Combining methods for simulating and improving the Emergency Rescue Chain

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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;

Resumo

A Cadeia de Emergência Médica (CEM) corresponde ao processo ativado por uma doença súbita e que culmina com a entrada numa unidade de cuidado de saúde, sendo centrada nas ocorrências no sistema de emergência médica na fase pré-hospitalar, sendo responsável pela: chamada para o 112, orientação de pacientes e serviço ambulatório. Esta tese desenvolve uma metodologia – baseada em técnicas de simulação computacional – para avaliar e explorar a CEM e investigar a possibilidade de métodos computacionais de simulação se ajustarem à monitorização e otimização dos processos que decorrem dentro da cadeia. A metodologia desenvolvida é especificamente usada para explorar as diferenças entre dois países distintos, Portugal e Alemanha. As Cadeias de Emergência Médica Portuguesa e Alemã serão detalhadas, assim como os maiores desafios que enfrentam nos dias de hoje. Adicionalmente, a aplicação da metodologia, foca-se no acidente vascular cerebral (AVC), uma doença cuja viabilidade de recuperação depende do tempo para o tratamento. A proposta metodológica corresponde a um conjunto de passo ordenados e a uma combinação de simulação baseada em agentes e de eventos discretos. Os resultados revelam que esta metodologia é bastante flexível e que o seu uso é útil para a avaliação e análise de diferentes CAM. No entanto, os resultados obtidos são apenas ilustrações de como a metodologia pode ser usada na prática. Sumariamente, a maior contribuição desta tese foca-se na proposta metodológica desenvolvida assim como a verificação da aplicabilidade de modelos de simulação para a avaliação de tópicos na área da emergência médica, tal como a CEM:

Palavras chave: Sistema de Emergência Médica (SEM); Cadeia de Emergência Médica (CEM); Portugal; Alemanha; Simulação; Acidente Vascular Cerebral (AVC).

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List of Acronyms

AA	Anglo-American
AEM	Ambulância de Emergência Médica (Medical Emergency Ambulance)
ALS	Advanced Level of Service.
AVC	Acidente Vascular Cerebral (Stroke)
BGM	Bundesgesundheitsministerium (German Ministry of Health)
BLS	Basic Level of Service
CIS	Commonwealth of Independent States
CODU	Centro de Orientação de Pacientes Urgentes (Urgent Patients Orientation Center)
CQI	Commonwealth of Independent States
CVD	Cerebrovascular Disease
DGS	Direção Geral de Saúde
ED	Emergency Department
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
ERC	Emergency Rescue Chain
FG	Franco-German
GIS	Geographic Coordination System
HCS	Health Care System
INEM	Instituto Nacional de Emergência Médica (National Institute for Medical Emergency)
NEF	Notarzteinsatzfahrzeug (Emergency Physician Vehicle)
NHS	National Health Service
QA	Quality Assurance
RA	Rettungsassistent (Rescue Chain Assistant)
RH	Rettungshelfer (Emergency Medical Technician-Basic)
RHA	Regional Health Administration
RS	Rettungssanitater (Paramedic)

RTW	Rettungswagen (Emergency Ambulance)
SGB V	Funften Buch Sozialgesetzbuch (Statutory Health Insurance)
SHI	Social Health Insurance
SIEM	Sistema Integrado de Emergência Médica (Integrated system for medical Emergency)
TEPH	Técnico de Emergência pré-hospitalar (Emergency technician pre-hospital)
U-AVC	Unidade de Acidente Vascular Cerebral (Stroke Unit)
VV	Via Verde (Green Pathway)
VVAVC	Via Verde para o Acidente Vascular Cerebral (Stroke Green Pathway)
WHO	World Health Organization

1. Introduction

Emergency Medical Service (EMS) is a health care 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 (World Health Organization, 2008, Al-Shaqsi, 2010, Reuter-Oppermann et al., 2017).

Rescue services are anchored in the emergency services. Actually, it is 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 (Koch et al., 2008).

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 (Koch et al., 2008).

Thus, the goal of this thesis 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 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 more complete coverage, taking into account different process and resources used by the rescue chain.

This dissertation is organized as follows. Chapter 2 contextualizes this research. It gives an overview regarding the health care systems in Portugal and Germany as well as main the functions and challenges faced by the emergency medical services in the two cited countries. In the end of this chapter, an explanation for considering the stroke as a case study is introduced. In Chapter 3, a literature review concerning the emergency services in the previously cited countries is given. A description of the rescue emergency chain is completed as well as the main challenges faced by either the emergency services, in specific during the stroke rescue. Also, there is an introduction to simulation theory. Chapter 4 describes the chosen methodology, namely, the steps that were taken during the research project. Chapter 5, depicts a possible application of the methodology described in Chapter 4 as well as the main limitations faced. The thesis ends in Chapter 6 with some final remarks on the usefulness of computer simulation models in the analysis of the emergency rescue chain and some recommendations on the topic. Also, it introduces some hints for a possible future work.

2. Context and case studies

According to the World Health Organization (WHO), health is a “state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (World Health Organization, 2006). The ultimate goal regarding health is enabling people to be “all they can be, to live as long as they live” (Jakab, 2011). This statement follows the one given by the New Zealand writer, Katherine Mansfield, saying “I want to be all that I am capable of becoming” (Jakab, 2011).

Giving a step backwards in time until 1950, , it is possible to observe that the general health status in Europe has been improving (Jakab, 2011). As an example, there is life expectancy at birth parameter. It has increased 5 years since 1980, reaching 75 years in 2010. However, there are still inequalities between countries with regard to their socioeconomic and educational status. Health inequalities correspond to contrasting health status or resources allocation among different population groups (Jakab, 2011, World Health Organization, 2017).

A health system can be described as a complex arrangement of parts with several interconnections and players that come together for a common purpose: ensuring people´s health. Besides patients and families, Ministries of Health, health providers and services organizations, pharmaceutical companies and health funding bodies also play important roles for an efficient health system (World Bank, 2007).

According to WHO, the main purpose of a health system is “to promote, restore or maintain health” (Magnusson, 2017). This statement goes further than the simple provision of health services. For an efficient health system, several building blocks must work for a common goal. WHO highlights six main components: leadership and governance, health information systems, health financing, human resources for health, delivery of health services and essential medicines and technologies. Governments must develop policies and structures to improve leadership and facilitate intersectoral actions to improve health. Health information systems comprehend the collection and management of information regarding health status/indexes/performance goals. Financing must ensure that there are enough funds to guarantee services with the quality required and avoid catastrophic expenditure (Magnusson, 2017).

In this chapter, a 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.

2.1. Health Care Systems in Europe

. Usually, for historical reasons, there are differences amongst almost all countries organizational structure and insurance system administration. Even if their overall administration seems to be similar, they differ in the treatment control at the healthcare facility and in the patient reimbursement (Gold, 2011).

"Most health systems have similar goals and face challenges, such as demographic change, limited resources and rising costs" (Papanicolas et al., 2013).

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. (Jakab, 2011, OECD, 2016a, Papanicolas et al., 2013).

Drawing comparisons between countries "offer the possibility of exploring new and different options", (Papanicolas et al., 2013) 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 (Papanicolas et al., 2013).

Therefore, a comparison between two distinct European nations takes place in the following sections: Portugal and Germany (Gold, 2011). 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 (OECD, 2016b). 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 (Busse et al., 2016). Understanding their health systems is important to comprehend the challenges that these countries are facing and accessing possible solutions (OECD, 2016b).

2.1.1. Portugal

In Portugal, all citizens have access to health care. It is provided by the National Health Service (NHS) that is mainly tax-financed. NHS was first established in 1979 after the 1974 revolution. The main goal was to guarantee a free universal health care regardless citizens economic state and social background. Until then, state did not have to ensure any payment for individual care. Actually, charity hospitals used to assure the care for the poorest, state only provided limited care, such as in maternal and child care (Pita Barros et al., 2011)

Nowadays, some public-private partnerships have been adopted to improve the efficiency of the healthcare system. Changes in the management of the structure models, pharmaceutical reforms, primary care reorganization and creation of long-term care networks are required (Pita Barros et al., 2011).

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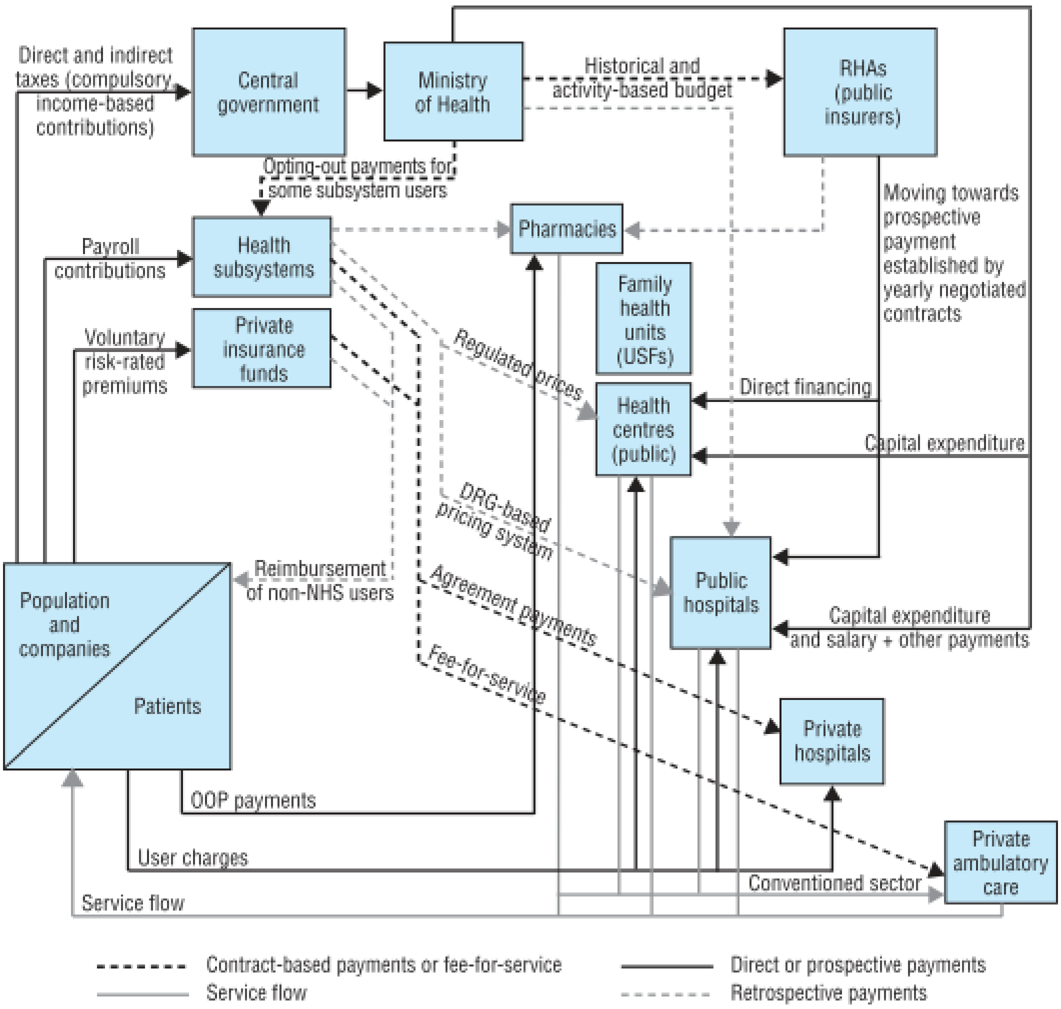

Figure 1 - Overview of the Portuguese Health Care System (Pita Barros et al., 2011).

Figure 1 summarizes Portuguese Health care system structure, showing that Portuguese health care system is managed at a central level. The Ministry of Health holds the function of regulating, planning and managing the NHS, even within the private sector. While the health policymaking process belongs to the ministry of health, its implementation is not only performed at a central level but at a regional level through Regional Health Administrations (RHA). By decentralizing the responsibility for health care, it is possible to have a better allocation of resources. Accessing the quality of care is a task mainly for the RHA. At a regional level is possible to verify the quality of providers as well as the compliance with the applied legislation. Developing strategies, coordinate health suppliers, supervise and managing health care providers are responsibilities for each RHA (Pita Barros et al., 2011).

In addition to the coverage provided by the NHS (Universal NHS), there are other health systems that coexist in Portugal: special public and private insurance, also called health subsystems. Approximately 25% of the population is covered by one of these systems. Though, only 2% of the population has a cumulative coverage for both health subsystems. (Pita Barros et al., 2011).

2.1.2. Germany

German HCS is mainly funded by the public sector and is a contribution based social insurance model. According to the German Law, more precisely according to the Federal Republic of Germany's Basic Law (*Grundgesetz),* state must guarantee to all citizen's social justice and appropriate treatment in case of illness. Minimum provisions for a human life with dignity must be ensured, including ambulatory services, impatiens beds, quantitative or qualitative measures and medical products (Döring et al., 2010).

Figure 2 summarizes the German HCS by presenting a chart that comprehends the most important stakeholders within the health system.

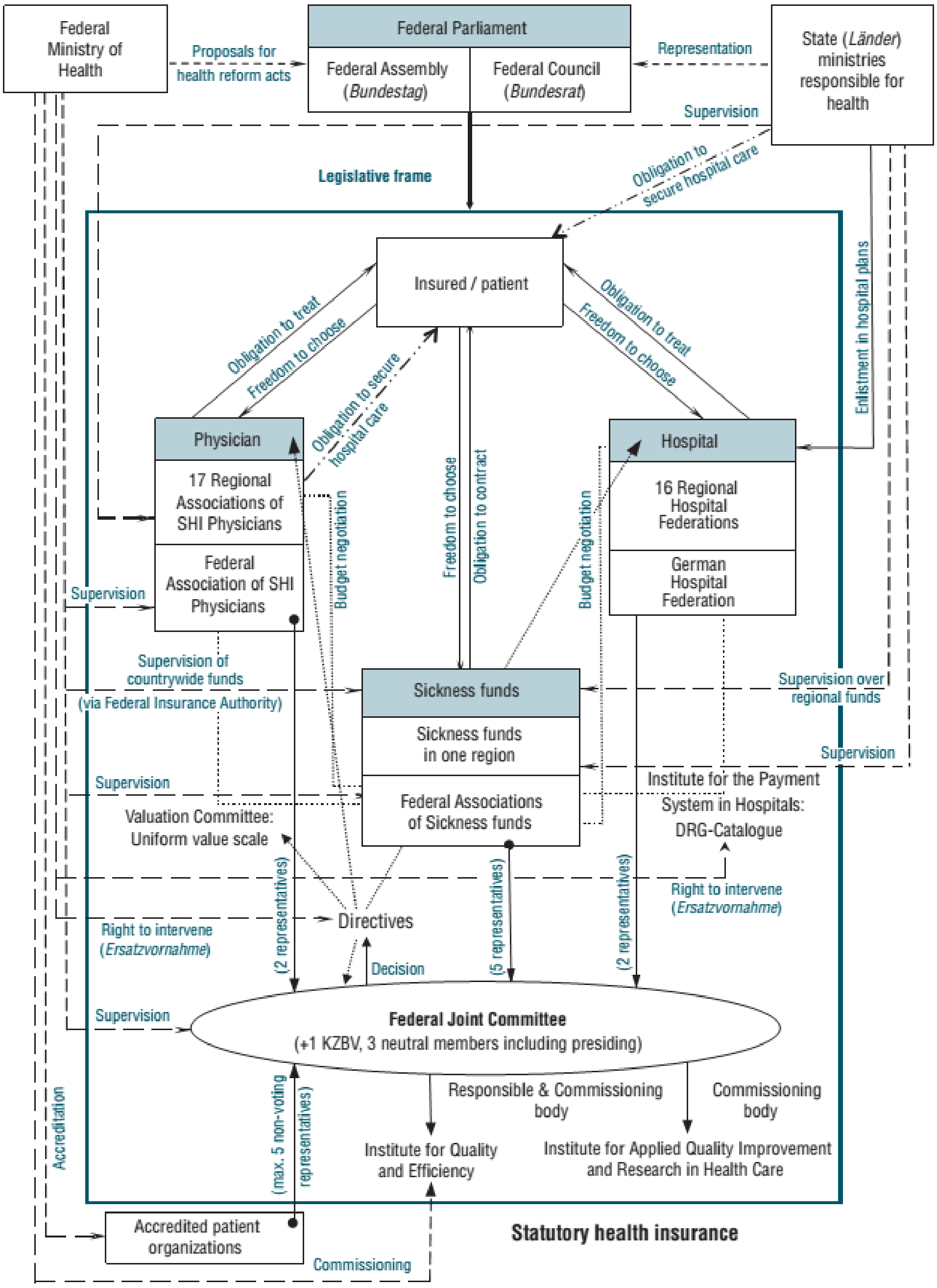

Figure 2 - German Health Care System organization (Busse et al., 2016).

The legislative Power is held by Federal Parliament (*Bundestag*) and by Federal Assembly (*Bundesrat*). Together, they set the legal framework: they are responsible for SGB V[1] and by deciding reform acts whenever is necessary (Nickel et al., 2016).

Reform acts are proposed to the Federal Parliament by the Federal Ministry of Health (*Bundesministerium für Gesundheit* - BGM). Federal states ministries of health (*Gesundheitsministerien der Länder*) are represented in the Federal Assembly.

Federal State Ministries of Health are in charge of controlling and supervising the implementation of the legal framework since it is applied by self-administration. The concept of self-administration implies that organizations are equally occupied by representatives of the insured as well as by the service providers, passing legal standard's to regulate individual actors (Nickel et al., 2016).

Furthermore, in public health insurance, state can delegate services to contracted state institutions. Thus, on a legal and decision-making level, health insurance companies and statutory health insurance (SHI) physicians act as indirect and outsourced public administration authorities with some self-governance (Döring et al., 2010).

In 2009, it was introduced a compulsory health insurance for all residents in the Federal Republic of Germany. About 90% of German citizens are in the statutory health insurance (SHI) system. SHI is mandatory for individuals with an income below 4050 € (threshold). An exception is only made to individuals who belong to a mandatory SHI (ex. professional group). SHI are obliged to accept any individual regardless its risk profile (Döring et al., 2010).

As SHI expenditure is calculated according to individual income, individual risk profile is not taken into consideration (Döring et al., 2010).

Furthermore, since SHI are statutory companies, health insurance companies must be supervised by the state and the funding of the SHI is managed by a centralized health fund and by a morbidity risk adjustment scheme. Companies must transfer all premiums (excluding supplementary charges) to the federal bank. Afterwards, Federal (Social) Insurance Office determines how much should be allocated to each insurance company (Döring et al., 2010).

As happens it in Portugal, in Germany there are two main types of insurance: private and public. Contrasting to public health insurances, private health insurances calculate an insurance rate based on the individual risk (Nickel, 2016). In private health insurance (PHI) companies their operation mode is on a profit basis. Only employees with regular earnings above the stated threshold are allowed to choose a PHI rather than SHI (Döring et al., 2010).

2.2. Emergency Medical Services

All public health care systems integrate a sector called Emergency Medical Service (EMS) (World Health Organization, 2008).

EMS provides 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 facilities (World Health Organization, 2008, Reuter-Oppermann et al., 2017).

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 calling, dispatching and ambulatory service (World Health Organization, 2008).

All European countries share a common emergency telephone number "112" that is free of charge from public payphones. Dispatch Centres receive 112 phone requests and allocate the correct resources to patients (ambulances, medical advice). Ambulatory service is activated by the call taker at the dispatch centre and is responsible for two main tasks: answering to emergency calls and patient transports. It is possible to divide the emergency calls into two main groups: life-threatening calls and urgent calls. Also, it is possible to set three main types of ambulances: advanced life support (ALS), basic life support (BLS) and rapid responders. ALS ambulances have the ability to answer to any type of call and are fully equipped and staffed with at least in paramedic. BLS ambulances are usually used in patient transport, and, for that reason are lower equipped and do not require a paramedic. Rapid responders can be described as vehicles with fully qualified paramedics without the ability to transport patients to the office (Reuter-Oppermann et al., 2017, World Health Organization, 2008).

