM, there is a 6 stages dynamic sequence that characterizes the Portuguese ERC. In table 1 there is a detailed description of Portuguese Rescue Chain. [13]

3.1.2. Stroke Rescue: Via Verde do AVC

Strokes are the major cause of death in Portugal. Hence, there has been the necessity to find a more effective way to control the treatment process [22].

Starting by defining *Via Verde* (VV) (green path), it is an organized strategy for the approach, routing and more adequate, planned and correct treatment, during the pre, intra and inter-hospital stages, of critical/severe and frequent clinical situations [22].

VV's main objectives are set in doing the correct diagnostic and applying the correct treatment within the approved time window (*Janela terapeutica*). Accomplishment a positive outcome in stroke rescue involves three key points. The first one corresponds to the education of the general population. Every citizen must be informed concerning the main strokes symptoms, alert signs e utilization of the emergency number (112). An early detection is crucial for a good outcome in stroke treatment. The second point is centred on having a correct diagnosis in the pre-hospital stage. From that, is dependent an appropriate training. The latter aspect is the transport for an adequate health care unit [22].

The strategy encompasses 3 different stages: pre, inter and intrahospital. Actually, the first presented stage, "*pre-hospital Via Verde*" has a higher priority if compared to the remaining as it is citizen activated. After calling, INEM is in charge to recognize the symptoms: first technic operators at CODU and later EMT's at the local of the incident [22].

VV Activation for strokes requires meeting all of the following mandatory requirements: [23, 24].

- Age < 80 years old;
- At least one of the 3 known symptoms: Mouth at the side; Lack of strength in certain parts of the body. Ex. Arm; Difficulty in speaking
- Symptoms with less than 3h of evolution
- Not previous dependence.

Since the introduction of the VV for strokes, there was a significative reduction on the death rate caused by this disease

This pathway has been designed in 2005 and launched in the emergency system in 2007 [22, 25].

Table 1 - Description of the stages of Portuguese ERC according to SIEM [13].

Stage	Description	Actors
Detection	A person with no medical knowledge (usually) detects a medical emergency.	Help/Victim
Alarming	112 Call.	Help/Victim
Pre-Help	Help that tries to minimize the victim risk of clinical state worsening provided via telephone by the CODU workers.	Dispatchers at CODU
Help at the scene	Emergency measures performed by the emergency team. The goal is stabilizing the victim.	EMT, Doctor, nurse
Transport	Primary transport of the victim to an adequate health care facility.	EMT, Doctor, nurse
Treatment at the clinic	The transition from the context pre-hospital to hospital.	EMT, Doctor

3.1.3. German Emergency Rescue Chain

In Germany, rescue services are anchored in the SGB V[1] and are characterized by emergency medical care, emergency medical and infrastructural maintenance (24-hour staffing as well as material), necessary medical equipment, special training for the staff and the legally prescribed relief period

The survival chain is the basic organizational principle for the emergency care. It sees the emergency care unit as a functional unit of a continuous, graduated care process from the site of the incident until the treatment in the healthcare facility [4]

Table 2 details the activities performed in each stage of the presented ERC.

Table 2 - Description of the German Rescue Chain according to the stage, activities performed and intervenient. [26]

Stage	Activities	Intervenient
Protection	1st you guarantee that you are safe and then you help the others	Caller
Emergency call / immediate measures	Securing accident site; Rescuing from the danger zone, resuscitation and breathing if necessary, blood stilling shock control production of the stable lateral position emergency call while performing the assistance	Caller and Dispatcher
First Aid	Extended emergency measures at the scene; Serious damage can only be prevented by immediate and proper intervention: Transport, workers, work colleagues, family; despite the speed of the modern emergency service.	Caller
Emergency Medical Services	Rescue Transport: Focus: restoration of the vital functions ate the incident scene and their preservation during the transport	EMT's / Paramedics/Doctor
The clinic	Diagnosis	Doctor

3.1.4. Stroke Rescue in Germany

As it happens in Portugal, stroke is one of the biggest challenges in Germany. The annual costs related to stroke incidents in 2008 were 8.1 Billion € [27].

During the past few years, stroke therapy has made considerable progress. Recent technical and medical developments have hoped for improvements in stroke management. Nevertheless, according to the statistics shown by Federal Statistical Office, it still is one of the major causes of death and disability [18].

