



Is there evidence of flexibility in the management of the Portuguese firefighting helicopter fleet?

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Abstract

Rural fires in Portugal have been a major public concern destroying year after year significant portions of the territory, threatening communities, resources and human lives. In the year of 2013, 23,136 occurrences were alerted that originated in 111,600 deployments. From these occurrences, 22% had the presence of at least a helicopter. During the Charlie phase, 66% of the verified occurrences were concentrated in 19% of all the available helipads in the country, and two thirds of the total burned area of the country was around 9 helipads. The main goal of this dissertation is to assess the degree of flexibility in the management of the firefighting helicopter fleet by the analysis of the available historical data. For the purpose of this work, it was only taken in consideration the year 2013, but the work can be replicated to past and future years. In order to understand how the helicopter fleet is used, several factors were taken in consideration, such as flight time, resources employed, and the helipads proximity to fires. This work sought the answer to three questions regarding the characterisation of the use of helicopters, what explained their intervention, and finally, were they being flexibly allocated to the different locations, according to the demand. An extensive work regarding the data available was carried out. In Portugal, the available information is separated between two datasets, containing the occurrences and the deployments respectively. Therefore, both databases need to be treated, in order to merge them with useful information regarding the occurrences and deployments. The final result was a main occurrence dataset containing the type of fire, date and time information, location, action times, burned area, number of deployments, number of different resources, in addition to information about closest helipad, presence of helicopter in initial attack/extended attack, amongst other.

This work evidences that there is a decision rational, when it comes to allocating helicopters to fires to rekindles. In addition, the high number of false alarms, alongside rekindles, represents a constraint in the fire management system, and in the allocation of helicopters. It also links the early use of helicopters, to a decreased of the area burned, which might indicate that it is a valuable suppression resource. This research also points out that in an attempt to modulate the use of helicopters, it can only be achieved by using the SLDTO and the number of deployments. However, since the number of deployments is influenced by the availability, and the time of flight and the SLDTO are both related, if two of these variables can be modulated, the others could derive from it. Regarding the factors that might explain the intervention of helicopters, it was used a *logit* model. From it, it became clear that helicopters are being rightfully used with a large array of ground resources, as intended, but not being used for fires with large burned area and a high number of deployments. In addition, helicopters are preferably used for forested area rather than agricultural areas.

Lastly, the variation of the number of occurrence against the number of helicopters is a strong indication that the fleet is not being managed with flexibility, as the demand created by the rising number of occurrences is not met by the number of helicopters close to the fire. Therefore, the answers to the questions formulated indicates that during the year of 2013, there was no flexible management of the helicopter fleet.

Resumo

Os incêndios nas zonas florestais de Portugal tem sido uma enorme preocupação, destruindo porções cada vez mais significativas de território, ameaçando comunidades, recursos e vidas. No ano de 2013, foram alertadas 23 136 ocorrências, originando 111 600 movimentos. Deste número de ocorrências, 22% contaram com a presença de um helicóptero. Durante o período Charlie, 66% das ocorrências estiveram concentradas em 18% das bases de helicópteros do país, assim como, dois terços da área ardida estiveram próximo de 9 bases.

Assim, o objetivo desta dissertação é averiguar se existe algum padrão de flexibilidade associado à gestão da frota de helicópteros analisando o ano 2013. Assim, este trabalho procurou responder a três questões relativas à caracterização dos helicópteros, o que explica a sua intervenção e se estavam a ser alocados com flexibilidade, de acordo com a procura.

Durante este trabalho foi realizado um trabalho extensivo, relativamente às variáveis e ao seu tratamento. Em Portugal, a informação disponível está dividida em duas partes, contendo uma o número de ocorrências, e noutra os movimentos. Por isso, foi necessário tratar toda a informação, para de seguida, junta-las. O resultado foi uma base de dados principal, contendo as ocorrências, assim como, tipo de fogo, data e horas reativadas ao alerta e a extinção, local, tempos de ação, área ardida, número de movimentos, categorizados por tipos, assim como, número de recursos distintos, categorizados por tipos. Para além disso, foram calculadas informações relevantes relativamente ao centro de meio aéreo mais próximo, presença de helicóptero no ataque inicial/ ataque estendido, entre outras.