"Countries will face major challenges to protect their populations from an increasing number of potential health threats in the future" (World Health Organization, 2008).

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 are necessary.

In the following sections, up to date EMS models and the Portuguese and German EMS are described.

2.2.1. EMS models

Since 1970's, health care delivery has two distinct categories in EMS pre-hospital settings: Franco-German Model and Anglo-American Model. Several countries across the world use these two models as guidelines for their own EMS system. Despite their differences, both models share a common mission: providing emergency care to the population (Al-Shaqsi, 2010).

Franco-German (FG) Model is based on the "stay and stabilize" (Al-Shaqsi, 2010) philosophy. Here, the main objective is to bring the hospital to patient, starting treatment procedures at the scene. It is usually run by physicians and uses other transportations methods besides ambulances, such as helicopters. This model is widely applied throughout Europe, in countries like Germany, Switzerland, Poland, Sweden, Spain or Italy (Al-Shaqsi, 2010).

Anglo-American (AA) Model is based on the "scoop and run" philosophy (Al-Shaqsi, 2010). Contrasting to the first described model, AA model has as primary goal rapidly bringing the patients to the hospital, having fewer pre-hospital interventions. It is usually deeply connected to the public services such as police or fire departments. Instead of physicians, it uses trained paramedics and Emergency Medical Technicians[2]. This model is usually applied in countries such as Canada, Australia, Denmark and Ireland (Page et al., 2013, Al-Shaqsi, 2010).

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[2] Both Paramedics and EMT's can transport patients and provide them emergency care. The major difference between them is their degree of. Contrasting with EMT's, paramedics are advanced providers of emergency medical care and are highly educated. UCLA. 2017. *What's the Difference Between an EMT and*

"*European Emergency Data Project" (Fischer et al., 2011)* was a "data based health surveillance system" (Krafft et al., 2002) designed to compare the two models by identifying several common parameters among European EMS. Therefore, significant differences in the quality provided and in the given medical care assistance were found. In more severe cases the pre-hospital care provided by the Franco-German model obtained better medical outcomes than the Anglo American one (doctors vs. paramedics). However, many other factors might influence the efficiency level measured. Problems such as queues in the dispatch centre, demography of the studied region, road accesses, available doctors and paramedics and predominant diseases arise as strong conditionings for a good outcome *(Fischer et al., 2011).*

As the doctor is the main provider of care in the Franco-German model, the diagnosed condition is accepted by the Emergency Department (ED). Therefore, when the patient arrives at the hospital, there is a faster admission for treatment in the hospital than in the Anglo-American model. Here, all transported patients must go through the hospital Emergency Department, requiring more time for diagnosis and treatment. In severe cases, where time is a crucial factor, this might be an issue (Al-Shaqsi, 2010).

Al-Shaqusi (Al-Shaqsi, 2010) found significant differences between the two systems. Table 1, summarizes their major differences:

Table 1 - Comparison between the Franco-German and Anglo American EMS models (Al-Shaqsi, 2010).

Model	**Franco-German**	**Anglo American**
Patients treated at the scene	+	-
Patients transported to hospitals (velocity)	-	+
Main care providers	Doctor	Paramedic
Destination of transported patients	Bypassing ED	Direct ED
Organization	EMS belongs to the public health organization such as hospitals or health care services.	EMS is a part of public safety organization such as police or the fire department.

2.2.2. Portugal

In Portugal, medical emergency system follows the Franco-German model. However, each situation has an adapted protocol depending on the type of occurrence, geographic characteristics, the experience of the pre-hospital emergency teams, not following necessarily an

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a Paramedic? [Online]. Available: https://www.cpc.mednet.ucla.edu/node/27 [Accessed 7th October 2017 2017].

exact model (Afonso, 2014). So, according to opinion of Dr António Marques da Silva, director of the Emergency Department of Saint António Hospital, the current model applied in Portugal is a mixed system: FG + AA. Here, the success of the emergency network is due to the articulation, integration and guarantee of continuous care, that is assured by having medical professionals with different levels of differentiation and training in this field (physicians, nurses, emergency technicians) (Padilha et al., 2015).

The mixed model valid in Portugal tries to take advantages of both models. 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 (Afonso, 2014).

Dr. António Marques da Silva, during an interview stated that the tendency will be to have a "scoop and play" system, where the patient is picked up and transported to an adequate hospital as fast as possible while paramedics perform some treatment measures. There has been an investment in technicians by providing them more training.

The concept of having an integrated system for medical Emergency (SIEM) has risen in 1981. SIEM is similar to a pool of entities that include policemen, firefighters, Portuguese Red Cross, hospitals and primary care centres, working for a common goal: provide assistance to the victims of accidents or sudden illness. (National Health Service, 2017)

INEM is acronym for National Institute for Medical Emergency and is a governmental organization in charge of coordinating SIEM in Portugal (excluding islands). (Gomes et al., 2004).

Actors and Ambulatory system

Emergency Medical System workers are divided into 3 levels (Gomes et al., 2004, Page et al., 2013):

1. Basic first responders - usually police officers and firefighters. They must go under 40h of training in basic first-aid and basic life support (Page et al., 2013).
2. Emergency technicians - second level. By having 210 hours of training they can perform "basic life support, basic wound management, oxygen administration, patient extrication, patient transfer, spine and fracture immobilization and uncomplicated obstetric delivery" (Page et al., 2013, Padilha et al., 2015).
3. Medical team - doctor and nurse. Besides their regular education, they must go through 74h of "additional training in advanced life support, paediatric advanced life support, and trauma life support. Nurses, however, receive 40 hours of driving instruction on top of that". (Page et al., 2013).

Regarding the used vehicles in emergency system, it is possible to distinguish 5 different vehicles that are described in Table 2. Helicopter is an extra vehicle used in situations in which is impossible to use roads or if the patient is in critical condition and requires a faster procedure. Helicopters require a doctor, a nurse and two pilots as staff members (Afonso, 2014).

Table 2 - Description of the vehicles from the Portuguese EMS (Afonso, 2014).

Vehicle	Actors	Description
AEM Medical Emergency Ambulances	2 EMT's	a) Equipment: evaluation, stabilization and resuscitation. b) Goal: Stabilization of patients in medical emergencies that require transportation to the most suitable medical unit. c) Ambulances that are sent in more critical situations.
SIV Immediate life support ambulances	Nurse + EMT	a) Immediate life support equipment. b) Goal: Stabilization of patients in medical emergencies that require transportation to the most suitable medical unit.
VMER Emergency and Resuscitation Medical Vehicle	Doctor + Nurse	a) Advanced life support equipment. b) Goal: Fast arrival to the scene. Provides a differential treatment during transport to the healthcare facility.
MEM Medical Emergency Motorcycle	EMT	a) Equipped with DAE, oxygen, ventilator, vital signs detector, airways' helper and other materials. b) Goal: fast arrival to the scene and primary evaluation of the victims, getting them ready for a possible transport. c) Important for triage situations.
TIP Paediatric Inter-Hospital transport ambulance	Doctor + nurse + EMT	a) Requires paediatric and neonatal knowledge. b) Equipment of evaluation, resuscitation and stabilization c) Goal: arrival to the patient, stabilization and transportation to a healthcare facility with human resources necessary to treat a newborn or a child.

Dispatch Centre – CODU

Answering 112 call is a task for the police. If the call is health related it is redirected to the emergency dispatch centre. In Portugal, dispatch centre is called Urgent Patients Orientation Centers (CODU) and belongs to INEM (National Health Service, 2017). There, a dispatcher fills out a questionnaire (supervised by a doctor) and, depending on the situation decides upon either giving advice or sending an emergency vehicle. There is a standardized approach when dealing with patients.(Afonso, 2014) In life-threatening situations, a doctor and a nurse will accompany the vehicle (Gomes et al., 2004, Page et al., 2013).

While allocating resources, control centre takes into account 3 criteria: victim situation, proximity to the incident location and accessibility to incident location. Also, the chosen hospital is preselected by CODU, based on location and available resources to provide the correct treatment to the victim (National Health Service, 2017).

If the call is classified as non-urgent, dispatcher does not allocate an INEM vehicle and transfer it to other entities such as the health line 24 (" Linha de Saúde 24). (Afonso, 2014).

The first CODU was founded in 1987 in Lisbon. Currently, there are three CODU's working 24 hours per day across the country: Lisbon, Porto, Coimbra (Padilha et al., 2015, INEM, 2017).

In these centres, there are three types of professionals:

1. Doctors guarantee a good clinical scenario evaluation and hold the following functions (Afonso, 2014, INEM, 2017):
    i. Triage control and support;
    ii. Emergency Vehicles monitoring;
    iii. Validation of the medical actions;
    iv. Coordination with the doctors from the healthcare units;
    v. Counselling in poisoning situations.
2. Technical emergency operators (TEPH) perform screening, counselling, selection and allocation of resources. They must handle calls, perform triage according to pre-defined algorithms and give counselling (Padilha et al., 2015).
3. Also, there are other healthcare professionals that guarantee the physiological support during emergencies (Afonso, 2014, INEM, 2017).

Figure 3 summarizes CODU functioning after receiving an emergency call.

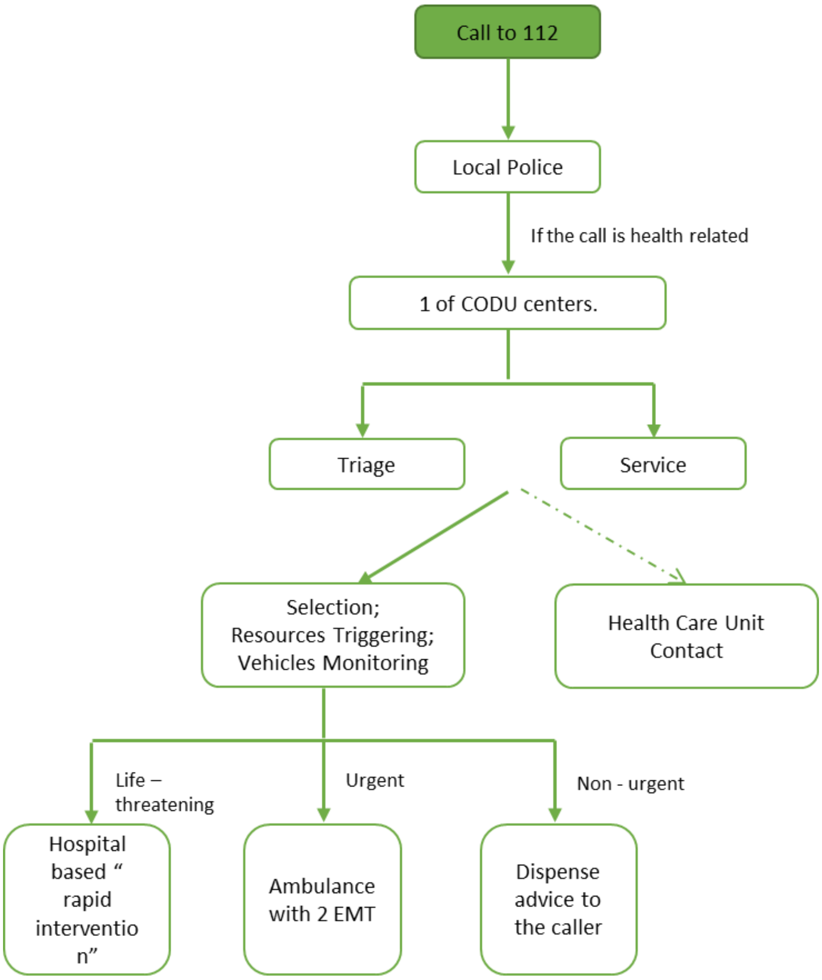

Figure 3 - Summary of the dispatch process (Christopher Page, 2013,(Afonso, 2014)).

2.2.3. Germany

Germany is organized 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 (Roessler et al., 2006).

The German Emergency Medical system is used as a role model for many nation EMS systems across Europe. However, over the past few years, a constant criticism has risen due to verified rising costs, decrease quality and efficiency pitfalls (Koch et al., 2008) .

Actors and Ambulatory system

German EMS use three different road vehicles:

- *Rettungswagen (*RTW), that is an emergency ambulance;
- *Krankentransportwagen* KTW), that is an ambulance used in non-emergency patient transport
- *Notarzteinsatzfahrzeug* (NEF), a small vehicle for emergency doctors (Roessler et al., 2006).

Moreover, depending on the severity level of the emergency, different staff levels might be used in the rescue chain. They can be divided into two major groups: non – physician and physician. The non - physician level is divided into three levels according to the degree of training: *Rettungshelfer* (RH) – basic EMT, *Rettungssanitater* (RS) – medium trained EMT and *Rettungsassistent* (RA) / paramedic. RH are usually used for non-emergency transports. Those levels are displayed in Table 3 below (Roessler et al., 2006). It is also possible to have emergency physicians. There are doctor that add a "rescue service" education (Deutsches Rotes Kreuz, 2017).

Table 3 – EMS workers: Detailed description (Roessler et al., 2006).

Level	**Training**	**More Info**
Rettungshelfer (RH) / basic EMT	240h: 160h (class room) + 80h (practical in hospital)	Focus on resuscitation and emergency medicine. They are usually volunteers either in events or are present in ambulances for non-emergency transport.
Rettungssanitater (RS)/ EMT	520h: 160h (class room) + 160h (practical in hospital) + 160h (practical training in ambulance)	
Rettungsassistent (RA) / paramedic	2 years: 1 year (1200h theoretical + 1200h practical) + 1 year (1600h in the ambulance)	

In German federal states, an emergency ambulance (RTW) has at least one RS and one RA. Since non-physicians workers are not authorised to either perform some more complex measures (intravenous access, defibrillation, intubation) or to give medications an emergency physician is always required (Roessler et al., 2006).

For special types of treatments, a doctor is always required by law. Then, ambulances must always be equipped by two staff members: 2 RS or, in emergency rescues, at least one RA. Also, a doctor meets the scene in a special car called NEF. In addition to these vehicles, also helicopters and aircraft can be used (Reuter-Oppermann et al., 2017).

Dispatch Centre: Function.

In order to ensure an effective emergency care, it is important that all time critical medical requests are centrally coordinated. Actually, eighty percent of all control centres are integrated centres that are able to coordinate simultaneously the EMS, non – emergency ambulance transport and the fire brigade Only police keep their own dispatch system (Roessler et al., 2006).

Answering an emergency call is one of the most important tasks within the Emergency Rescue Chain (ERC). This is processed in the integrated control centre. A qualified emergency call is required to get a fast and secure answer, categorize the deployment and thus allocate the appropriate resources (Roessler et al., 2006).

According to the critical time level, three service categories can be distinguished. The more critical the requirements for the control centre are, the more original is this service. Table 4 lists the main services according to the assigned category (Koch et al., 2008).

Table 4 – Some listed services examples according to categories (Koch et al., 2008)

Original services Core competence; Mandatory a fast answer.	**Peripheral services**	**Additional services** Try to respond do specific regional requirements.
b) All time-critical medical help c) Fire protection d) Civil protection after catastrophe	a) Poison Counselling b) Pharmacy service c) House emergency call d) Transport of sick people e) Psychosocial services f) Social services	a) Health care counselling

Taking an emergency call should not take longer than 120 seconds, considering the running time between the call acceptances until the alarming. This amount of time depends on the considered federal state. For example, 120 seconds is the target time in Baden – Wuttenberg(BW). In BW the median time level for the past year layed in the 115 seconds and the 95% percentile is 251 seconds (Lohs, 2017).

Control centre has several staff members called dispatchers. They are usually employees or officials at the control centre. The number of allocated workers depends on the calculated workload. Depending on the internal organization of the centre, a dispatcher might either takeover a complete emergency or share/split the task among other workers that might exist. The dispatchers in the control centre often have the medical training, which is also necessary for the on-site staff (Lohs, 2017).

According to the protocol available for the Kaiserslautern city, there are five questions/steps to be answered when taking an emergency call (Stadt Kaiserslautern, 2017). They are valid all across Germany:

1. Where is the accident?
2. What happened?
   a. By answering this question, the dispatcher is able to classify the call in one of the six types of incidents: inserts burn; traffic accidents; dangerous substances; animals; people in compulsory condition; Medical (serious) incident. With this classification is possible to have a better allocation of resources and even a combination of classification for one incident.
3. Number of injured people/ type of injury.
4. Who is reporting the accident?
5. Instructions to the caller.

Giving a correct answer to these steps is key to the success of the rescue chain that is going to be explained in the next chapter.

2.3. 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 (OECD, 2016a). 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 (Silva et al., 2012). 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 (Holtmann et al., 2006).

In this dissertation, stroke, a commonly known vascular disease is going to be evaluated in terms of EMS answer after an occurrence, due to its severe incidence, frequency and medical outcome.

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]”(Silva et al., 2012).

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 (Vaz, 2011) .

As strokes have a narrow treatment time window, according to Vaz Vaz (2011), the severity of neurological damage is intrinsically connected to the time that elapses until the end of the treatment process. In Portugal, EMS services show a special treatment process when it comes to rescuing stroke patients while in Germany there is no treatment protocol exclusively directed to stroke patients.

2.4. Final Considerations

Along this chapter, an insight about health care systems and emergency medical services in Europe and their main features in Portugal and Germany is presented. Posteriorly, there is an introduction to the strokes as a critical issue in nowadays society.

In the next chapter, we will start by reviewing the Portuguese and German literature regarding the ongoing rescue emergency chain then we will present the set of challenges that have been recorded by the official reports and experts on the topic.

From this chapter, it is possible to conclude that, taking into consideration nowadays society, HCS and EMS, it is imperative to evaluate and improve the emergency systems. It is extremely important to reply to the demographic and epidemiological changes that have already been identified.

3. Literature Review

This chapter offers a review of the main concepts that exist in the literature in the emergency rescue chain topic. Different methods that allow evaluating the rescue chain will be analysed.

The purpose of identifying and structuring concepts concerning the Emergency Rescue Chain (ERC), 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” (Kaiser et al., 2015) through the application of a model (Kaiser et al., 2015).

3.1. Review of Concepts: Emergency Rescue Chain

Globally, Emergency Rescue Chain (ERC) corresponds to the process activated by a sudden illness that culminates in the arrival to the health care 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 calling, dispatching and ambulatory service (World Health Organization, 2008).

Rescue chain is a sequence of chronologically and qualitatively successive subprocesses within emergency rescue that must ensure a total coordination between the rescue service team and the hospital (Koch et al., 2008).

In addition to patient considerations, several other factors affect prehospital care: personnel, environment, resources and logistics (Wilson et al., 2015).

In the following sections, Portuguese and German ERC are 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 (Figure 4). In Table 5 there is a detailed description of Portuguese Rescue Chain. (Afonso, 2014)

Figure 4 - Portuguese Rescue Chain (Afonso, 2014).

Table 5 - Description of the stages of Portuguese ERC according to SIEM. (Afonso, 2014)

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

3.1.2. 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 (Coordenação Nacional para as Doenças Cardiovasculares et al., 2007).

According to Dr António Marques da Silva's opinion, the creation of alternative pathways - named *Via Verde* (VV) - for critical diseases was triggered by a malfunction in the Portuguese EMS System (Marques da Silva, 2017).

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, that must be taken into account since they are an important issue for the population general health (Coordenação Nacional para as Doenças Cardiovasculares et al., 2007).

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 and 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 that requires appropriate training. From that, is dependent an appropriate training. The later aspect is the transport to an adequate health care unit (Coordenação Nacional para as Doenças Cardiovasculares et al., 2007).

Before adopting VV, different regional differences concerning the cardiovascular diseases, available resources and necessities had to be accounted. It was also crucial to adopt clinical recommendations, involving INEM, defining adequate network points and creating evaluation systems (Coordenação Nacional para as Doenças Cardiovasculares et al., 2007).