Time pressure in the acute stroke care has strengthened the awareness that stroke treatment as an acute emergency is more than justified. The goal is to make the preclinical care interval as short as possible

3.2. Simulation Theory

"A simulation model is a computer model that imitates a real-life situation"[28]

A possible methodology for evaluating the emergency rescue chain of both systems described might be the introduction of a simulation model to reproduce the process.

Mathematical models represent systems by a series of equations while for computer simulations, logical models (flowcharts) are required [29]. A simulation mimics the behaviour of a "system, phenomenon or process" [20] through the application of a model [20]. Model experiments might be sophisticated, giving use to several statistical design techniques. There are certain advantages in employing a simulation approach rather than a mathematical model. First, the majority of mathematical models cannot cope with dynamic/transient effects, operating only with average values. Second, there are some non-standard probability distributions that are only possible to sample with simulation models [29].Third, by using simulation is possible to obtain "entire distribution of results" [28], not only one. Therefore, raises the possibility of finding solutions and their respective analysis when analytic calculations are not suitable [30].

A simulation model is always an "executable model" [30] that triggers changes in the final state of the system, providing flexibility at the expense of accuracy of results [31]. In order to obtain operational information in a simulation process, the execution of a model, in which, the

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[1] SGB V is acronym for Funften Buch Sozialgesetzbuch (Statutory Health Insurance) and corresponds to the article that describes how the public health insurance acts. SGB V is the Article 1 published on the 20th December 1988 in the Federal Law Gazette, volume 2477.

output data describes the behaviour of the simulated system [31].

4. DESIGN METHODS TO EVALUATE EMERGENCY RESCUE CHAIN

4.1. Proposed Methodology Description

Considering the process that is being described in this project, it is decided to use computer simulation techniques to evaluate the ERC. According to Michael Pitt, "in a computer simulation, we use the power of the computer to carry out experiments on a model of the system of interest" Pitt [29]. Furthermore, after going through the available literature on the topic, it is inferred that either an agent-based simulation, a discrete event modelling or a combination of the different approaches can be used [29, 30].

As we are dealing with several details from a complex and real system, a set of ordered steps must be met. Hence, figure 1 summarizes the proposed methodology. The process starts by data collection. It is gathered through two different methods: qualitative (semi structured interviews to experts) and quantitative (literature review). Having all information together, it is possible to identify the main faults and limitations in each system and which questions should be answered. The process of identifying the main faults and structuring the problem is a symbiotic process since there is an exchange of information that leads to the model assembly. Bizagi Modeler is used to designing the model to be applied and then the AnyLogic is used to run and evaluate the ERC by changing several parameters. The last step is, after validating the model, to evaluate the ERC and find where there are time losses and verify how the system behaves by varying doctor necessity, control centre servers and available ambulances.

4.2. Applied Methodology

The proposed methodology described in 4.1 would be the ideal methodology for problem-solving. However, due to several factors, this was not straightforward. In the following subsections, the applied methodology is described.

Nevertheless, some stages are common to both cities. Hence, stages 4.1.2 (Faults Identification), 4.1.3 (Conceptual Model) and 4.1.5 (Proposed simulation model) are shared by both cities; stages 4.1.1 (data collection) and 4.1.4 (input data) are different among Lisbon and Stuttgart and stages 4.1.6 and 4.1.7 cannot have a clear application.

Thus, the main purpose of the applied methodology is to prove the effectiveness of computational simulation models to evaluate ERC.

4.2.1. Data Collection
Portugal

In Portugal, data was directly obtained from INEM using both collection methods: qualitative and quantitative.

Qualitative information was assembled after meetings with Dr Luis Meira and Dr Francisco Marcão. Quantitative information was retrieved from INEM statistics. The collected information draws the reality back in 2016

Germany

In Germany, the collected data was retrieved from quality reports in Baden-Württemberg [32]. However, as not all the required information can be directly deduced from the quality report, some estimations were calculated. For example, the information relative to the location of the emergency calls per district per day has to be estimated by experts. Hence, it can be concluded that not all the information available for the simulation is real [32].
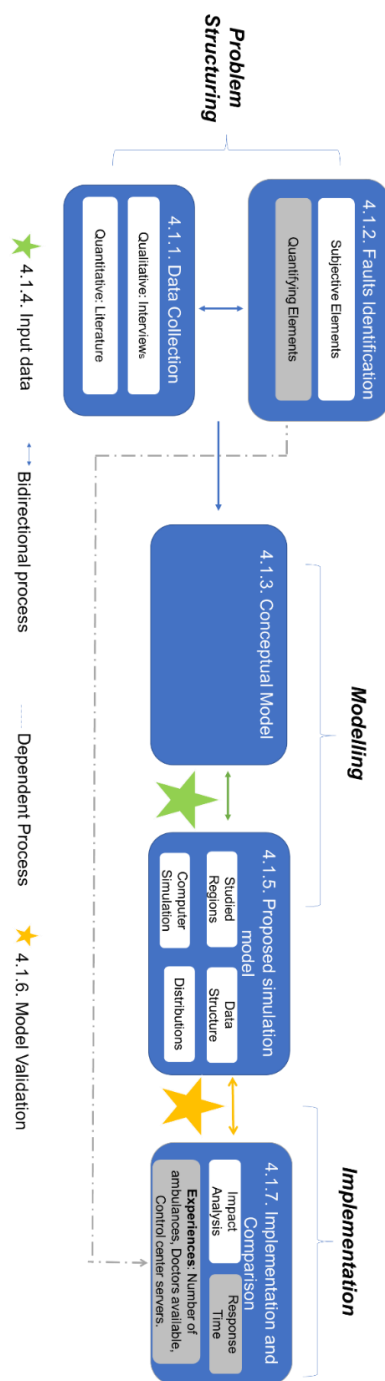

Figure 1 - Scheme of the proposed methodology.

4.2.2. Faults Identification

Scares resources can be tackled as quantifying limitations and can be analysed by the computational simulation model and suit both the Portuguese and the German ERC Model: Time Response; Number of Doctors; Base Locations; Number of Dispatchers; Number of ambulances available.

4.2.3. Conceptual Modelling

According to Michael Pitt [29], the conceptual model captures the essential features of the system that is being analysed. This stage involves two main processes: identifying the problem main features and understand how do they interact [29].

Therefore, after completing stages 4.1.1 and 4.1.2 of the proposed methodology is possible to design a primary ERC that fits both countries. Usually, the representation of the model uses flowcharts. Here, *Bizagi BPMN software* is used as an auxiliary tool to draw the diagram of the ERC model. Bizagi is a process modelling software. In this study, it is used for picturing the overall ERC that is being evaluated.

4.2.4. Input Data

In Portugal, INEM provided information relative to 2016. Nevertheless, in Germany, available data to run the model is only an estimation. Therefore, Table 3 compares the required data with the one that was made available in both countries.

Overall there is a lack of input information and a misfit among the two data of the two countries. Though by making some changes is possible to run the same simulation for the two models, the differences are in the input data collection and distribution functions. The next subsection will explain the computer simulation proposed

4.2.5. Proposed Simulation Model
Studied Regions

Before moving towards the computer simulation topic, it is important to analyse the two areas that are being studied: Stuttgart and Lisbon. The most important question to be answered when looking at these two cities is: are the cities comparable?

Table 4 draws a comparison between the two studied areas. For example, it is possible to observe a big gap considering the number of dispatchers in the emergency control centre. This can be explained by Portugal having 3 CODU spread across the country to handle all calls. Lisbon CODU handles the entire metropolitan area of Lisbon, that has more than 2 million habitants. In Germany, the EMS is regionalized and in Stuttgart due to the number of inhabitants and calls per day, it is not required to have so many workers. However, emergency demand between the two countries is similar.

Table 4 - Comparing Lisbon vs. Stuttgart [32-34].

	Stuttgart	*Lisbon – AML*
Population	*612 441*	*1370611*
Area [km²]	*207,4*	*603*
Number of ambulances	*20*	*20*
Number of bases	*6*	*14*
Number of dispatchers (average per day)	*3*	*28*
Emergency Demand (calls/day)	*194,5*	*188*

Distributions Estimations

Each step in the ERC has a service time associated. Since it does not have a stochastic behaviour, probability distributions are used. Parameters that fit each function used data from the Quality Report in Emergency Services in Baden-Württemberg 2016 [32] and from INEM statistical data (Lisbon).

Some specific functions are being used. A Poisson distribution is chosen to represent the influx of calls in the call centre. Actually, according to Van Buuren in 2015 [35], calls' arrival process can be assumed as a Poisson process with exponentially distributed inter arrival times [35].

Dispatch centre service level representation uses queuing models. Among the possible queueing functions, an Erlang C function is used to represent the control centre service level. Here, if a patient finds all servers busy waits in a queue and is served by the first available server [36].