The strategy encompasses 3 different stages: pre, inter and intrahospital. Prehospital VV corresponds to the EMS on scene treatment and transport to the respective hospital unit. This transport is usually a task for INEM or fireman services. Inter-hospital VV is also a task for INEM but requires physician supervision. At this stage, the main goal is the patient transport to a higher unit level. Therefore, the articulation between the different hospitals is crucial. The last stage is the intra-hospital VV and refers to the procedures performed upon patient's arrival to the hospital. According to the Institute of Neurological Disorders and Strokes, the maximum time between the arrival to the hospital and clinical evaluation is 10 minutes. The overall time, since the arrival to the hospital until the fibrinolysis, should not be more than 60 min. Above all, in vascular diseases like strokes, the severity of neurological damage is intrinsically related to the time that elapses until the end of the treatment (Vaz, 2011).

Actually, the first presented stage, "*pre-hospital Via Verde*", has a higher priority when compared to the remaining stages 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 (Coordenação Nacional para as Doenças Cardiovasculares et al., 2007).

VV Activation for strokes requires meeting all of the following mandatory requirements: (Moutinho et al., 2013, Soares-Oliveira et al., 2014).

- 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.

A stroke victim should be transported to a hospital with a stroke unit. A stroke unit (U-AVC) is an area within the hospital that deals almost exclusively with stroke patients. According to Health General Board (*Direcção Geral de Saúde* – DGS), stroke patients must be treated, at least during the critical stage, in a stroke unit. (Coordenação Nacional para as Doenças Cardiovasculares et al., 2007). A healthcare facility should meet all of the following requirements in order to be considered a stroke unit: (Soares-Oliveira et al., 2014)

1. External emergency system team can directly contact the hospital, in specific, the medical team in charge for strokes;
2. Providers of care have specific training:
   a. Alarming signals;
   b. Criteria for inclusion/exclusion;

c. Relation between time and outcome;

3. Having an emergency team in charge of VVAVC 24h/day, 365 days per year;
4. CT availability 24h/day, 365 days per year;
5. Thrombosis and Hematosis laboratory;
6. Fibrinolytic medicines available;
7. Available beds for patients with Strokes;
8. Implemented system for the record, monitoring and audit.

In Portugal, there are three stroke unit levels (A, B, C). Level A (central stroke units) and level B (regional stroke units) units can provide Fibrinolytic treatment. Level C units (basic stroke units) only receive the patients without indication to that treatment. Patients must be allocated, by CODU, to one stroke unit as fast as possible, having into account time and availability. Here, the traditional criteria of geographic influence no longer applies. (Vaz, 2011)

Since the introduction of the VV for strokes, there was a significative reduction on the death rate cause by this disease (Figure 5). This pathway has been designed in 2005 and launched in the emergency system in 2007. (Marques da Silva, 2017, Coordenação Nacional para as Doenças Cardiovasculares et al., 2007).

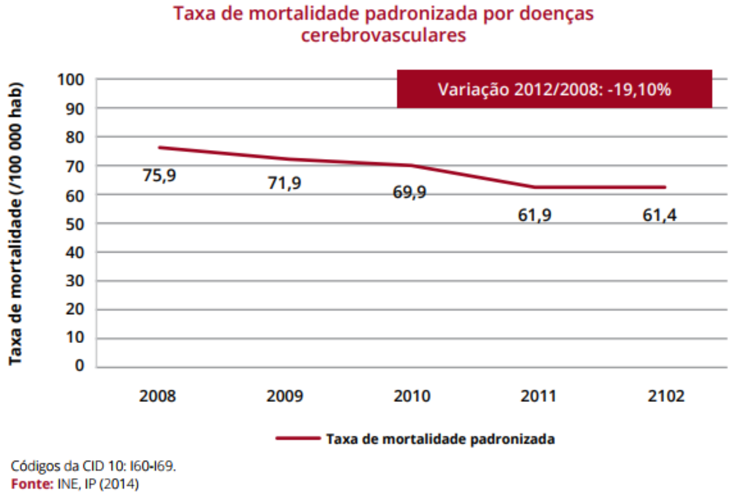

Figure 5 – Stroke death between 2008 and 2012 rate evolution.(Ferreira, 2016)

Though the hopeful results, there are still a lot of fragilities and limitations within the system that will be detailed in the following paragraphs.

3.1.3. Problems/Challenges in Portugal

In Portugal, Emergency Systems do not seem to share the same level of medical outcome with the remaining countries of European Union. For example, regarding strokes, by looking at appendix A, Figure 47, is clear that there is still a gap.

According to Dr António Marques opinion, EMS can be perceived as a survival chain. Each chain is as strong as its weakest link. In Portugal, there is a weak link called: education of the population. Knowing that VV-AVC is citizen activated and if citizens ask too late for help, the probability of arriving in due time to the hospital is reduced. It is necessary to invest in both education for recognizing symptoms and for preventing illnesses. Without strengthening this bond will be impossible to achieve better results, even, if there are improvements in the assistance network (Ordem dos Enfermeiros, 2012)

Furthermore, other problems emerge when considering detail to the ERC. In the dispatch centre (CODU), sometimes TEPH workers face difficulties. Users are not always capable to answer questions due to the emotional shock, leading to triage. Also, there is lack of supervision. TEPH are not physicians, and sometimes there is a misfit between the diagnosed severity and the real one, blocking the allocation of the correct resources (Ordem dos Enfermeiros, 2012, Afonso, 2014).

Also, there are frequently difficulties in the allocation of resources: most adequate vehicles are not available. A possible solution goes by triggering other vehicles from more distant stations (Afonso, 2014).

Regarding hospitals, not all health facilities have capacity to receive emergency patients, in particular patients that have been allocated to VV's. There is no connection between the primary care facilities and the emergency departments. Some patients should be allocated to the primary care facilities, leading to an overload in the hospitals with emergency departments. There is also a lack of training for doctors (Ordem dos Enfermeiros, 2012).

Over and above these problems, Portugal also reveals regional asymmetry, this means, some regions do not have access to the best emergency response because there are no ways to do it (Ordem dos Enfermeiros, 2012).

3.1.4. German Emergency Rescue Chain

It is the task of the rescue service to ensure that the population has access to the appropriate emergency rescue services, with and without an emergency physician, as well as transportation to the most suitable healthcare facility (Koch et al., 2008).

Emergency patients show a high risk of a life-threatening disturbance of the vital functions (breathing and circulation) or serious disturbances of other important functional circuits such as consciousness, water-electrolyte balance, acid-base metabolism and metabolism (Koch et al., 2008).

In Germany, rescue services are anchored in the SGB V 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. The emergency care unit is a functional unit of a continuous, graduated care process from the site of the incident until the treatment in the healthcare facility (Koch et al., 2008).

The main goal of the rescue service team is to perform life-saving techniques for emergency patients at the incident location, if necessary, make the patient transportable, transport them to an appropriate healthcare facility, while restoring and/or maintaining their transportability and avoiding further damage (Koch et al., 2008).

Figure 6 reveals the implemented Pre-hospital Rescue Chain in Germany. Table 6 details the activities performed in each stage of the presented ERC.

Figure 6 - German Rescue Chain (Deutsches Rotes Kreuz, 2017)

Table 6: Description of the German Rescue Chain according to the stage, activities performed and intervenient. (Deutsches Rotes Kreuz, 2017)

Stage	Activities	Intervenient
Protection	a) 1st you guarantee that you are safe and then you help the others	Caller
Emergency call / immediate measures	a) securing accident site; b) rescuing from the danger zone, c) resuscitation and breathing if necessary, d) blood stilling e) shock control f) production of the stable lateral position g) emergency call while performing the assistance	Caller and Dispatcher
First Aid	a) Extended emergency measures at the scene b) 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	c) Rescue d) Transport e) Focus: restoration of the vital functions ate the incident scene and their preservation during the transport	EMT's / Paramedics/Doctor
The clinic	a) Diagnosis	Doctor

3.1.5. Stroke Rescue in Germany

Stroke is one of the biggest challenges in Germany, as in Portugal. The annual costs related to stroke incidents in 2008 were 8.1 Billion € (Görlitz et al., 2012). The total number of strokes in Germany is about 165,000 annually, which can be traced back to approximately 150,000 newly occurring and approximately 15,000 relapsed cases per year. Stroke-related death rate is about 40% within the first year after the occurrence, which means that about 66,000 strokes per year are fatal. Of the nearly 100,000 stroke patients who survive the first year, around 64,000 require post-hospital treatment, having 15% from those still to be cared for in nursing homes after one year (Holtmann et al., 2006).

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 (Holtmann et al., 2006).

Therefore, the approval in 2000 of thrombolysis as treatment of ischemic stroke improved the patient survival and healing chances, within a maximum period of three to six hours after the first appearance of the symptoms (Holtmann et al., 2006).

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. Therefore, three main categories can be highlighted to reach this purpose (Holtmann et al., 2006):

1. Educating the population about the stroke;
2. Organization of acute stroke care;
3. Optimal management of acute stroke.

If these three areas were transferred to the overall process of the stroke supply, we would have three distinct stages: (Holtmann et al., 2006)

1. Detecting and alarming;
2. Preclinical (out of the hospital);
3. Inner clinical. (in the hospital).

According to the literature, the three stages presented above show different limitations, leading to efficacy challenges. The possible solutions and result are displayed in Table 7. Time-saving is always the major factor when dealing with strokes. The faster the patient is identified and transported, the higher is the probability of having a good outcome. (Holtmann et al., 2006)

Table 7 - Stages of stroke rescue and possible solutions according to the literature (Holtmann, 2006).

Stage	Solution	Result	Reason
Detecting and alarming (Silver, 2003)	Education programs	Improved knowledge and awareness of the symptoms of acute stroke in the general public.	The amount of time between the occurrence of the first symptoms until the arrival of the rescue service could be reduced.
Preclinical phase (Busch et al., 2003, Kluth et al., 2005, Hennes et al., 1999)	Better paramedics training and optimization of logistical problems.	Quick and safe stroke recognition.	Time saving
Inner-clinical phase. *(Holtmann, 2006)*	Medical training	Better clinical care process beginning.	Time saving

Furthermore, based on the recognized guidelines, the appropriate therapy must start within a 90 min period for stroke emergencies (Lackner et al., 2009).

To meet these requirements, in-patient diagnosis and therapy must start at least 60 minutes after the emergency call. Moreover, ambulatory travel time until the incident location should not surpass 15 minutes. As around 15 minutes is required for onsite care, then a maximum of 30 minutes remain for the transport to the target clinic (Lackner et al., 2009).

In the article " Stroke Management as a Service – A distributed and Mobile architecture for post-acute stroke management" from Roland Gorlitz (Görlitz et al., 2012), the biggest problem faced by Germany regarding stroke rescue is revealed: lack of connection between the different stakeholders involved in the treatment process, such as doctors or nurses, leading to information asymmetries and uncoordinated process. (Görlitz et al., 2012)

Accomplishing better results in terms of efficiency requires a cross-sectional view of the supply process. Preclinical and In-Hospital stages cannot be analysed separately. A better connection between the rescue service and the clinical must exist (Holtmann et al., 2006). By using information technology resources, it is possible to positively affect the procedures and to obtain better treatment outcomes.

3.1.6. Stroke Angel project - Germany

Stroke Angel was a pilot project that tried to optimize the preclinical rescue assistance in Germany by introducing mobile devices. It focused on the entire process – from the emergency call to the patient's discharge. By developing this experiment, a database to evaluate service quality and innovation was designed (FZI, 2013). This study was conducted by the neurology department of the Rhön Clinic and some partners. Figure 7 depicts the main idea concerning the required resources along the treatment process.

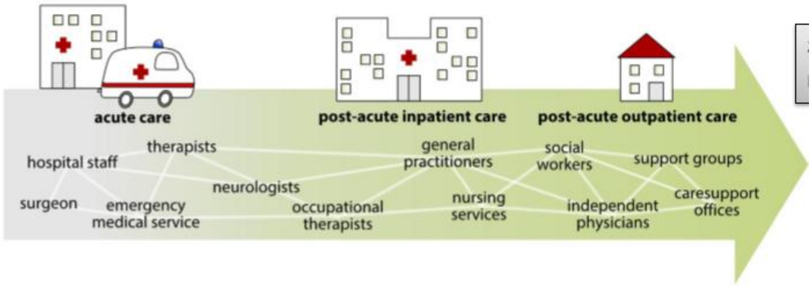

Figure 7 - Stroke Angel necessary resources. (FZI, 2013)

Figure 8 summarizes the intervention of this process across the treatment chain. Two different stages are presented, stroke angel (prehospital EMS) and stroke manager (in hospital EMS), that focuses after the patient enter in the healthcare facility.

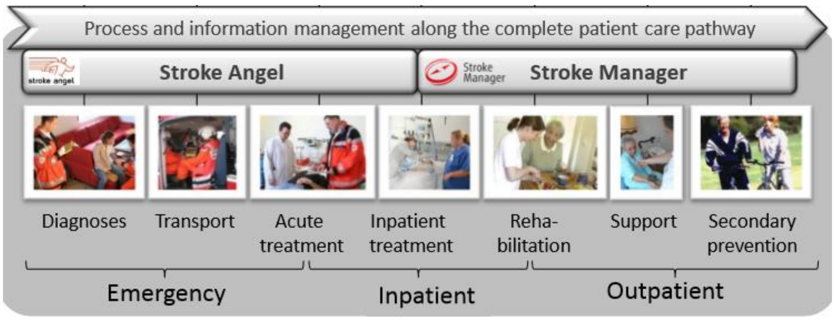

Figure 8 – Complete patient care pathway (FZI, 2013)

The project Pervasive Computing in Networked Medical Care (PerCoMed) evaluated stroke angel by looking into the chances and risks in healthcare sector arising from the use of mobile technologies in networked medical care. It used an interdisciplinary approach that not only examined technical issues as well economic and social ones. (Holtmann et al., 2006)

According to Holtmann (Holtmann et al., 2006), results from Stroke Angel evaluation system were very optimistic (Figure 9). This project verified that speed and quality of stroke diagnosis could be increased, as well as having a patient-centred system with a more efficient supply. (Holtmann et al., 2006)

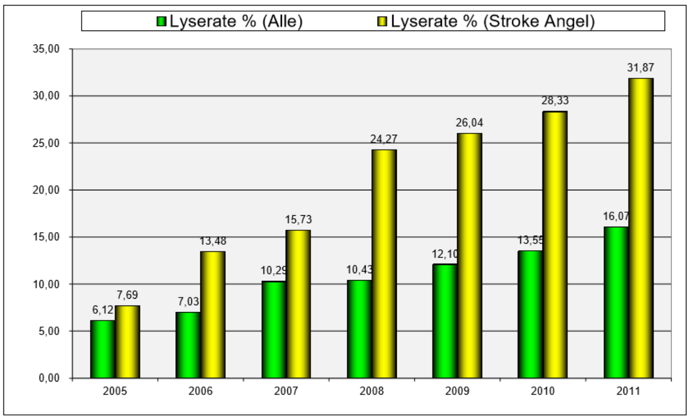

Figure 9 - Stroke Angel Results (Stroke angel, inspire) (FZI, 2013)

3.1.7. Problems/Challenges in Germany

Demographic change (sparsely populated regions, migration of young people, and the influx of older people) is increasing the pressure for reforms on the healthcare system. The ageing society will lead to the increase in cardiovascular, chronic diseases (ex. Diabetes) and morbidity, with a serious rise in health expenditure. So, the overall use of the rescue services will increase. Changing social structures and structural problems are nationwide challenges (Koch et al., 2008).

Emergency care structures must maintain the quality of the services provided. However, due to factors such as age-related retirement, lack of specialist personnel up to the regional medical profession, lack of staff members, and increase in morbidity and comorbidity rates, EMS services must be overhauled (Koch et al., 2008).

The risk of misuse of the emergency care structures due to incorrect allocation, lack of coordination of the participants and sectoral disintegration will be reflected in the further quality and efficiency losses (Koch et al., 2008).

Actions such as locally oriented care facilities and patient-oriented structures as well as improving social services are essential to counteract the decrease of quality of the EMS and the effects of demography change (Koch et al., 2008).

Currently, investment funds for hospitals are declining. As a consequence, from the reduction of the number of hospital facilities and working days (political plan), the flow of in-patients into the healthcare facilities increases, even if their residence time is smaller. This development entails the risk that emergency rescue operations in structural regions will ultimately be performed by the "Rotsift" (Lackner et al., 2009).

As a result, existing target clinics or local hospitals are no longer participating in the acute segment of hospital services in the rescue service (Lackner et al., 2009). A possible solution to face these problems might go by having a clear access regulation and central coordination of all time-critical medical emergencies. (Koch et al., 2008)

Due to the time pressure that is submitted, the integrated dispatch centre should be first evaluated and then optimized, by applying the following measures (Koch et al., 2008):

1. Establishment of the control centres according to some valid minimum standards.

2. All time-critical medical help requests must be handled via the control centre and centrally coordinated.
3. Training of the control centre personnel according to established minimum standards.

Concerning the rescue emergency service, due to the lack of coordination between the rescue service and the medical service, there was a relative failure rate of 30%-40% until 2008. A possible solution is a systemic integration of preclinical and intra-clinical emergency care by setting up a central emergency unit. (Koch et al., 2008)

The systemic integration of the preclinical and intra-clinical emergency care leads to a synergy which results in a more efficient and effective system. Moreover, the interfacial problems during the admission of patients are reduced. Also, there are fewer information losses. From an economic perspective, the cooperation between the rescue assistants in the emergency room might lead to a better refinancing and a personal saving. (Koch et al., 2008)

The patient-centred and effective emergency care with efficient structures can be achieved by a systemic integration of the joint planning of the hospital emergency care and the rescue service. Simultaneously there is a central coordination of all medical help requests. (Koch et al., 2008)

Assuming 24 medical emergencies per 1000 inhabitants and year, about 2 million emergency medical units were performed nationwide. From a purely arithmetical point of view, about 800,000 emergency medical devices are not genuine emergency medical devices. As some medical care emergencies situations can be treated by the general practitioner in an effective and efficient way, the emergency physician is not required in these situations. A rational use of the resources should be taking into account also in the number of health professionals used. (Koch et al., 2008)

Several reasons might appear to explain the misuse of the emergency care system:

1. Consciousness of the Population;
2. Quality of the emergency care by the emergency physician of the rescue service;
3. Confusion/ignorance of the emergency physician and emergency service/standby service;
4. Availability 24h.

Overall, Germany is facing several challenges in the upcoming years and a system adaptation is mandatory. Otherwise, the risk of system failure will increase exponentially. (Koch et al., 2008)

3.2. Simulation as a methodology

“A simulation model is a computer model that imitates a real-life situation”(Winston et al., 2009)

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. The next sub-chapters attempt to outline some theory regarding simulation model techniques.

3.2.1. Introduction to Simulation Theory

"Simulation can be defined, in general terms, as means for deriving measures of performance about a complex system by conducting sampling experiments on a mathematical model of the system over periods of time"(Lee et al., 1985).

Mathematical models represent systems by a series of equations while for computer simulations, logical models (flow charts) are required (Pitt, 2004). A simulation mimics the behaviour of a "system, phenomenon or process" (Kaiser et al., 2015) through the application of a model (Kaiser et al., 2015). 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 (Pitt, 2004).Third, by using simulation is possible to obtain "entire distribution of results" (Winston et al., 2009), not only one. Therefore, raises the possibility of finding solutions and their respective analysis when analytic calculations are not suitable (Grigoryev, 2015).

A simulation model is always an "executable model" (Grigoryev, 2015) that triggers changes in the final state of the system, providing flexibility at expense of accuracy of results (Lee et al., 1985). In order to obtain operational information in a simulation process, it is required the execution of a model, in which, the output data describes the behaviour of the simulated system (Lee et al., 1985). Figure 10 represents the in-out flux during a simulation.