The lognormal distribution is chosen for the service time (triage) by the call taker for each incoming call. Bolotin in 1994 [35], showed that lognormal distributions are a good fit for call centre service times. As the control centre

Table 3 Input Data comparison

Input Data required	Available data - GER	Available data - PT	GER vs. PT
Number of emergency calls per day	Yes	Yes	✓
Number of emergency calls per day that are identified as strokes	No	No	x
Number of incidents per district per day	Yes	No	X
Number of incidents per district per day identified as strokes	No	No	X
Location of the ambulance stations	Yes	Yes	✓
Number of available ambulances	Yes	Yes	✓
Location of the healthcare facility	Yes	Yes	✓
Health care facility capacity	No	No	X
Number of dispatchers available in the call centre	No	Yes	X
Number of emergency doctors available	Yes	Yes	✓
Number of calls that require doctor per day	No	No	X
Location of emergency doctors	Yes	No	X
Flux of incoming calls during the day	No	Yes	X

function can be roughly approximated to a call centre, this function can be used [35].

Treatment duration can be described either by a Gamma distribution or by a Normal function. During the simulation, the best fit will be chosen.

All of the remaining distributions were assumed by me since there was no literature on the topic confirming what would be the perfect fit. These functions were approved by experts on the topic beforehand.

Data Structure

While Portuguese data uses GPS coordinates for the ambulance base location, counties and hospitals. German data uses a matrix with estimated travel times, not being required to know counties' exact location. Overcoming this difference requires different starting points in the model simulation. These differences will be visible in during the computer simulation explanation

Computer Simulation

At the present stage, study region must be analysed and then the computer implementation produced. It is important to look carefully to the study regions if there is more than one place since regions must produce comparable outputs throughout the simulation. Regarding the computer implementation, AnyLogic software is chosen and used. AnyLogic is a Java-based software that allows a multimethod modelling: combines different methods leading to more efficient models [30].

In this simulation model, there is a combination of discrete with agent-based simulation. In discrete event modelling, the system is organized as a sequence of processes. However, in the proposed simulation model agents also have a key role. If we only had discrete event modelling, entities would be passive objects and the focus of the system would be exclusively the logic block process. By combining both methods, entities become agents. Therefore, the "entity generation corresponds to the creation of an agent"[37]. Each agent is modelled by adding parameters and charts that will influence their behaviour.

Computer implementation between the two countries tried to be as similar as possible. Nevertheless, some minor changes had to be performed. It is important to take into account that all agents will run in the main agent, even though ambulance, patient and hospital being characterized their action will be only visible in the main diagram.

Though, the results produced from these two experiments are similar since both ERC models are based on a similar logic block and due to the lack of data that forced the decision of making assumptions. Therefore, the results depicted will be only an illustrative demonstration.

4.2.6   *Validation, Implementation and Comparison*

According to Michael Pitt, validation of the model is crucial during the modelling stage of a computer simulation model. As models are applied to evaluate concepts that are not fully understood, a complete validation is never possible [29].

Validation intends to check if the computer programme is providing "valid results for the system that is representing"[38], evaluating the performance of the simulation system and comparing it with the value measured for the real system [38].

In the specific case of the ERC, validation process should be performed through the comparison with the measured values in the region of study. Also, an approval by experts is also interesting to be explored.

However, in the modelled ERC was not possible to validate the model due to several limitations already exposed. In fact, lack, structure and complexity of the data are the main reasons for this obstruction.

Therefore, this computational simulation model is used to depict how the evaluation and comparison of the two ERC would be possible by changing their different parameters. Thus, in the next chapter, will be presented the results from experimenting the ERC's

5. RESULTS AND DISCUSSION

In this section the results for the application of the previous methodology are presented. The results depict how the use of the methodology is flexible and useful for evaluation and analyse of distinct ERC's

Nevertheless, it is important to take into account that obtained results are merely illustrations for the computational model that was built. The main contribution of this dissertation is the proposed methodology as well as the verification that computational simulation models can be used to evaluate EMS topics, such as the ERC: As ERC input parameters have a stochastic distribution, output values change consequently as simulations are run, reducing the accuracy of the model.

Furthermore, one goal of the dissertation was to implement the model for a stroke rescue scenario. However, representing stroke ERC was not a straightforward task due to the lack of collected data. Though the implemented model in both countries takes into account the special ERC applied in Portugal for strokes (VV-AVC) since there is a detailed algorithm that explains the different rescue stages. In Germany, the available ERC is very simplistic and overlaps stages.

5.1 Limitations

Assembling this ERC was not a straightforward process, several obstacles were found along the way. The major limitations are based on the lack of data, information uniformity and also derived from the complexity of the software. Furthermore, evaluating strokes pathway was a difficult task since there was not a complete dataset regarding this disease.

5.1.1.   *Problems in data collection*

Assembling and comparing the two executed models was a complex process. Besides being two different countries with different available input parameters, data structure was different. The main difference was set on the ambulance and hospital location distribution. While Portuguese data uses GPS coordinates, German data

uses a matrix with estimated travel times, not being required to know counties' exact location.

5.1.2. Problems in input data

By looking at table 3 in chapter 4.2.4, several inputs are missing. Portuguese data does not provide the exact district/location of an incident. Instead, it only gives the amount of answered calls per Emergency ambulance (EAM). EAM is the only type of emergency vehicles being considered here and, according to the literature, in Lisbon Delegation it corresponds solely to 15% of the medical triggering. Furthermore, in CODU there is daily an average of 28 workers. These workers hold approximately 3755 calls/day. In this model, only 188 calls/days are being considered, as those are the ones that lead to EAM activation. Hence, it is not possible to evaluate accurately the target answer time at CODU. Information relative to stroke incidents is also few. Only average statistics are available, there is no data connection to number and location of emergency calls/day identified as strokes. Some, medical emergency situations require physician intervention. However, there is no available information regarding the number of calls that require doctor per day as well as their location. Healthcare units' capacity is not revealed, being impossible to know, while choosing patient's movement towards the hospital, if the healthcare facility is full.

The flux of calls during a day is known, as well as the number of workers available. In CODU there are shifts according to the forecasted demand. However, as in Germany, there is no information regarding this parameter and as this is solely a computer simulation model to evaluate the efficiency of the methodology, this parameter did not experiment.

Moreover, to evaluate EMT performance, would be important to have information regarding EMT's arrival time. However, only approximately 30% of the EMT's in Lisbon had sent information regarding this performance parameter [39]. Therefore, is not possible to compare it with the obtained output.

In Germany, regionalized services make few data available. Until having a systemic integration of data, accessing information will always be a hard task. Also, by looking at the BW 2016 quality report, it is verified that not all control centres give back performance reports, blocking a correct parameters construction. From the 34 dispatch centres within BW, only 17 provided the correct information [32]. Some estimations had to be executed, and even there, there is information missing. There is no information regarding the number and location of emergency calls per day that are identified as strokes, the only information available in the literature is the probability of having a stroke in Germany, knowing that there is an emergency. Also, the number of dispatchers available in the control centre is not available, there is only an estimation.

Furthermore, in Germany, several emergencies require, by law, a physician at the incident location. The information regarding this number is not available. It was decided to consider as mandatory a doctor every time there was a stroke, but that does not represent the reality. As it happens in Portugal, health care facility capacity is an unknown value.

5.1.3. Problems in the proposed simulation model

Comparing the data between Portugal and Germany is not a simple process. As Lisbon CODU comprehends the entire metropolitan Lisbon the sample size differs a lot from the one measured in Stuttgart. Also, information from Lisbon is real (2016 – INEM statistics) and the data from Stuttgart is merely partial real, this means, part of the information is estimated by experts but does not represent 100% the reality.

Therefore, establishing comparison lines between the two systems was a difficult process. Not all the desired comparisons were possible.

5.2. Application of the proposed methodology

Having into account the described limitations, an illustration of a possible application of the proposed methodology is being presented in the following paragraphs. The application of the proposed methodology follows the steps introduced in chapter 4.

For example, applying the methodology to the German situation, these episodes correspond approximately to 1 month of medical emergencies.

As depicted in figure 3, 5854 patients were generated at source element. All patients were processed at the *EMS_centre*. However, when it came to "*assign an ambulance*" only 2214 were released in the considered interval. In all the remaining blocks the flux of in and outpatients was constant.

Actually, in the blocks" *local treatment*" and "*go to hospital*" there were 1 and 2 patients respectively that were not processed, however, this number is meaningless having the sample size into consideration.

Therefore, the biggest delay in ERC takes place during ambulance assignment. Furthermore, by looking towards the resource pool utilization rate (figure 2), it is possible to observe all vehicle resources are being used, so the problem is either in the assignment delay or not in the number of vehicles available during the simulation execution.