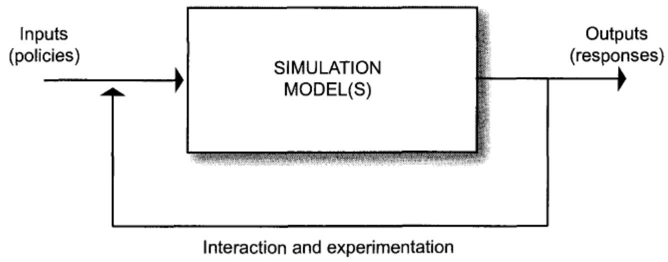

Figure 10 - "Simulation as experimentation"(Pitt, 2004).

A simulation study can be briefly described by being a three stages problem: problem structuring, modelling and implementation. The first, problem structuring, is an attempt to understand the issues that are being proposed and respective challenges and interconnections. The second, modelling, can be seen as the "technical heart" of the study and is defined as a gradual learning process. The model execution should start with simple representations and move "step-by-step towards a more complete representation" (Pitt, 2004), in which, there is a portrayal of all the requested features. Upon each stage there should be a partial validation. Figure 11 attempts to reveal links among the different pieces of the modelling process (Pitt, 2004).

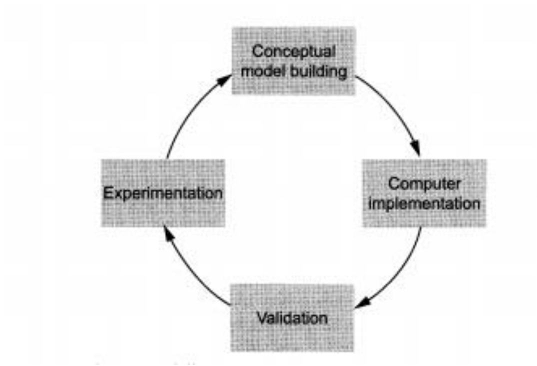

Figure 11 - Simulation Modelling (Pitt, 2004).

Conceptual Model Building captures the essential features of the system that is being analysed. This stage involves two main processes: identifying the problem main features and understand their interaction. The representation of this primary stage is made throughout sets of flow diagrams, text or a mixture between the two and is followed by a computer implementation. Validation classifies as suitable the developed model and determines if the model is a real system representation (Pitt, 2004, Lee et al., 1985). As most of simulation models are used to investigate subjects that are not fully understood, a complete validation is never possible. The final node during the modelling stage is the experimentation, where the model is used (Pitt, 2004).

The last step, implementation, rises as an attempt to integrate any recommendations that have emerged from problem structuring and analysis (Pitt, 2004).

A system that is being modelled is either deterministic or stochastic. Different classifications are connected to different modelling approaches. A system is considered deterministic if "its behaviour is entirely predictable" (Pitt, 2004). Contrary to deterministic systems, in stochastic systems is not possible to predict its performance. Usually stochastic systems are described by statistical distribution models. (Pitt, 2004)

Before starting a simulation is important to choose the abstraction level and modelling language. There are three different abstraction levels: low, medium and high. The lower the abstraction, more are the details required. Each abstraction level is connected to a different simulation method. There are three types of event: (Grigoryev, 2015)

1. Discrete event modelling – Represents the system as a process: a sequence of steps/operations that agents perform. It is connected to a low abstraction level. Operations might include: delays, services, splits, queues, etc.
2. Agent based simulation – Clients, employees, etc. This simulation level can vary from a low abstraction level (detailed) to a higher one.
3. System dynamic modelling – Represents processes such as stocks and flows. These systems appear as series of interacting feedback loops or balances. Due to the high level of aggregation of objects that are being modelled, the individual properties are lost, so it represents a higher abstraction level. When the individual characteristics are important is better to use discrete or agent based event modelling.

3.2.2. Discrete Event Modelling

Discrete Event Modelling (DEM) is a “next-event technique to control the behaviour of the model” (Pitt, 2004), mainly applied in queuing systems or in series of processes. There is a non-official agreed standard terminology, that divides DEM into two different sets: objects and operations (Pitt, 2004).

1. Objects of the system (Pitt, 2004):
    a. Entities: individual elements that are being simulated and whose characteristics are analysed
    b. Resources: individual system elements that are not modelled individually, being treated as countable items. So, they consist of identical items that the program keeps a count.
2. Operations (of the entities) (Pitt, 2004):
    a. Event: instant of time at which there is a change in the state of the system.
    b. Activities: entity moves from on set to another due to the operation and processes they engage. The operations and procedure that occur at an event are called activities.
    c. Process: sequence of events in the order they occur.

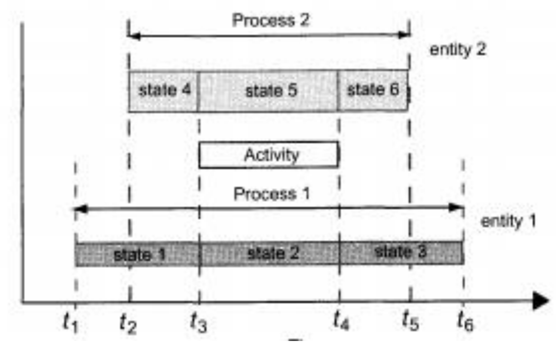

Figure 12 - Events, activities and processes (Pitt, 2004).

Figure 12 gives a visual idea for the time distinctions in the outlined operations.

3.2.3. Queueing Theory Models in simulation

Queues are formed when, upon a requested service at a service facility, a customer cannot be served immediately (Gupta, 2013).

Different scientific research has already been carried out to study queueing systems and their implications. Each system has the following elements: service stations (define the flux of customers), servers, service protocol, service time distribution, arrival process, size of the waiting room at each station (Gupta, 2013).

In Health Care Sector, queues creation is very common since it is frequent to have unmatched patients number with of service providers number. Here, patients are considered the “customers”. The service facilities can be, for example, a certain department within a hospital. Each service facility might have one or more service stations where customers (patients) are served. A service station has a specific task at the facility and might comprise one or more servers. The different servers can be grouped or not (Gupta, 2013).

The vast majority of queueing models consider customers a discrete variable and the amount of customers in the queueing line an integer value (Gupta, 2013).

Queue analysis has generally different purposes: evaluate, quantify and determine whether is possible to optimize the system (Winston et al., 2009). In this dissertation, queueing theory models are being explored in order to analyse and evaluate the different emergency call centre stations in ERC.

Assessing queuing systems remit to two different approaches: analytical or simulation. Analytic techniques involve complex mathematical formula calculations that frequently require *a priori* simplifications. Usually these simplifications make the process unrealistic, too simple and look only into the system steady state. By using simulation techniques is possible to reproduce more complex models without losing the “real” factor (Winston et al., 2009).

However, according to Winston, “Queueing simulation are not really straightforward” (Winston et al., 2009). The main reason for this phenomena is the necessity of generating random times between customer arrivals and service times(Winston et al., 2009). Therefore, it has several advantages that make simulation an easier tool rather than analytic calculations. Firstly, it is not restricted to use assumptions, avoiding unrealistic conceptions. Secondly, it grants a cross-sectional view of the entire queue across time. The downside of using simulation techniques is intrinsically connected to the fact that is hard to keep a track “of the systems as events occur through time (Winston et al., 2009).

3.3. Conclusions of the literature review

This literature review points out the major problems regarding EMS and ERC. Germany reports as major issues demographic change and lack of coordination between rescue service and medical service. The progressive ageing of the population increases the morbidity levels that, in turn increases the overall use of the rescue services. The later issue, is visible in the relative failure levels (30% - 40% until 2008). A systemic integration is key for solving this problem. In Portugal, regional asymmetries verified in Portugal contribute to the misuse of the emergency system. Furthermore, an insight about simulation theory is given.

Thus, next chapter will describe a possible methodologic approach that tries to analyse the existing problems in the ERC’s in both countries by taking in computer simulation techniques.

Therefore, a procedure to run a simulation that mimics the Portuguese and Germany ERC is suggested.

4. Design Methods to evaluate the Emergency Rescue Chain

In previous chapters, the importance that EMS systems hold at saving lives was explained and Portuguese and German EMS, focusing on ERC, have been described. Furthermore, simulation theory has been introduced.

Taking into account those reviews and the fact that, in the literature, there is no methodology that directly helps to evaluate the ERC, it was suggested looking at the currently used structure. The chosen software used to evaluate the ERC was AnyLogic.

4.1. Proposed methodology description

In this project, it was decided to use computer simulation techniques to evaluate and analyse the ERC process. According to Michael Pitt, “in a computer simulation we use the power of computer to carry out experiments on a model of the system of interest” (Pitt, 2004). 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 should be used (Grigoryev, 2015, Pitt, 2004).

As we are dealing with several details from a complex and real system, a set of ordered steps must be met. Hence, Figure 13, summarizes the proposed methodology. The process starts by data collection. It is gathered through two different methods: qualitative (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 address which questions to 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 design 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 implement the ERC and verify how does the system behave, by varying doctor necessity parameter, control centre servers and available ambulances.

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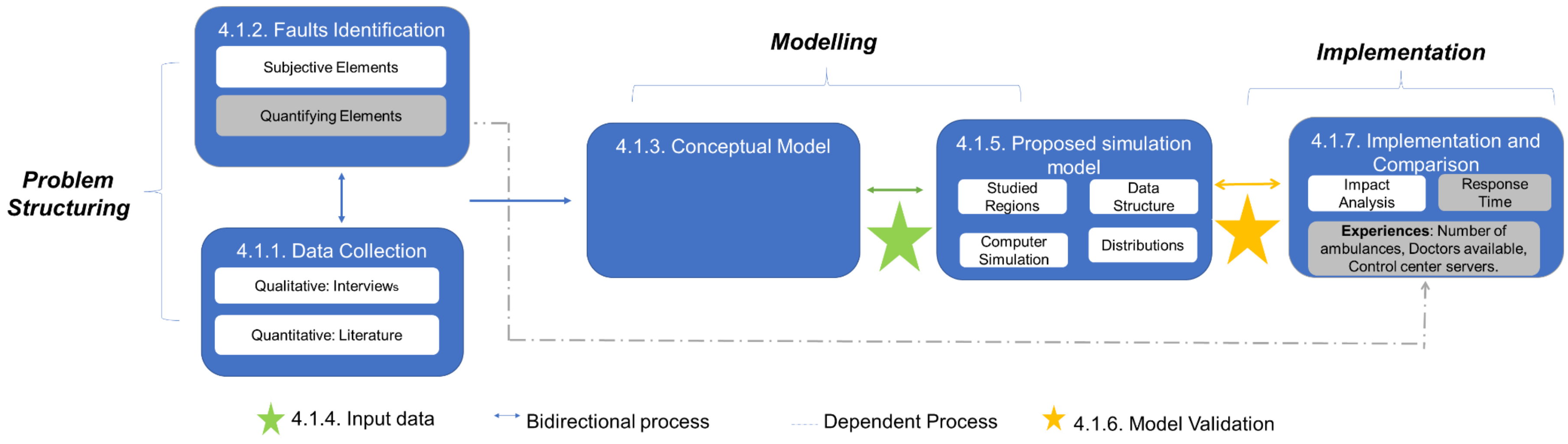


Figure 13 - Scheme of the proposed methodology

4.1.1. Data Collection

The first step of the proposed methodology is data collection and is the main source of information used in the following stages of the methodology.

Two different approaches are used to retrieve the necessary and appropriate data: qualitative and quantitative. Qualitative information is obtained through semi-structured interviews to experts, while quantitative information is the one gathered from the literature. At this point, using both gathering techniques is crucial to have a better understanding regarding the ERC. Experts express their point of view based on the reality, fact that is not always detectable in the literature.

4.1.2. Faults identification

From the collected data, it is possible to identify the main concepts that should be analysed in the studied systems. As there are some known limitations that require finding theoretical information in the literature to support their validation, the process of collecting data and identifying faults is considered a bidirectional process (identified by a bidirectional arrow in Figure 13).

4.1.3. Conceptual Model

According to Michael Pitt (Pitt, 2004), 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 (Pitt, 2004).

Therefore, after completing stages 4.1.1 and 4.1.2 of the proposed methodology, it 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 ERC model diagram.

4.1.4. Input data

Conceptual model is followed by a computer implementation. Before moving towards this step is crucial to identify which is the data required to execute the computer simulation model. In the case of the ERC the necessary input is:

1. Number of emergency calls per day;
2. Number of emergency calls per day that are identified as strokes;
3. Number of incidents per district per day;
4. Number of incidents per district per day identified as strokes;
5. Location of the ambulance’ stations;
6. Number of available ambulances;
7. Location of the health care facilities;
8. Health care facility capacity;
9. Number of dispatchers available in the call centre;
10. Number of emergency doctors available;

11. Location of emergency doctors;
12. Flux of incoming calls during the day.

4.1.5. Proposed Simulation Model

At the present stage, the study region must be analysed and then the computer implementation produced. It is important to look carefully at the study regions if there is more than one place. Different regions must produce comparable outputs throughout the simulation. AnyLogic software is chosen and used for the computer implementation. AnyLogic is a Java-based software that allows a multimethod modelling: combines different methods leading to more efficient models (Grigoryev, 2015).

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"(Borshchev et al., 2004). Each agent is modelled by adding parameters and charts that will influence their behaviour. Figure 14 shows how the combination of these two techniques takes place.

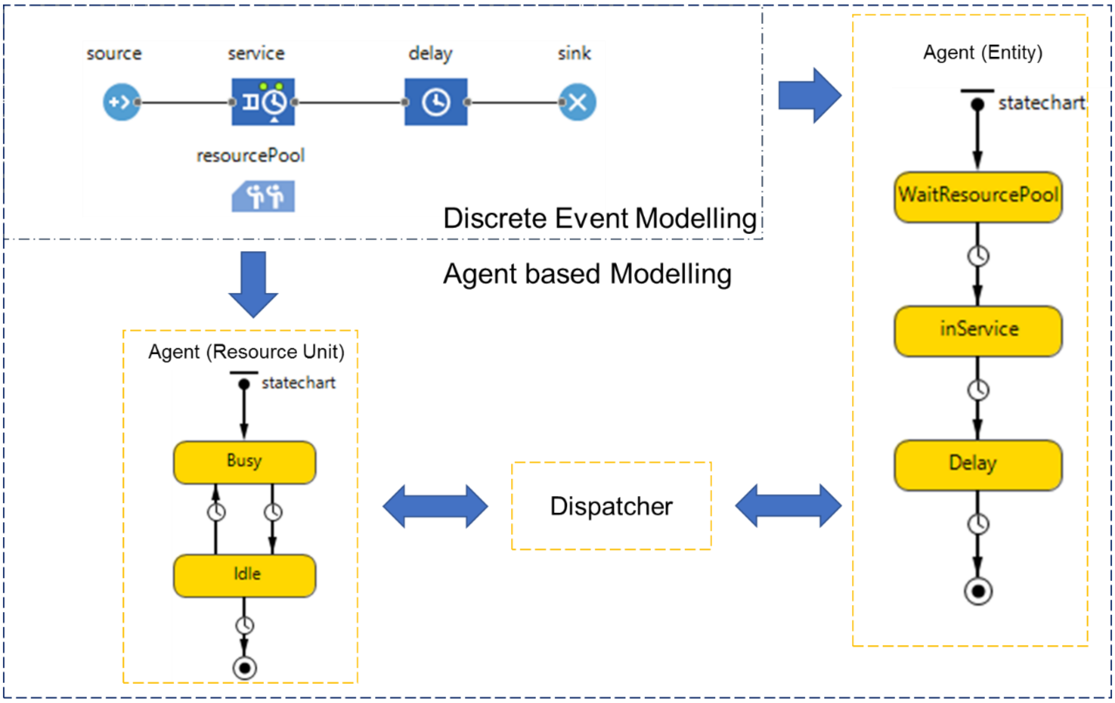
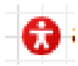
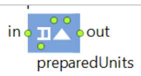
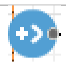
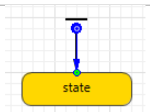
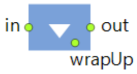


Figure 14 - Combination of Agent based with Discrete event based techniques. Inspired on: (Borshchev et al., 2004).

According to the software support tools there are some key features worth being summarized (Table 8). Some of them are also depicted in Figure 14.

Table 8 - Description of AnyLogic main features (The Anylogic Company, 2017)

Feature	Symbol	Description
Agent		Agents are used as building blocks of the model. They can have behaviour, memory, timings, etc. and can be characterized by parameters, variables, state charts, diagrams, etc.
Delay		Delay represents agents that are delayed for a period of time. Time is defined by the user dynamically.
Function		Functions are coded in Java and „return the value of an expression“ defined by the user „at each time the user calls it from the model“(The Anylogic Company, 2017).
Parameter		Parameters are used to represent the agent characteristics. They are visible and can change throughout the model execution.
Resource Pool		Resource Pool defines a set of resources that can be used in flow chart blocks.
Seize		Seize takes the resources in the resources from a Resource Pool and
Select Output		Select output routes agents „ to one of two outputs“ depending on a condition “(The Anylogic Company, 2017).
Service		Service comprises three different tasks: for a given number of resource unit seizes it, delays the agent and then release the seized units.
Sink		Sink corresponds to the end point of a process model.
Source		Source is usually the starting point of a model, being able to generate agents.
State chart		State charts can describe more complex behaviours, that cannot be described by a simple event.
Release		Release object releases a number of units that have been previously seized.
Variable		Variables are used to store the results of model simulation or modelling data units changing over time.

When modelling a process with AnyLogic there is a step order to be considered to simplify the intellectual process (Grigoryev, 2015).

1. Identify the agents involved;
2. Create Agents:
   a. Assigning Parameters to each agent;
   b. Assigning locations nodes to the corresponding agents;
3. Creating the Graph;
4. Matching the nodes locations of each agent with the graph;

5. Create State-Charts;
6. Model time units;
7. Add Distributions in the Flow charts;
8. Create Charts to visualize output associated with each agent;
9. Add effects between agents;
10. Identify Stocks and Flows;

4.1.6. Model Validation

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 (Pitt, 2004).

Validation intends to check if the computer programme is providing “valid results for the system that is representing”(Hillier et al., 2015), evaluating the performance of the simulation system and comparing it with the value measured for the real system (Hillier et al., 2015).

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

4.1.7. Model Implementation and Comparison

The later stage of the presented methodology corresponds to the use of the model. As some models can be used as tools for thinking and the designed methodology emerges in this line, the implementation goal is to have “ improved knowledge and insight” (Pitt, 2004).

Therefore, implementing the model offers the possibility of analysing control’s center ability to handle all incoming patient requests, ambulance assignments, response times, requiring a doctor and distribution of the overall ERC duration are analyzed.

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.

As it has been said before two study regions are being explored. In particular, two different cities are chosen: Lisbon and Stuttgart. Due to the origin of the data obtained, costumed methodologies had to be applied.

Nevertheless, some methodology’ 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

Therefore, four different interviews were carried on:

1. Prof. Dr António Correia de Campos – 18/05/2017
2. Dr Luis Meira and Dr Francisco Marcão – 23/05/2017
3. Dr António Marques da Silva - 23/05/2017
4. Dr Francisco Marcão – 14/09/2017

A summary about what was recorded during these interviews is placed in Table 9:

Table 9 – Interviews summary description.

Interview	Description
1	Reason for VV for strokes creation.
2	Problem identification in the VV for strokes. Literature data collection.
3	History about the Portuguese EMS until the VV for strokes creation.
4	Data collection regarding EMS and AVC in Portugal.

Germany

In Germany, the collected data was retrieved from the quality reports in Baden-Württemberg (Lohs, 2017). 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 must be estimated by experts. Hence, can be concluded that not all the information available for the simulation is real (Lohs, 2017).

4.2.2. Faults Identification – Portugal and Germany

According to section 4.1.2, it is important to retrieve Portuguese and German common system flaws and limitations. Those are broadly explored in Chapter 3.

Scarce resources can be tackled as quantifying limitations and analysed by the computational simulation model, suiting both the Portuguese and the German ERC Model.

1. Time Response;
2. Number of Doctors;
3. Base Locations;
4. Number of Dispatchers;
5. Number of ambulances available.

Systems subjective limitations cannot be run in the simulation. Nevertheless, if these problems were solved there would be a positive impact in the final output.

1. Education of the population;
2. Impact on the medical outcome of the quality of the health facilities;
3. Amount of information loss in the last stage of ERC;
4. Quality of medical response.

4.2.3. Conceptual Model – Portugal and Germany

Conceptual Modelling tries to capture the essential features of the systems that are being analysed. Though, for increasing model pragmatism and moving towards a real context, a detailed conceptual model was designed. This model suits features of both ERC models.

Bizagi is a process modelling software. In this study, it is used for picturing the overall ERC that is being evaluated. This design has 4 main parts that are showed in Figure 15 -18. The 4 figures together depict the essential features of the ERC.

1. Caller;
2. Dispatcher;
3. Paramedics/EMT
4. Paramedics and Doctor.

The designed process starts by triggering a call after an incident identification. Here there are two different options, either is the same person that has the accident that makes the call to the emergency number or a helper at the scene.

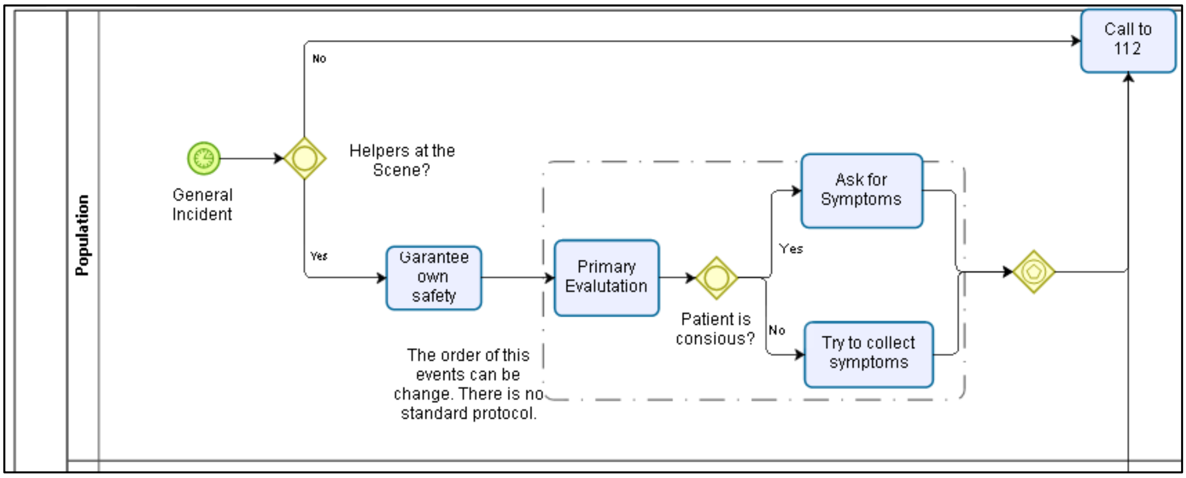


Figure 15 – First part of the Emergency Rescue Chain designed with Bizagi Modeler (a)

Afterwards, the call arrives at the dispatch centre where it must be answered. Two main tasks must be covered: triage and triggering the appropriate emergency service means (ambulance, doctor). Also, the hospital is contacted to ensure that has enough capacity to receive and treat the patient in the best way. In Portugal, in the case of a stroke, hospital must be contacted to ensure that it has a stoke unit.

The second part of Figure 16 shows that there are two options for the ambulatory transport in case of requiring a doctor: it can either meet directly the victim at the scene (*rendezvous*) or go inside the ambulance. In both cases, time is a crucial factor.

In the performed computer simulation, a call arrives at the call centre, and the waiting time for answering the call is simulated through a delay. Both dispatching of vehicles and doctor is simulated through a service delay.

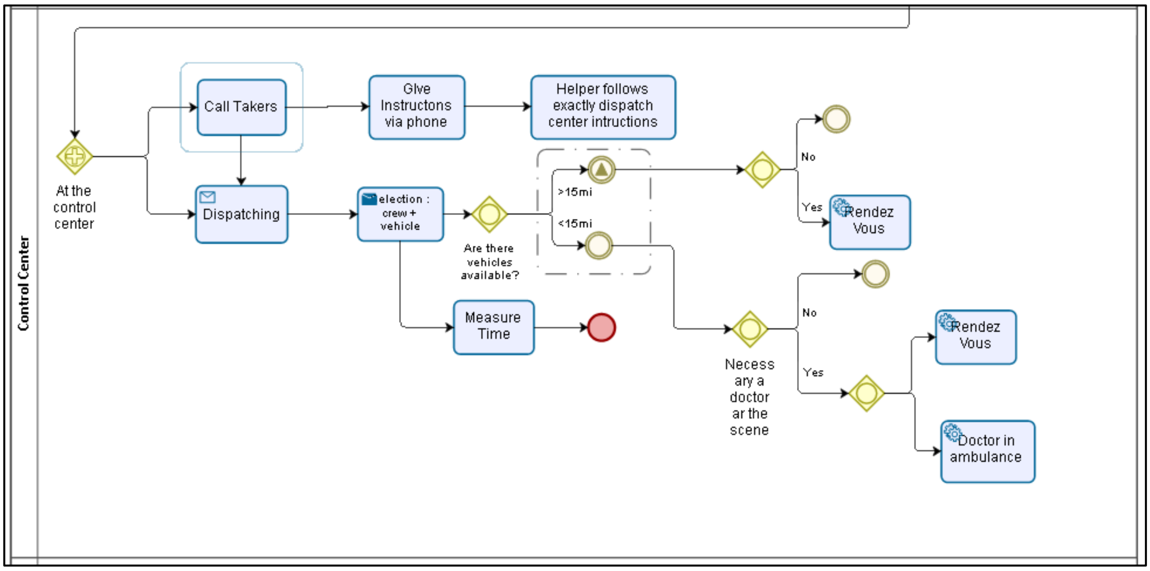


Figure 16 - Second part of the Emergency Rescue Chain designed with Bizagi Modeler (b)

After being dispatched, emergency vehicles reach incident scene. Figure 17 describes the different stages that take place at the incident location. While moving to the latest step, transport, one of two options can be selected: it can go either to the closest health care facility or to the most suitable one. This option depends on the severity of the situation, country and paramedics training.

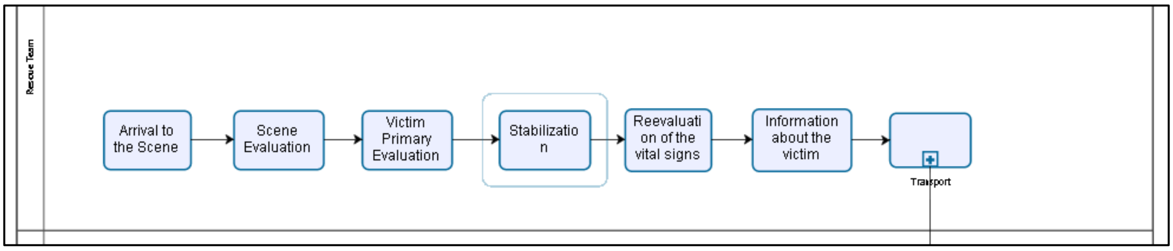


Figure 17 - Third part of the Emergency Rescue Chain designed with Bizagi Modeler (c)

Figure 18 represents the most critical step in terms of information losses as it represents the transferal from the pre-emergency services to the health care facility. Since there is no complete integration of the system, several times the paramedics do not give the patient's details to the doctors in clinics.

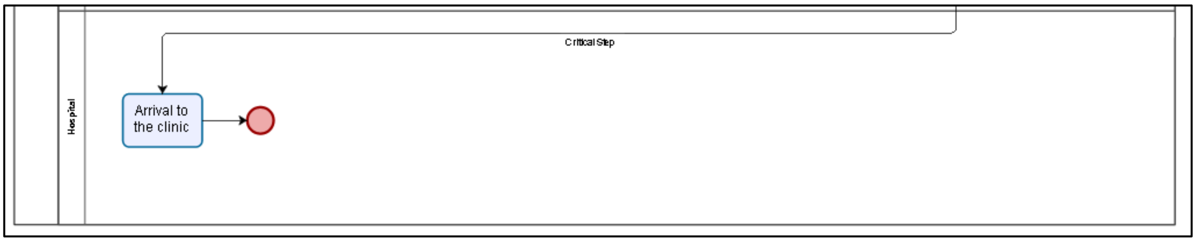
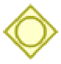
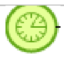


Figure 18 – Forth part of the Emergency Rescue Chain designed with Bizagi Modeler (d)

Overall Figures 15 – 18 will be simplified in the stage 4.2.5 of the proposed methodology to facilitate computer simulation process. Therefore, to better comprehending the depicted images, it is crucial to understand the meaning of each object. Table 10 briefly describes the tools used in those figures.

Table 10 - Description of the objects used in the Figures 14-18.

Symbol	Name	Function
	General Task, Receive Task and Send Task	Activity that is included in a process. There are several task types, such as, receive task and send task.
	Gateway	Decision Branch. The process can take one of two pathways. Allows creating conditions.
	Inclusive Gateway	Branching point where alternatives are based on conditional expressions. The true evaluation of one condition does not exclude the evaluation of the other conditions. Can be used to merge a combination of alternative and parallel paths.
	Parallel Event	All of the events must be triggered to create a process instance. It cannot have incoming transitions.
	Start Event - Timer	Indicates where a process with start.
	Signal Event	Type of Intermediate Event. Corresponds to something that happens between and the start of a process.
	End Event	End of flow. This ends the flow of the process, and so, does not have any outgoing sequence flow.
	Sub-process	Activity that contains other processes.

4.2.4. Input Data – Portugal and Germany

In Portugal, INEM provided information relative to 2016. Nevertheless, in Germany, available data to run the model is only an estimation. Therefore, Table 11 compares the required data with the one that was made available in both countries.

By looking at Table 11, it is possible to observe that within the available data of both countries, there are some disparities. Nevertheless, it is still possible to run a simulation. Finding a solution is crucial, and, for some parameter it is possible to make some assumptions:

- Number of emergency calls per day that are identified as strokes: consider the relative number of strokes per year
- Flux of incoming calls during the day: use a mean value.

Therefore, overall there is a lack of input information and a misfit between the two data sets 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 collected and distribution functions. The next subsection will explain the computer simulation proposed.

Table 11 – Available data comparison: available data for Portugal, Germany.

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 health care 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

4.2.5. Proposed Simulation Model – Portugal and Germany

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? This is considered a central question.

Therefore, the size of the sample that is being studies should be verified. In Stuttgart, there are approximately 612 441 people and in Lisbon metropolitan area (AML), there are 2 815 851 people. AML comprises 18 counties, and, in this study, 6 from the 18 counties are included in the available data, comprehending: Lisboa, Almada Seixal, Setúbal, and Loures. Figure 19 represents the entire AML, with the chosen county's highlighted. In this region there are approximately 1 370 611 inhabitants, a value closer to the one found for the German city.

Figure 19 - Counties included in this dissertation (Área Metropolitana de Lisboa, 2011) .

The number of ambulances available in Lisbon and in Stuttgart is also similar. Both cities have the same number of ambulances available (20). However, they differ in the number of stations available. While Stuttgart has only 6, Lisbon has 14. Lisbon metropolitan area corresponds to a wider area to cover.

By looking at Table 12, 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 are 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 12 - Comparing Lisbon vs. Stuttgart (Lohs, 2017, Área Metropolitana de Lisboa, 2011, INEM, 2017).

	Stuttgart	**Lisbon – AML section**
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

Thus, it is possible to say that drawing a comparison between these two areas is not straightforward, but, some lines can be drawn and relationships established.

Distributions Estimation

Developing the process described requires defining some parameters and probabilities distributions. By looking into the literature and by making some assumptions the main characteristics of the probability distributions can be defined. It is essential to represent the reality in the most truthful way.

Table 14 summarizes the proposed distributions and respective values. Each step in the ERC has a service time associated. Since this time does have a stochastic behaviour, probability distributions are used. The parameters that fit each function used data from the Quality Report in Emergency Services in Baden-Württemberg 2016 (Lohs, 2017)) and from INEM statistical data (INEM, 2017).

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 (Buuren et al., 2015) , calls' arrival process can be assumed as a Poisson process with exponentially distributed inter arrival times (Buuren et al., 2015).

Dispatch centre service level representation uses queuing models. According to the literature on the topic (chapter 4.2.3), assessing queuing systems remit to two different approaches: analytical or simulation (Winston et al., 2009). In this methodology, simulation is the technique being applied. Nevertheless, analytic calculations were also performed as a confirmation mean. 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 (Zeng, 2003).

From an analytical point of view, Erlang C formula depends on two variables: number of servers' M and traffic intensity A. The probability of having all server busy, i.e. if the call is placed in a waiting line, is named P_C and depends on M and A. Pc is given by (Chromy et al., 2011):

$$P_c(M,A) = \frac{\frac{A^M M}{M!\,(M-A)}}{\sum_{i=0}^{M-1}\frac{A^i}{i!} + \frac{A^M M}{M!\,(M-A)}} \quad [1]$$

$$A \approx \frac{\lambda}{\mu} \quad [2]$$

$$\mu = \frac{t}{Ts} \quad [3]$$

$$\eta = \frac{A}{M} \quad [4]$$

Table 13 - Description of the Erlang C parameters.

λ	Average number of calls per period of time
μ	Average number of requests processed per time
t	Interval Seconds (s)
Ts	Call Duration (s)
η	Agent Occupancy

Probability P_C depends on two major properties. An increasing number of servers has an effect of decreasing the P_C value and a rising in the traffic intensity will lead to a rising of P_C. (Zeng, 2003)

Through a *Matlab* experiment is possible to make a primary forecast to obtain the probability of the call being assigned to a waiting queue by knowing the number of dispatchers in the control centre and having into account the data available. The obtained results are available in Appendix B, Table 20 and confirm the ones obtained in the simulation model.

Lognormal distribution is chosen for the service time (triage) by the call taker for each incoming call. Bolotin in 1994 (Buuren et al., 2015), showed that lognormal distributions are a good fit for call centre service times. As the control centre function can be roughly approximated to a call centre, this function can be used (Buuren et al., 2015).

Treatment duration can be described either by a Gamma distribution or by a Normal function. During the simulation the best fit will be chosen. Therefore, it was chosen to have a gamma function for Germany and a normal function for Portugal.

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.

Table 14 - Probability Distributions proposed in the simulation mode (INEM, 2017, Lohs, 2017)l

	Distribution	**Germany (Stuttgart)**	**Portugal (Lisbon)**
Arrival Rate	Poisson, with λ = arrival rate per day	194,52	188
Service/Queue	Erlang C function (shape, scale, minimum value)	(0.5; 120; 55)	(28;4,61)
Triage	Lognormal - min	(0.19, 0.5,0.5)	(0.19, 0.5,0.5)
Treatment at the scene	Gamma (Ger) NormalTruncated (Por) - min	(1.4, 1.4, 8)	(7.5, 25, 20, 1)
Probability of having a stroke	Random	True = 2,9%	True = 20,9%
Probability of requiring a doctor with a stoke	Random	True = 100%	n.a

Data Structure

While Portuguese data uses geographic information system (GIS) 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

In this subsection, computer simulation executed for Portugal and Germany as well as the variables, parameters and distributions functions implemented are explained in detail.

Computer implementation for the two countries tried to be as similar as possible. Nevertheless, some changes had to be performed. Therefore, created agents will be explained first for the

Portuguese case and later for the German case. It is important to take into account that all agents will run in the main agent.

The results produced from these two experiments are similar since both ERC models are based on a similar logic block and lack of data that forced making of assumptions. Therefore, the results depicted in Chapter 5 will be only an illustrative demonstration of the methodology potential.

The following tables (Table 15-16) detail the "*Main*" parameters and functions used in both models.

List of Parameters

Table 15 shows the parameters available in the main function, all the remaining parameters (agent's parameters) are in Table 21-29 in the appendix section. Furthermore, some adjustments had to be performed to execute the simulation model, especially in the Portuguese ERC. As it is depicted above, *Number of CODU workers* in the Portuguese model are 28, being an overall average for the overall flux during the day. However, only emergency calls that use EAM are being considered, so, the number of calls is too low for 28. Therefore, this number was reduced to 3 agents, the same number applied in Germany.

Table 15 - List of the parameters used in the model - Main

Name	Description	Value - DE	Value - PT
Nagents (all)	Number of workers at EMS_centre.	3	28
Nagents (used)	Number of workers at EMS_centre applied in the simulation	3	3
Arrival Rate (days)	Corresponds to the rate at which patients are read from the patient_events table.	Poisson (194*30)	Poisson (188*30)
Arrival rate (min)	Deducted from above	Poisson (1)	Poisson (1)
AbandonmentTIm (s)	Time after which patient leaves the waiting queue for the 112 call (threshold)	100	100
ServiceTime (min)	Measures the patients waiting time on a queue by an Erlang function.	Erlang (0.5, 120, 55)	Erlang (0.5, 120, 55)

List of Functions

In Table 16 are revealed the functions used in the two models. Nevertheless, due to data structure not all had to be used in both cases. As the Portuguese ERC is using GIS locations in a map, it can account alone the distance and travel times. Therefore, only *serviceTime1* is a common function to both countries, the remaining are only applied to the German model.

Table 16 – List of functions used in the model - Main

Name	Description
serviceTime1	Uses parameter serviceTime to produce a triangular distribution having into account the parameter values.
distanceFromArray (Germany)	Uses java code to locate the position within an excel table, that holds an array with the time-distance between 2 points (origin: row; destination: column) and returns a numerical value. Uses: *CellReference.convertNumToColString () and returns excelFile.getCellNumericValue (cellName);*
waitingTime4 (Germany)	Uses java code and the “distanceFromArray” function, to calculate and compare the time-distance from the doctor and the ambulance to the patient. . Returns the farthest way value.
waitingTime5 (Germany)	Returns the time-distance from the ambulance to the incident location (patient), by using “distanceFromArray” function.
waitingTime2 (Germany)	Uses java code and the “distanceFromArray” function to calculate the time-distance between the patient and all the hospitals and returns the hospital with the smallest time-duration pathway.

Main Agent – Portugal

In Portugal, as the ambulance locations, hospital locations and counties were given in GIS coordinates, it was possible to have a visual look of the places that are being studied. Figure 20 depicts the studied area in Lisbon AML.

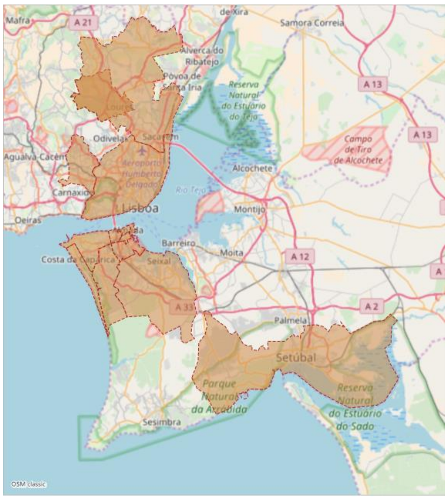


Figure 20 -Studied area in Lisbon AML depicted with the AnyLogic software

Figure 21 depicts a logic block in which the main process of this ERC is being executed. Moving towards an accurate description, in the "*source* "block, patients are generated with an arrival rate detailed in Table 15. After being created they enter into a queue block. On exit, this block measures the time at which patients are generated, and places them in the map (Figure 20).

Patient moves to a dispatch centre where the call is processed. The diagram block types for this action are a "*queue*" and a "*delay*" named "*PatientsQueue*" and "*CODU*" respectively. These two blocks could be also merged into one "*service*" block, but for this experimental method a *queue* + *delay* was considered. The block "*PatientsQueue*" orders patients that are entering and waiting to be accepted in the next block "*CODU*" that has a delay time corresponding to a service time (servicetime1) read from Table 16. Another delay that is required in series with the previous block is the logic block "*Triage*". It adopts the time required for the TEPH to run the call protocol to patients and dispatch the most suitable emergency means. As it is detailed in the literature, it assumes a lognormal distribution.