Overall, the executed model was a good illustration of the capacities of the explored methodology and model. By executing the computer simulation model with Analogic was open the possibility of analysing the promising features of the software in the computer simulation field.

Furthermore, the proposed methodology offers the opportunity of comparing different ERC systems and shows that the software can run an ERC example model with two different types of data: GIS locations or matrix with previous estimated travel times. Therefore, it notices the flexibility and efficiency of the simulation method, being able to adapt to different ERC contexts.
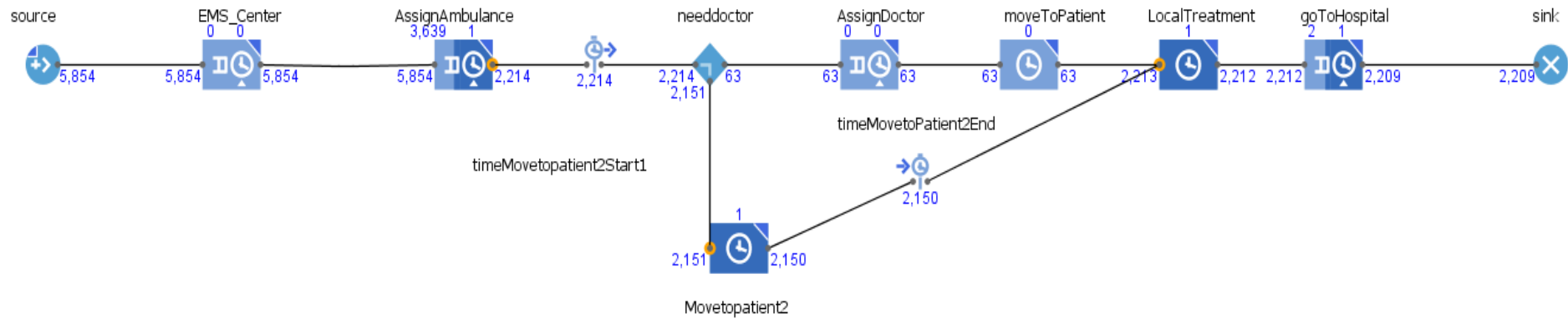
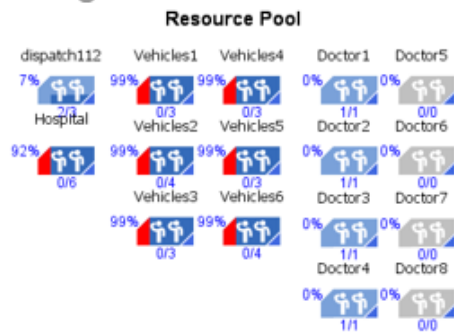Figure 2 – Germany: Logic Block result with control values applied

Figure 3 - Resource pool utilization for the standard experiment depicted in figure 4

CONCLUSION

In this work, was proposed to evaluate the pre-hospital emergency Rescue Chain in Germany and Portugal

In order to analyse this problem, a methodology was proposed and a computer simulation model using AnyLogic software was developed.

The proposed approach corresponds to a set of ordered steps and combines discrete with agent-based simulation. The results depict how the use of the methodology is flexible and useful for evaluation and analyse of distinct ERC's. Overall, the main contribution of this thesis is the proposed methodology as well as the verification that computational simulation models can be used to evaluate EMS topics, such as the ERC.

As future developments, new strategies for dispatching and deployment of ambulances have been designed. The currently applied strategy, "closest idle", chooses as the ambulance to send the one that is closest in time to the scene. Also, assumes a correct knowledge concerning the locations of the available ambulances. It has been proved that the classical dispatch approach of the "closest idle" vehicle is not always optimal [3, 40].

Jagtenberg et al. [40, 41] developed several algorithms that try to optimize dispatching and relocation problem. The first addresses questions such as the best location for ambulance bases or the number of vehicles to be positioned at each station. Here, solutions are usually given through mixed integer linear programming. The latter considers problems related to the relocation of idle ambulances and their dispatching to a specific incident. [40, 41].

As final remarks, this dissertation focus is on the emergency rescue chain process, and the executed computer simulation model has shown that AnyLogic is an interesting tool to use when evaluating and exploring ERC. Nevertheless, it requires a proper validation and complete set of data, otherwise, the obtained outputs cannot be connected to the reality

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