. As we are dealing exclusively with emergency calls that require emergency vehicles, this delay unit is called "*PreparingToMove*" and makes use of the resource pools of vehicles (Figure 22) called "Ambulances". The delay time assumed to be a triangular function. Before assigning an ambulance, it is required to have a "*seize*" block that makes the resources leaving the resource pool block immediately. Ambulances' resource pool has a capacity correspondent to a parameter named "*nVehicles*". As ambulance is also an agent its creation is dependent on the ambulance patient that will be detailed later on.

Afterwards, ambulance and doctor move towards the patient. In the "delay" block *moveToPatient* is accounted a new delay that mimics the time that the ambulance needs until arriving

Upon arrival, there is a "*patientLocalDelay* delay, characterized by a normal truncated distribution and then a decay unit "*movingToHospita*l", where the closest hospital is picked and then the process ends. When the patient is moving towards the hospital a block called "*releaseAmbulance*" is required. This block will release all the resource units that had been used, namely the vehicles, doctor and dispatch112.

Patient Agent - Portugal

Creating an agent follows series of steps:

1. Choose the type of agent: population, single or agent type;
2. Create new agent type: give a name and decide whether the agent will be created from the scratch or from a database through excel files.
3. Considering that it is generated from a database, choose the database table that contains data for this agent type.

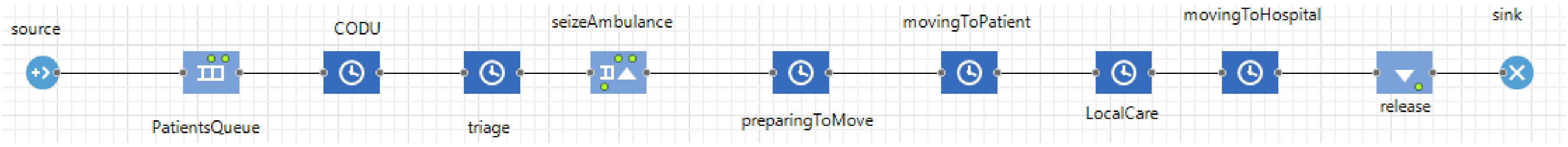


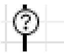
Figure 21 - Main logic block for the Portuguese ERC

Figure 22 - Resource Pools in the main agent.

Patient characteristics are chosen on generation. The following parameters are described in Table 21 in appendix section: latitude, longitude, district designation, ID, ID district, district demand, time arrived, time enter, home, parNearestAmbulance and parCODU.

Patient's behaviour is controlled by a state-chart as in Figure 23. After the agent being created and characterized, the first assigned state is called "*atHome*" and corresponds to the moment before the incident. In this state it is assured that patient is at incident location. When a sudden incident occurs, the patient moves to the next state "*calling112". The transition to this second state is triggered by a timeout.

After calling to the emergency number, patient needs first to wait for help, and later receiving treatment. Hence there is one transition, "*LocalCare* where patient is waiting for another agent to execute their task (ambulance arrival and doctor/EMT treatment).

Finally, after being assisted, patient transits to a final state, in which there is hospital arrival. This state is "*atHospital*" and is the last transition is triggered by a condition "true" ()

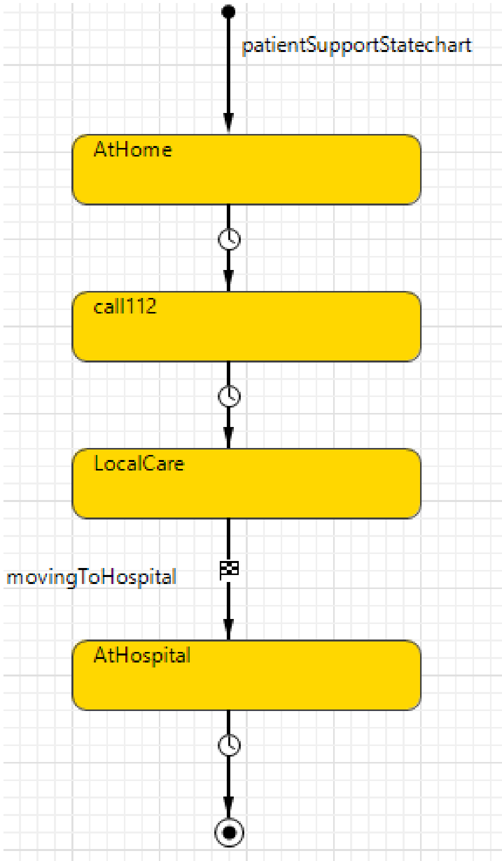


Figure 23 - Patient state-chart.

Ambulance Agents - Portugal

Ambulance agent is also a population of agents and has the following parameters as characteristics: *ambulanceID, ambulance district id, ambulance district, ambulance lat ambulance long*. As in patients', parameter's details are in Appendix C, Table 24.

This agent behaviour is also controlled by a state chart. Figure 24 depicts the designed state-chart. In the initially stage, ambulances are in the state "*at base*", and upon a timeout the transition is triggered. In this moment the state of the ambulance is "*PreparingToMove*", from here goes under states "*movingToPatient*" which final location is control by a command "*getNearestAgentByRoute(main.patient)*" that gives the closest route to meet the patient. The transition to "*atHospital*" is trigger by agent arrival to the incident location ( ).

From here, the vehicle returns to its home base.

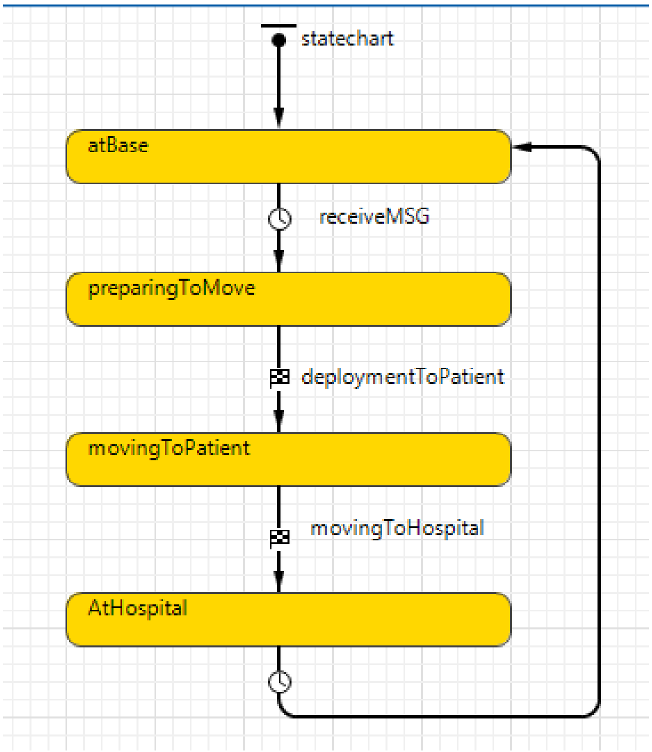


Figure 24 - Ambulance State-chart.

Hospital, CODU and Home Agent's - Portugal

The Hospital and home agents were created as resource type agents and are also populations of agents. Resource type agents represent staff, equipment and usually have a resource pool associated (The Anylogic Company, 2017).

Each agent type, upon their creation, have parameters that characterize their action. Hospital characteristics are: latitude, longitude, district designation, hospital ID, district ID, address. Their characteristics are also displaced in the Appendix C, specifically in Table 23.

Home agent correspond to home location of each patient. As there was no information available concerning the exact location of each incident, it was decided to generate randomly a place from the available GIS data on the considered AML region. This agent's behaviour is controlled by the following parameters, described in Appendix C,Table 25: Id, latitude, longitude, districtDesignation, idDistrict and Location´

Regarding CODU agent, it only receives an emergency message with all the patient details, that is sent towards the assigned ambulance unit ("*send (agent, unit)*"). CODU also has parameters, described in Appendix C, Table 24: parTextNeedHelp, parPatient.

Random Table

Moving towards German ERC, the data available from the German Medical Emergency system included an incident summary table that proved to be too demanding to be used by the simulation application. Therefore, it was decided to generate an emergency incident table in which, for each patient was attributed a random incident location that takes into consideration the demand of each district. The demand of each district (number of incidents per district per year/month/day) is given in the available dataset.

The incidents are generated for a period of time of one month. “Month” is used as time duration to increase the number of detected incidents per district. A daily bases duration would have demands inferior to zero, what would be harder to judge subsequently.

The obtained table can be directly imported to AnyLogic, where is used as a mechanism to generate incidents.

Table 17 illustrates a small part of the obtained random table. On the whole, the table has approximately 5800 lines.

Table 17 - Incident location random table for Stuttgart data – “patient_events”

PatientID	PatientLocationID	DistrictID	DistrictDesignation
1	24	24	Berg
2	10	10	Heusteigviertel
3	35	35	Kaltental
4	101	101	Oberturkheim
5	49	49	Seelberg
6	143	143	Zuffenhausen-Hohenstein
7	142	142	Zuffenhausen-Mitte
8	86	86	Mohringen-Nord

Appendix D, Figure 48– 53 are an illustration of the implemented Java code. EMS 3 is the main Java class to read csv file and produce a random incident emergency datafile. Java code is correctly commented to make the easier comprehension. The JAVA project (EMS3) supports reading a CSV file with aggregated medical emergency data and produce an excel file with a random list of daily medical emergency incidents, including 5 classes.

. The class EMS3.java supports provided the methods to read a CSV file to an array, generate a random number with its range limited to the number of districts identification index, generate an array of daily medical emergencies and to export the data to an excel file. The classes Patient.java, Agent.java and Victim.java provide the constructors and methods to support the manipulation of data structures (arrays) required by EMS3 and the ExcelUtils.java provide the constructors and methods to support exporting data to an Excel file. Agent is a class created to manipulate the Agent Array with data to be exported to an Excel File. Victim is a class to manipulate the temporary Victim Array like Agent Array. ExcelUtils is the class that supports the generation of an excel file.

Main Agent - Germany

The computer simulation designed in Germany presents some differences if compared to Portugal. In the following paragraphs, German computer simulation is detailed. Considering the construction of Table 17 an auxiliary process, the first step to make when building the model is to identify agents. Following this primary step, a careful description takes place. There are five main agents in the model: main, patient, hospital, doctor, ambulance. In all of the created agents, their characteristics are read from excel files.

The Main agent tries to represent the already described dispatch centre. Here, a patient is generated and enters in the process. Afterwards, the patient is handled and the appropriate emergency means are activated. The diagram ends with patient arrival to the hospital.

Moving towards a careful description of the diagram, the action in the Main agent occurs through logic blocks, starting by a "*source*", as it is shown in Figure 25. In the source block, patients are created by the table *patient_event*, with an arrival rate defined in Table 16 – List of functions used in the model - Main. On exit, this block measures the time at which patients are generated. Patient moves to a dispatch centre where the call is processed. The diagram block type for this action is a "*service*", called *EMS_center*. *EMS_Center* is a service unit that makes use of a resource pool called "*dispatch112"* where are the call takers. The service time (also considered a delay) of answering a patient call is given by the function "*ServiceTime*". Still in the control centre, there is a *delay* block representing triage duration. As it is detailed in the literature, it assumes a lognormal distribution. As we are dealing exclusively with emergency calls that require emergency vehicles, this service unit is called "*AssignAmbulance*" and makes use of several resource pools of vehicles (Figure 26) called "Vehicles(i), $i \in [1,6]$". Here, there is also an associated delay time assumed to be a triangular function. Before assigning an ambulance, it is required to have a "*seize*" block that makes the resources leaving the resource pool block immediately.

While assigning an ambulance, must be decided whether a doctor is required or not. Thus, a "*select ouput*" block named "*needdoctor*" was designed. There is a probability *x* of needing a doctor and *1-x* of not needing.

If a doctor has been assigned, a new service unit is necessary. The block *"AssignDoctor*" makes use of the resource pools of doctors and also has a triangular delay associated.

Afterwards, both ambulance and doctor move towards the patient. In the "delay" block *moveToPatient* is accounted the maximum time between the time that the ambulance needs until arriving or the doctor. This choice is made by using a function called "*waitingTime4*". If no doctor is required, after *needdoctor,* the block "*MovetoPatient2*" only accounts the required time by the ambulance to arrive to the incident location, by using *waitingTime5* function.

Upon arrival, there is a *"LocalTreatment*" delay, characterized by a Gamma distribution, then a service unit "*goToHospital*", where the closest hospital is picked and then the process ends. When the patient is moving towards the hospital a block called "release" is required. This block will release all the resource units that had been used, namely the vehicles, doctor and dispatch112.

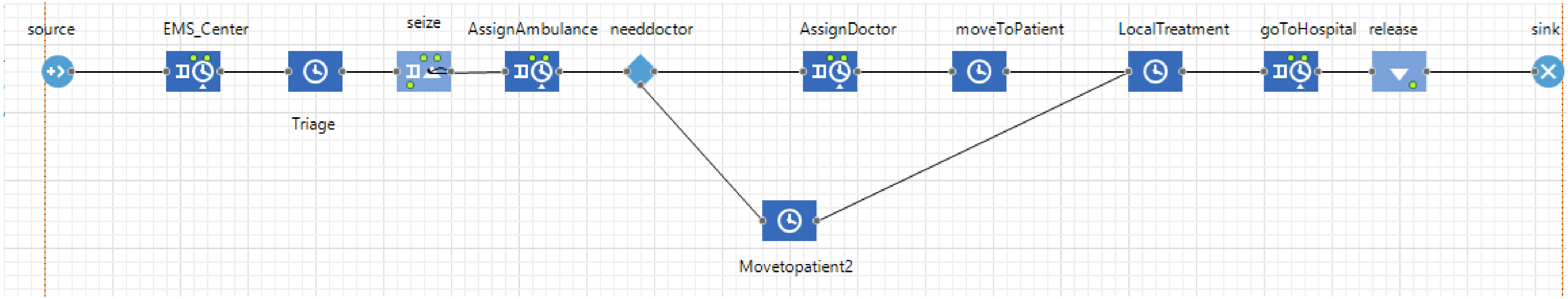


Figure 25 - Main Process for the German ERC.

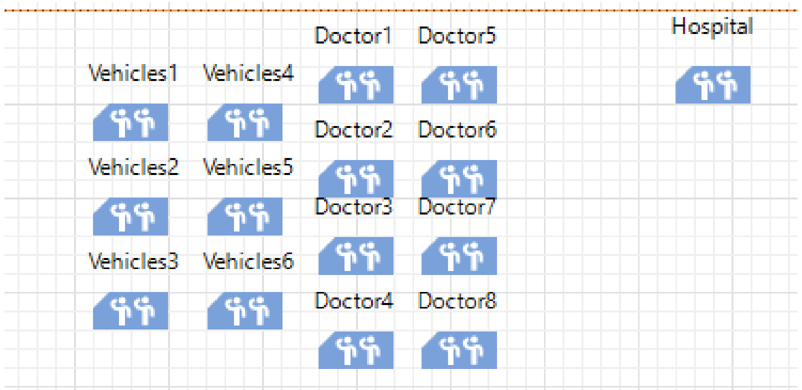
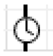


Figure 26 - Resource Pools in the main agent.

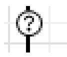
Patient Agent

The patient agent is considered to be a population of agents that is initially empty. Patient characteristics are read from a database. The chosen database table corresponds to the random one explained before and named *patient_events*. From here, the following characteristics are chosen: PatientID, PatientLocationID, DistrictID and District Designation. Appendix C,Table 26, , summarizes patient's characteristics.

Patient's behaviour is controlled by a state-chart as in Figure 27. After the agent being created and characterized, the first assigned state is called "normal state" and corresponds to the moment before the incident. When a sudden incident occurs, the patient moves to the next state "waiting 112". The transition to this second state is triggered by agent arrival (), since it is activated upon the agent creation and entering in the source in the main agent.

Afterwards, patient needs to wait until the emergency call, moving towards "calling112" state. As the transition is controlled by a mean time between the detection of an incident and the call, the trigger will be a timeout ().

After calling to the emergency number, patient needs first to wait for help, and later receiving treatment. Hence there are two more state transitions, "waitingHelp" and "beingSupported" both triggered by agent arrival (). In both these cases, patient is waiting for another agent to execute their task (ambulance arrival and doctor/EMT treatment).

Finally, after being assisted, patient transits to a final state, in which there is hospital arrival. The last transition is triggered by a condition "true" () that is activated after the treatment being completed.

Doctor, Ambulance and Hospital Agent's

The Doctor, Ambulance and Hospital agents were created as resource type agents and are also populations of agents. Resource type agents represent staff, equipment and usually have a resource pool associated.(The Anylogic Company, 2017).

Each agent type, upon their creation, have parameters that characterize their action, detailed in Appendix C, Tables 29-31. Hospital characteristics are based on an excel file called "hospital_locations", that give details regarding their district name, index and address. Doctor characteristics are based on an excel file called "*doctor_location*", that give details regarding their district name, index and number of doctors per location. Ambulance characteristics are based on an excel file called "*station_locations*", that give details regarding their Homebase id, number of ambulances per base station, and district.

Statistical Data

Frequently, visualizing the outputs from the computer model is a hard task. Hence, Anylogic software has several available tools allowing the collection of statistics.

Therefore, there is an "Analysis" palette inside the software that has several charts and data available. Figure 28 shows the options for statistical data collection.

The collected statistics will be presented in the next chapter. By comparing different statistics, is possible to compare the ERC's of both countries.

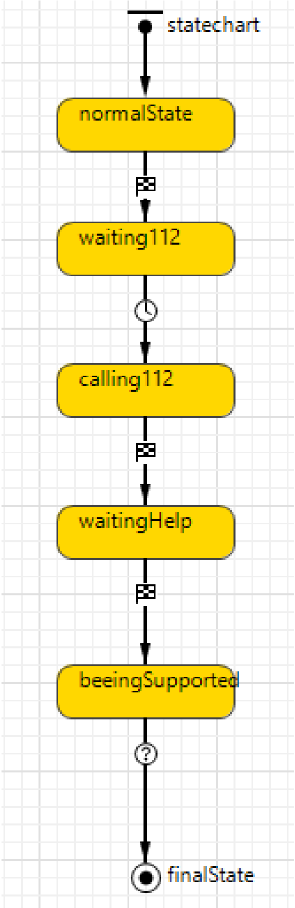


Figure 27 - Patient State-Chart.

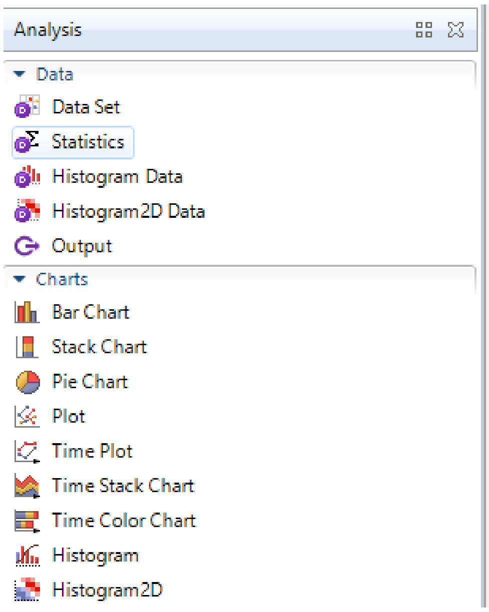


Figure 28 - Available statistics in AnyLogic.

4.2.6. Validation, Implementation and Comparison

As it has been explained, validation is always a hard task. In this specific case was not possible to validate the model due to several limitations already exposed. In fact, lack, structure and complexity of the data were 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 and discussed the results from experimenting the ERC's.

5. Results and Discussion

In this chapter the previous described methodology is being applied by using partial results from Portugal and Germany.

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 build. 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, it was intended to implement the model for a stroke rescue scenario. However, representing stroke ERC was not a straightforward task due to the lack of available data. However, this was not possible. In Portugal, as there is some information directed to stroke, it was more viable than in Germany. Here, the only collected data was the probability of having a stroke (2,9%), that is represented by the chance of requiring a doctor in the model (2.9%). In Portugal, chosen distributions were picked according to stroke data as well as hospital locations. Also, the implemented model in both countries takes into account the special ERC applied in Portugal for strokes (VV-AVC) since there is detailed algorithm that explains the different rescue stages. In Germany, the available ERC is very simplistic and overlaps stages.

The next subchapter will explain with more detail the limitations for the application of the proposed methodology. Afterwards, the results from the computational simulation model will be presented.

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: Structure of data

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 11 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 EAM. EAM are 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 are 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 connected 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. Health care units' capacity is not revealed, being impossible to know, while choosing patient's movement towards the hospital, if the health care 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 was not experimented.

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 (Marcão, 2017). 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 centers give back performance reports, blocking a correct parameters construction. From the 34 dispatch centers within BW, only 17 provided the correct information (Lohs, 2017). 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

Studied Regions

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.

Computer Simulation

Due to the lack of information, there are missing some key details in the designed computer simulation model that would be crucial during the validation process.

1. EMS control centres in both countries act in different ways: in Germany person that handles the call is responsible for the entire process. In Portugal, a person handles the call, doing triage, and another one calls the makes vehicle dispatching, hospital and doctor notifications.
2. In the ambulance agent, relocations upon hospital arrival are not being considered. All the ambulances, after receiving the patient, are traced back to their home station. In a real-life context, ambulances are usually relocated right after releasing the patient.
3. In Portugal, there is no available information regarding the number of doctors that are available to attend an emergency. Furthermore, in both studied countries, there is no official data concerning the situations that require a doctor. Therefore, in Germany as there is an estimation for the number of doctors available and by linking it with the probability of having a stroke, it is possible to simulate the probability of requiring a doctor. Nevertheless, many other situations require doctors, so this is only an illustration.
4. In control centres there is a big flux variation of calls during the day, and this is not being taken into consideration.
5. Regarding the software, it runs in model time units and in real time. Executing a simulation that would represent 1 month in real time would take too long, therefore, model time units have to be considered. As ERC evolution is highly time dependent, this fact reduces the accuracy of the model.

5.2. Application of the Proposed simulation model

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 the Chapter 4.

Thus, the two studied regions are analysed separately and the results from the computer simulation model are also presented in distinct sections.

5.2.1. Portugal

The following paragraphs depict the obtained results from the application of the proposed methodology in Portugal. As it has been described in section 4.2.4, the input values were previously estimated.

Regarding the computer simulation model, the general results from this computation application are now presented. As it has been detailed in section 4.2.5, data structure in Portugal is based on latitude and longitude coordinates. Thus, when the model is executed it is possible to observe Figure 30. To have a better comprehension, Figure 29.

Ambulance base location

Patient

Hospital

Ambulance

Figure 29 - Figure 30 symbols characterization

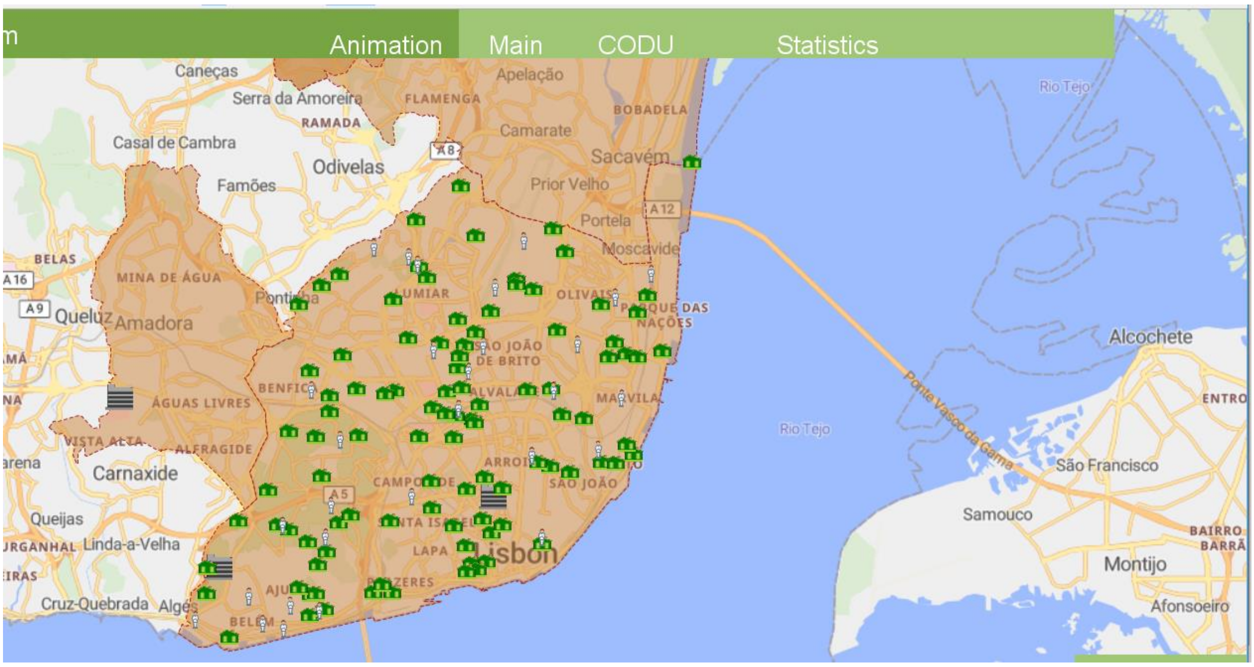


Figure 30 - Animation output from running the model for a period of 1 month. In this figure are depicted patients, ambulances and hospitals.

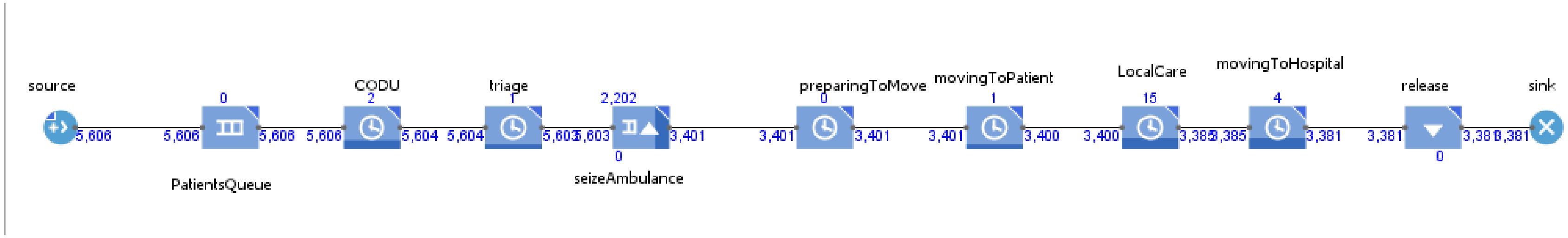


Figure 31 - Logic Block for the portuguese ERC.

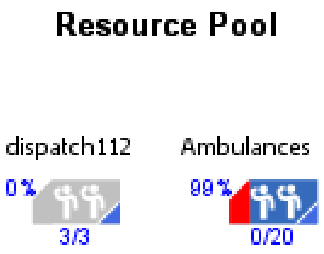


Figure 32 - Resource pool utilization for the standard experiment depicted in figure 31

Figure 31 and 32 are the result from the run experiment. As depicted in Figure 31, 5606 patients were generated at source element. All patients were processed at *CODU*. However, when it came to *"seize*" an "*assign an ambulance*" only 3041 were released in the considered interval. In all the remaining blocks the flux of in and out patients was almost constant.

Actually, in the blocks "L*ocalCare"* and "*movingtoHospital*" there were 15 and 4 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 32), 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. As the logic block produced from this simulation will show similar results to the one produced for the German case, it was decided not to show a higher level of detail here.

Thus, the German illustrative example will show the remaining details and potentials of the computer simulation model.

5.2.2. Germany

The following paragraphs depict the obtained results from the application of the proposed methodology in Germany. As it has been described in section 4.2.4, the input values were previously estimated.

Regarding the computer simulation model, the general results from this computation application are now presented. Patients are read and generated from *patient_event's* table. These episodes correspond approximately to 1 month of medical emergencies.

Firstly, a control experiment was run. As depicted in Figure 33, 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 out patients 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 34), 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.

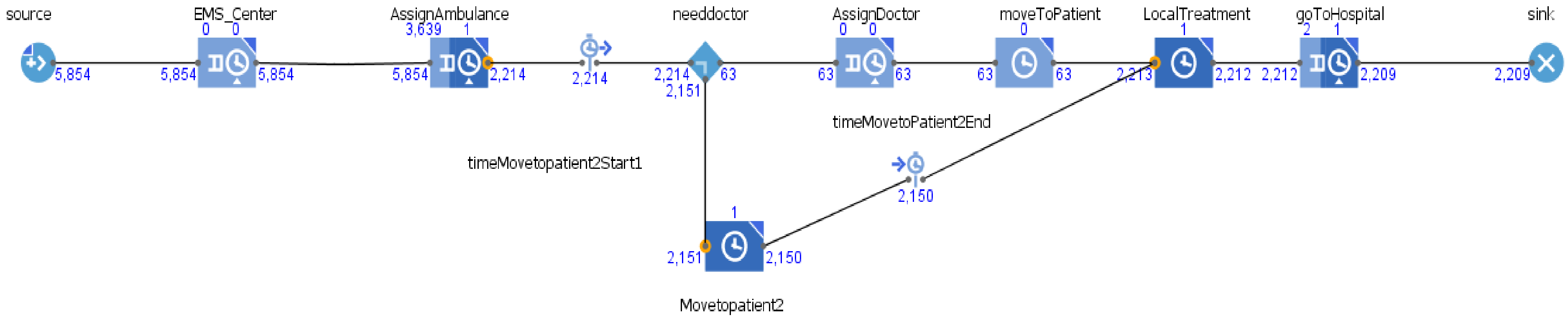


Figure 33 – Germany: Logic Block result with control values applied

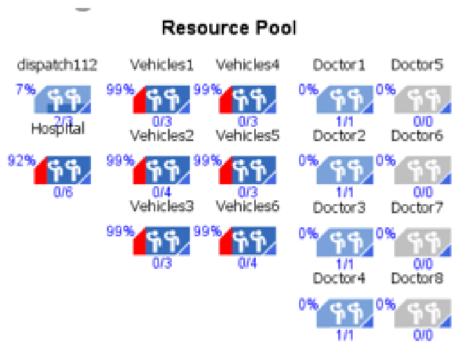


Figure 34 - Resource pool utilization for the standard experiment depicted in Figure 33.

5.3. Application of a possible Implementation and Comparison

The step that follows and links the computer simulation with the implementation is the model validation. As it has been explained, a model validation could not be executed for this ERC model. Nevertheless, an exemplification implementation is performed for both models.

Hence, different experiments are showed, revealing the system capacity of capturing the system simultaneously as a whole and with detail, looking to the behaviour of each logic block.

As running experiments follows the same logic for both ERC models and as the results are only an illustration of the potentials of the system, it was decided not to make a full description of the Portuguese ERC application.

5.3.1. Germany

To have a better understanding on how the system behave, some experiments were made. Experiments try to go towards the points identified in section 4.2.2. Furthermore, if the model had been previously validated, by running different experiments it would possible to evaluate the performance level of the system and analyse it for a real context, 69Table 18 summarizes the input values that were changed, in relation to the control ones. By running different experiments, control's center ability to handle all incoming patient requests, ambulance assignments, response times, requiring a doctor and distribution of the overall ERC duration are analyzed.

Beforehand, is important to measure the different time responses across the logic block distribution. Thus, the following times are being measured: overall time response, EMS_centre waiting time, local treatment, go to hospital. Figure 35 -38 show measure time responses. Nevertheless, we must take into account that charts measuring "*overall time*" and "*go to hospital* "are not providing the result in real units but in model time units, since they are obtained with a "*Time Measure Start/ End*" block. This block measures the simulation time (not real time) between two points of the logic block one. The remaining statistics were measured from variables vary according to a specific logic block, which has a defined time unit.

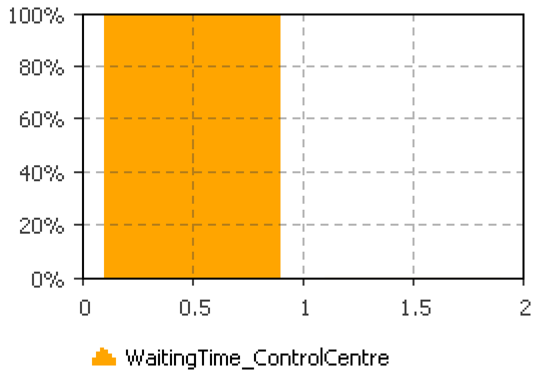


Figure 35 - Standard Experiment: Control centre waiting time histogram distribution (vertical axes - % samples, horizontal axe – time in minutes)

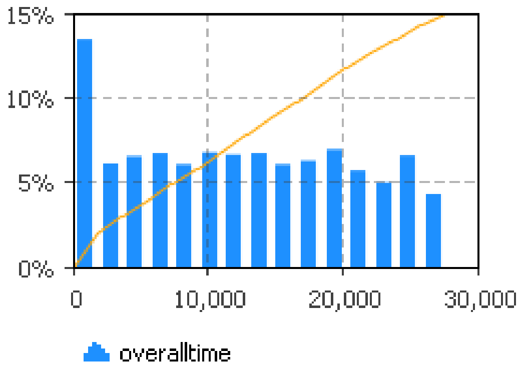


Figure 36 - Standard Experiment: ERC overall time distribution measured in model time units (vertical axes - % samples, horizontal axe – time model unit time the orange line is the CFD).

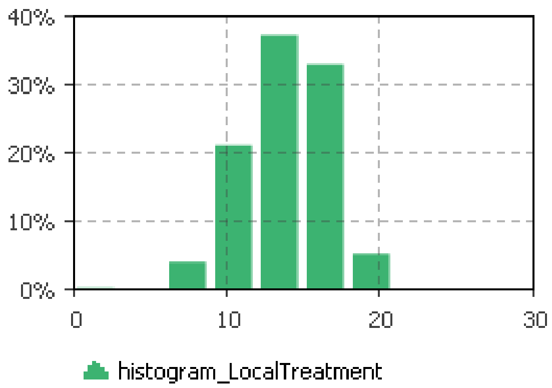


Figure 37 - Standard Experiment, Local treatment time distribution measured in minutes (vertical axes - % samples, horizontal axe – time in minutes)

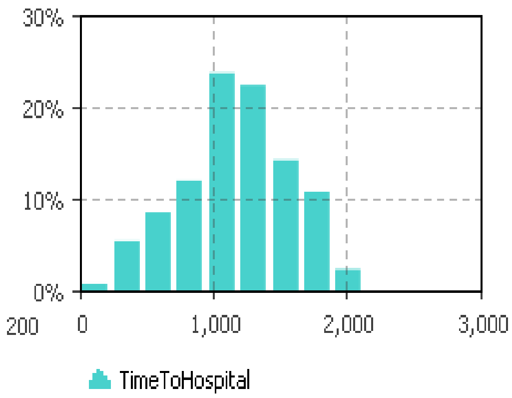


Figure 38 – Standard experiment: gotohospital time distribution measured in model time units (vertical axes - % samples, horizontal axe – time in model time units minutes).

Table 18 – Inputs used in the different experiments.

Parameter	Control Value	Experiment 1	Experiment 2	Experiment 3
Nagents112	3	1	3	3
Number of ambulances	20	20	20	20
Probability of Having Doctor	2,9%	2,9%	0%	100%
Arrival Rate	Poisson (194*30)	Poisson (194*30)	Poisson (194*30)	Poisson (194*30)
Service Time1	Erlang(0.5, 120, 55)	Erlang(0.5, 120, 55)	Erlang(0.5, 120, 55)	Erlang(0.5, 120, 55)

Depending on the experiment, different statistical distributions are relevant. Thus, for experiment 1 waiting time at the control centre should be measured (EMS_centre). The time for "*assign ambulance*" would also be interesting to analyse, but as it depends exclusively on a delay it is not relevant to measure it. Experiments 2 and 3 investigate the impact on having different doctor probabilities.

Experiment 1

According to Figure 40 and 40, waiting time in the control centre changes if the number of *“Nagents112*” is reduced from 3 to 1. However, waiting time is almost non-existent in both cases. In experiment 1 the maximum predicted waiting time is close to 4 seconds.

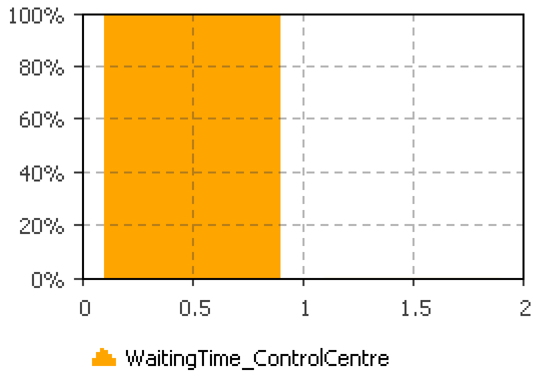


Figure 39 - Standard Experiment: Control centre waiting time histogram distribution .(vertical axes - % samples, horizontal axe – time in minutes)

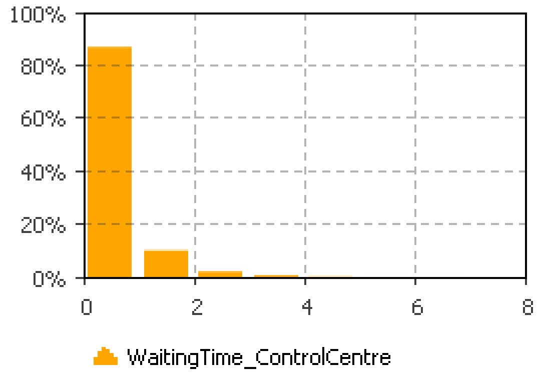


Figure 40 - Experiment 1: Control centre waiting time histogram distribution (vertical axes - % samples, horizontal axe – time in minutes)).

Furthermore, occupancy time across time of the ERC is minimum. For the standard experiment is only 8% and for experiment 1 is 23%. Nevertheless, this model is not considering Nagents112 assigning the ambulances, the relation between the assigned ambulances and Nagents112 is still to be explored. This way, establishing the relation between the number of control centre workers required and reduction of assignment of ambulances time is not straightforward.

Experiment 2 and 3

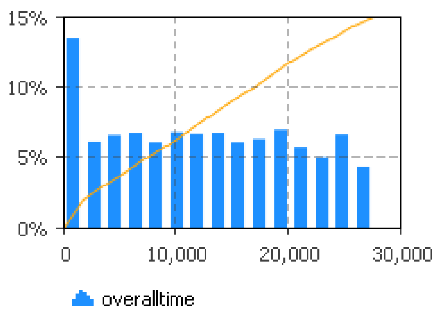


Figure 41 - Standard Experiment: ERC overall time distribution measured in model time units(vertical axes - % samples, horizontal axe – time in model time units minutes)..

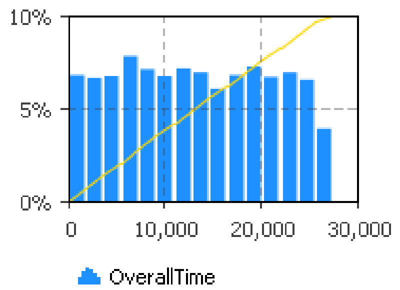


Figure 42 - Experiment 2 ERC overall time distribution measured in model time units (vertical axes - % samples, horizontal axe – time in model time units minutes).

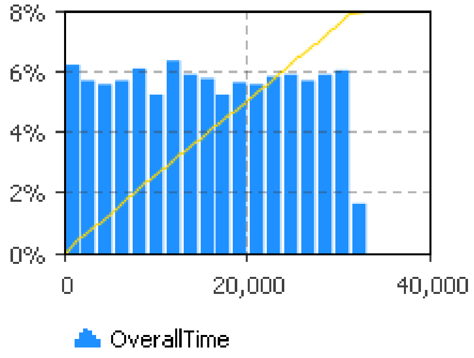


Figure 43 - Experiment 3 ERC overall time distribution measured in model time units vertical axes - % samples, horizontal axe – time in model time units minutes).

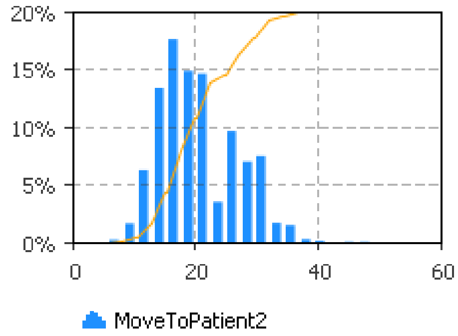


Figure 44 - Standard Experiment: movetopatient 2 distribution measured minutes (vertical axes - % samples, horizontal axe – time in minutes)

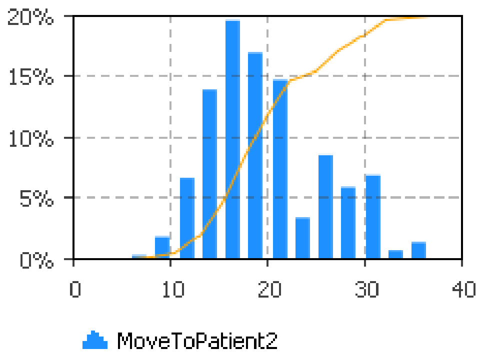


Figure 45 - Experiment 2: movetopatient 2 distribution measured in minutes (vertical axes - % samples, horizontal axe – time in minutes)

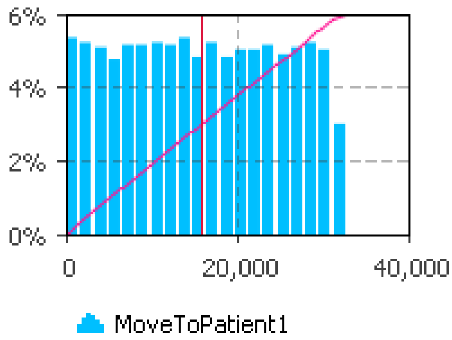


Figure 46 - Experiment 3: movetopatient distribution measured in model time units vertical axes - % samples, horizontal axe – time in model time units minutes)..

By varying the probability of requiring a doctor, as depicted in Figure 42 – 44 there is almost no overall time difference in running the model with no doctors required or with doctors always required. Since the considered probability of requiring a doctor is only 2.9% it is obvious that there would not be significant difference from not requiring one. Experiment 3 checks the response if a doctor was always required. Even if the overall time response does not reveal a considerable difference, it is important to look at the queue at “assign doctor” block. Furthermore, by analysing the exact time that ambulances need until arriving to incident location, Figure 42 – 44 show that there is not a significant difference.

Experiment 3 analysis system behaviour if there is a probability 1 of requiring a doctor. Figure 46 shows the time distribution for arriving to incident location when there is always required a doctor. As it is possible to observe time required is higher than the depicted in Figure 42 – 44.

Running different simulations offer the possibility of comparing simulation measure time results with the ones available at the BW quality Report. Therefore, as an example Table 19 makes a direct comparison between the measured values and some real ones.

Table 19 - Comparison between the obtained in the simulation model and in the BW quality report (Lohs, 2017).

Indicator	Median	Simulation Result
Waiting time Control Centre	0:06 – 0:26 (s)	0,6 (s)
Transport time Emergency doctors	6:10 – 13:23	13,5
Transport time Ambulances (min)	6:05 – 14:05	19,4
Treatment at the scene (min)	Minimum value 8	Mean: 14

5.4. Final Remarks

The executed model was a good illustration of the capacities of the explored methodology and model. By executing the computer simulation model with Anylogic 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.

6. Conclusion and Future Remarks

The objective of this dissertation is to evaluate, by running a simulation, the pre-hospital emergency Rescue Chain in Germany and Portugal. This problem was proposed by Professor Stefan Nickel, head of the chair in Discrete Optimization and Logistics at the Institute for Operations Research, Karlsruhe Institute of Technology, to address the need for improving the German Rescue Chain to reduce the delays during the process by evaluating the number necessary resources.

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. Nevertheless, it is important to take into account that the obtained results are merely illustrations for the computational model that was build. 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, upon the occurrence of an accident, 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 but it is still the most common dispatch solution in the vast majority of countries. (Jagtenberg et al., 2016, Reuter-Oppermann et al., 2017).

Jagtenberg et al. (Jagtenberg et al., 2016, Jagtenberg et al., 2017) developed in 2016 and 2017 several algotithms 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. Two types of solutions can also be considered: static and dynamic. In a static solution, each ambulance has a fixed base and cannot drive to other. Also, the home base for any ambulance is known in advance. Furthermore, the ambulance location is another parameter that must be accessed. The later considers problems related to the relocation of idle ambulances and their dispatching to a specific incident. (Jagtenberg et al., 2016, Jagtenberg et al., 2017).

Furthermore, in a future work, the proposed methodology could be upgraded in terms of developing an entire methodology with the stakeholders involved in the ERC process. Therefore, it could be validated and applied in a real context. Nevertheless, in this situation it would require all the input data detailed in 4.2.4 and some more details required by the actors involved. For example, it would make the complete evaluation of the German ERC possible and maybe optimized in terms of resources allocation.

As final remarks, this dissertation focus is on the emergency rescue chain process, and the run 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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8. Appendix

8.1. Appendix A - Mortality Rate

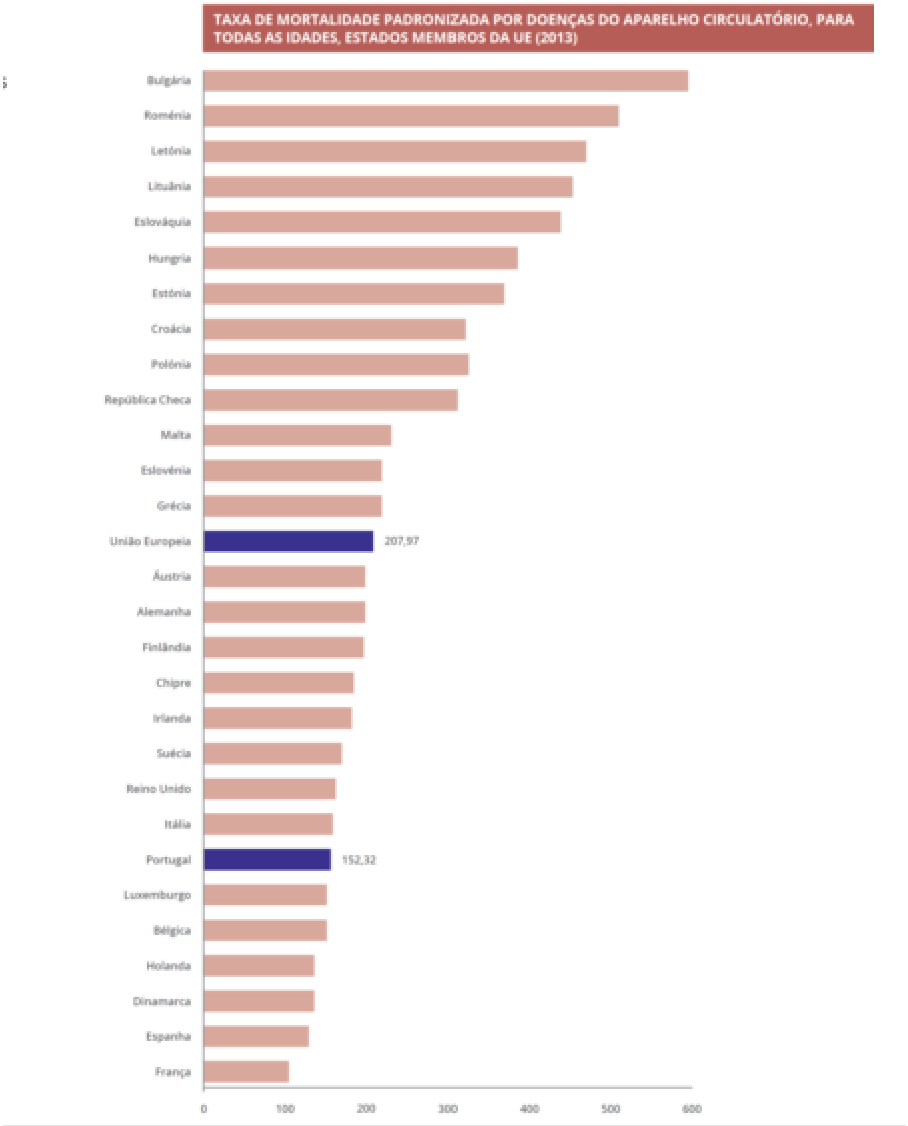

Figure 47 - Patronized mortality rate for cardiovascular diseases in UE (2013) (Ferreira, 2016).

8.2. Appendix B – Erlang C

Table 20 - Erlang C algorithm application using Matlab software.

Germany

N	M	t (s)	Ts	A	η	μ	P_C
3	194,5	86400	115	0,258883102	0,086294367	751,3043478	0,0257
3	194,5	86400	115	0,258883102	0,086294367	751,3043478	0,0257
3	194,5	86400	251	0,565040509	0,188346836	344,2231076	0,0893
3	194,5	86400	251	0,565040509	0,188346836	344,2231076	0,0893
1	194,5	86400	115	0,258883102	0,258883102	751,3043478	0,1914
1	194,5	86400	115	0,258883102	0,258883102	751,3043478	0,1914
1	194,5	86400	251	0,565040509	0,565040509	344,2231076	0,2458
1	194,5	86400	251	0,565040509	0,565040509	344,2231076	0,2458

Portugal

N	M	t (s)	Ts	A	η	μ	P_C
14,00	298,31	28800,00	240,00	2,48590973	0,177564981	120	3,20E-07
33,00	703,16	28800,00	240,00	5,859644362	0,177564981	120	7,53E-15
31,00	660,54	28800,00	240,00	5,504514401	0,177564981	120	4,44E-14
14,00	298,31	28800,00	240,00	2,48590973	0,177564981	120	3,20E-07
33,00	703,16	28800,00	240,00	5,859644362	0,177564981	120	7,53E-15
31,00	660,54	28800,00	240,00	5,504514401	0,177564981	120	4,44E-14
28	1662,01	86400	240	4,616689498	0,164881768	360	1,25E-13

8.3. Appendix C – Parameters

8.3.1. Portugal

Table 21 - Portugal: Patient parameters

Parameter	Description
Latitude	Patients GIS latitude
Longitude	Patients GIS longitude
distictDesignation	String with district designation
id	Table index
idDistrict	District index
districtDemand	Number of occurrences per district and month
timeArrived	Measured time for leaving in the sink block
timeEnter	Measured time for enter in the source block
home	Home agent object
parCODU	Object parameter for CODU agent

Table 22 - Portugal: Ambulance parameters

Parameter	Description
AmbulanceID	ID index of the ambulance
AmbulanceDistrictID	Ambulance District ID
AmbulanceDistric	String with ambulance district name
AmbulanceLat	Ambulance Latitute Coordinate
AmbulanceLong	Ambulance Longitude Coordinate
Location	GIS Point object

Table 23 - Portugal: Hospital parameters

Parameter	Description
Latitude	Hospital GIS latitude
Longitude	Hospital GIS longitude
District designation	String with district designation
HospitalID	ID index of each hospital
DistrictID	Index location / county
Adress	String with hospital adress
Location	GIS Point object

Table 24 - Portugal: CODU

Parameter	Description
parTextNeedHelp	Stores the message "I need help!”
parPatient	Patient object

Table 25- Portugal model: Home

Parameter	Description
Id	Table index
latitude	Patient ‘s home GIS latitude
longitude	Patient ‘s home GIS longitude
districtDesignation	String with district designation
idDistrict	Index location / county
Location	Random GIS Point object

8.3.2. Germany

Table 26 - Germany: Patient parameters

Parameter	Description
patientiD	Index of the generated patient
patientLocationId	Index location of the generated patient
DistrictId	Index location / county
DistrictDesignation	String with location name
timeArrived	Measured time for arrival/enter in the source block

Table 27 - Germany: Ambulance parameters

Parameter	Description
homebaseID	ID index of each ambulance home station
Ambulances	Number of ambulances available in each district
districID	Index that identifies distict
District Designation	String with district name

Table 28 - Germany: Hospital parameters

Parameter	Description
hospitalID	ID index of each hospital
nameHospital	String with hospital name
address	String with hospital adress
hospitalDistrictID	ID index of each hospital location
hospitalDistrictDesignation	String with hospital district designation

Table 29 - Germany: Doctor parameters

Parameter	Description
notarzID	ID index of each doctor
emergencyPhysicians	Number of doctors available in each district
doctorDistrictID	Index that identifies district where doctor is placed
doctorDistrictDesignation	String with distict name

8.4. Appendix D – Java Classes

```java
import java.io.FileNotFoundException;
import java.io.BufferedReader;
import java.io.File;
import java.io.FileReader;
import java.util.Random;
import java.util.Scanner;

import org.apache.poi.hssf.util.CellReference;

import java.lang.NumberFormatException;

public class EMS3 {

    /*
     * Class to Read a CSV File with agregated medical emergency data and produce an
     * excel file with a random list of daily medical emergency incidents
     */


    static String xStrPath;
    static String InputLine = "";
    public final static int rows = 54; // 148 for German data
    public final static int cols = 8;
    public final static int Arows = 6000;

    String [][] auxMatrix = new String[rows][cols];
    public static Patient [][] MyArray = new Patient [rows][cols];
    public static Agent [][] AgentArray = new Agent [Arows][6]; //5839
    public static Patient [][] TempArray = new Patient [rows][cols];
    public static int Distances [][];

```

Figure 48 - EMS3 Java Class

```java
    public static void ReadMyCSVArray() throws FileNotFoundException
    {
        String [][] auxMatrix = new String[rows][cols];
        String xFileInputLocation;

        /** Method to read a CSV File with Medical Emergency data including:
         * District ID (origin)- integer
         * Daily probability - float
         * Daily number of medical emergencies - float
         * District ID - integer
         * District Designation - string
         * Monthly number of Emergencies - integer
         * District Latitude (for Portuguese data)- float
         * District Longitude (for Portuguese data)- float
         */


        // Data file Stuttgard
        //  xFileInputLocation = "C:\\Users\\Joao\\eclipse-workspace\\EMS\\PatientsAlterada.csv";

        // Data file Metropolitan Lisbon Area
        xFileInputLocation = "C:\\Users\\Joao\\eclipse-workspace\\EMS\\PortugalDemand.csv";

        Scanner scanIn = new Scanner (new BufferedReader(new FileReader(xFileInputLocation)));

        for (int i = 0; i<rows; i++) {

            InputLine = scanIn.nextLine();

                String [] auxArr = InputLine.split(";");

                Patient p = new Patient();

                for(int j = 0; j< auxArr.length;j++) {
                    auxMatrix[i][j] = auxArr [j];
                    MyArray[i][j] = p;
                }

            }
```

Figure 49 Method to read CSV file to array (a).

```
        }

        for(int i = 0; i < rows; i++) {
            for(int j = 0; j<cols;j++) {

                if (j == 0) {

                    MyArray[i][j].setOriginId(Integer.parseInt(auxMatrix[i][j]));
                }
                if (j == 1) {
                    MyArray[i][j].setProbability(Float.parseFloat(auxMatrix[i][j]));
                }

                if (j == 2) {
                    MyArray[i][j].setEmergencyDay(Float.parseFloat(auxMatrix[i][j]));
                }

                if (j == 3) {
                    MyArray[i][j].setDistrictId(Integer.parseInt(auxMatrix[i][j]));
                }
                if (j == 4) {
                    MyArray[i][j].setDistrictDesignation(auxMatrix[i][j]);
                }
                if (j == 5) {
                    MyArray[i][j].setNumberEmergencyMonth(Integer.parseInt(auxMatrix[i][j]));
                }
                if (j == 6) {
                    MyArray[i][j].setDistrictLatitude(Float.parseFloat(auxMatrix[i][j]));
                }
                if (j == 7) {
                    MyArray[i][j].setDistrictLongitude(Float.parseFloat(auxMatrix[i][j]));
                }

            }

        }

        scanIn.close();
    }
```

Figure 50 - 49 Method to read CSV file to array (b)

```
public static Agent[][] verifyMontlyData(Patient[][] a, File file) throws Exception
{

    Patient [][] a1 = a;

    for (int i = 0; i<6000; i++)
    {

        Agent p = new Agent();

        for(int k = 0; k < 6; k++)
        {

            AgentArray[i][k] = p;

        }

    }

    int j=0;

    /*
     * Cycle to generate a list of random observations in accordance with data file
     */


    for (int i=0; i<20000; i++)
    {

        int locationId = generateRandomId();

        System.out.print(a1[locationId-1][5].getNumberEmergencyMonth()); // nº de emergências mensais da freguesia cujo nº foi gerado aleatóriamente


        if ((locationId == a1[locationId-1][1].getOriginId()) && (a1[locationId-1][5].getNumberEmergencyMonth() > 0))
        {
            j++;

            a1[locationId-1][5].setNumberEmergencyMonth(a1[locationId-1][5].getNumberEmergencyMonth()-1);

            AgentArray[locationId-1][0].setLineId(j);
            AgentArray[locationId-1][1].setOriginId(locationId);
            AgentArray[locationId-1][2].setDistrictId(a1[locationId-1][3].getDistrictId());
            AgentArray[locationId-1][3].setDistrictDesignation(a1[locationId-1][4].getDistrictDesignation());
            AgentArray[locationId-1][4].setDistrictLatitude(a1[locationId-1][5].getDistrictLatitude());
            AgentArray[locationId-1][5].setDistrictLongitude(a1[locationId-1][6].getDistrictLongitude());
```

Figure 51 - Method to prepare and export data to excel file.

```java

    public static Agent[][] prepareEmergencyData (Patient[][] Array, File file) throws Exception
    {

        Patient[][] victim = Array;

        return verifyMontlyData(victim, file);

    }

    public static void main(String[] args) throws Exception
    {


        ReadMyCSVArray();

        TempArray = getMatrixPat();

        Patient[][] x = getMatrixPat();

        File file = ExcelUtils.FileName("C:/Users/Joao/eclipse-workspace/EMS/PortuguesePatients.xlsx");

        ExcelUtils.setExcelFile(file,"Data");

        prepareEmergencyData(TempArray, file);

        return;

    }
```

Figure 52 - Main Class

```java
import java.io.File;
import java.io.FileInputStream;
import java.io.FileOutputStream;
import org.apache.poi.xssf.usermodel.XSSFCell;
import org.apache.poi.xssf.usermodel.XSSFRow;
import org.apache.poi.xssf.usermodel.XSSFSheet;
import org.apache.poi.xssf.usermodel.XSSFWorkbook;



public class ExcelUtils { •••
//              Row = ExcelWSheet.createRow(RowNum - 1); •••
        } catch (Exception e) {
            throw (e);
        }
    }

    public static void setCellData(Agent[][] Result, int RowNum, File Path) throws Exception { •••
/*          •••
*/ •••
        } catch (Exception e) {
            throw (e);
        }
    }

    @SuppressWarnings({ "static-access", "deprecation" })
    public static void setCellInteger(int Result, int RowNum, int ColNum, File Path) throws Exception { •••
    }

    @SuppressWarnings({ "static-access", "deprecation" })
    public static void setCellInteger2(int Result, int RowNum, int ColNum, File Path) throws Exception {
            try {
//                  Row = ExcelWSheet.createRow(RowNum - 1); •••
            } catch (Exception e) {
                throw (e);
            }
        }


    @SuppressWarnings({ "static-access", "deprecation" })

    public static void setCellDouble(double Result, int RowNum, int ColNum, File Path) throws Exception { •••
    }

    public static void setCellFloat(float Result, int RowNum, int ColNum, File Path) throws Exception { •••
    }

    public ExcelUtils() {
```

Figure 53 - ExcelUtils.java class