Este trabalho demonstra que existe uma decisão racional no que toca à alocação de helicópteros para certos fogos, como reacendimentos. Para além destes, é verificado que o importante número de falsos alarmes representa um constrangimento para o sistema de gestão de fogos, e para a alocação de helicópteros. Para além disso, foi possível demonstrar a relação entre o uso precoce de helicóptero e a área ardida, realçando assim, o seu efeito supressivo. Este trabalho procurou também modelar o uso de helicópteros, tendo apenas conseguido através da distância até à ocorrência e do número de movimentos diários. No entanto, através da modelação de dois parâmetros, conseguimos modelar todo o sistema. A respeito dos fatores que podem explicar a intervenção do helicóptero, foi usado um modelo *logit*. Daí conclui-se que os helicópteros estão a ser usados com meios terrestres, como era de esperar. No entanto, não estão associados a fogos com áreas ardidas grandes, nem com fogos com muitos movimentos terrestres. Para além disso, são usados preferencialmente em zonas florestais, ao contrário de zonas agrícolas.

Por último, a variação do número de ocorrências comparadas com o número de ocorrências com helicópteros, é um forte indício que a frota não está a ser gerida com flexibilidade visto que não é capaz de atender a procura criada através do número de ocorrências, através do número de helicópteros nas proximidades dos fogos. Ao analisar as respostas obtidas, às questões formuladas, conclui-se que não houve flexibilidade na gestão da frota de helicópteros.

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“À ceux qui ignorent, enseignez-leur le plus de choses que vous pourrez; la société est coupable de ne pas donner l’instruction gratis: elle répond de la nuit qu’elle produit. Cette âme est pleine d’ombre, le péché s’y commet. Le coupable n’est pas celui qui fait le péché, mais celui qui fait l’ombre.”

Vitor Hugo

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Abbreviations and symbols

ANPC	<i>Autoridade Nacional de Proteção Civil</i> - National Civil Protection Authority
BA	<i>Base Aérea</i> - Military Aereal Base
CMA	<i>Centro de Meio Aéreos</i> - Helipad
DECIF	<i>Dispositivo Especial de Combate a Incêndios Florestais</i> - Special unit for forest firefighting
DON	<i>Diretiva Operacional Nacional</i> - National Operation directive
EA	<i>Extended Attack</i>
FA	False alarm
DSR	Daily Severity Rating
FWI	Forest Fire Weather Index
GVA	Gross Value Added
ha	Unit of hectare
HEBL	<i>Helibombardeiro Ligeiro</i> - Small Helicopter
HELIFA	<i>Helicóptero das Forças Armadas</i> - Military Helicopter
HEBM	<i>Helibombardeiro Médio</i> - Medium Helicopter
HEBP	<i>Helibombardeiro Pesado</i> - Large Helicopter
IA	<i>Initial Attack</i>
ICNF	<i>Instituto da Conservação da Natureza e das Florestas</i> - Nature and Forest protection Institute
Rkd	Rekindle
SLDTO	Straight line distance to target occurrence
VCi	<i>Veículo de Combate a Incêndios</i> - Firefighting vehicle
VCOC	<i>Veículo de Comando e Comunicações</i> - Command and Communication vehicle
VFCI	<i>Veículo Florestal de Combate a Incêndios</i> - Forest firefighting vehicle
VLCI	<i>Veículo Ligeiro de Combate a Incêndios</i> - Small firefighting vehicle
VTTF	<i>Veículo Tanque Tático Floresta</i> - Water tank
WUI	Wildland urban interface

Chapter 1

Introduction

1.1 Dissertation Goals

Every Summer, Portugal's news is flooded with reports about forest fires that consume an important portion of the natural resources of the country, alongside infrastructures, and, tragically lives. Wildfires have risen several concerns in the country government and several measures have been implemented, forcing to draft, each year, several plans regarding fire management, imposing fire suppression and fire prevention measures aiming to reduce fire ignition and spreading, and their consequent damage. Taking in consideration, previous data provided, more precisely the year of 2013, regarding the number of occurrences and consequent movements, this research aims to understand how the helicopter fleet is being use and if it is being used with flexibility.

Bearing in mind the main goal, a few questions were formulated.

- What are the characteristics of the management of th helicopter fleet?
- Which factors explain the decision to use a helicopter?
- Is there evidence of flexibility in the use of the helicopter fleet?

1.2 Dissertation Outline

This dissertation begins by the literature review about fire management, regarding prevention and suppression, in the chapter 2. In addition, the role of helicopters and the fire weather is explained. Following, in chapter 3, a brief overview of how the Portuguese suppression system is organised and the resources available, is explained. Later the data and the methods used are presented, with a careful explanation of all the data manipulation done. Afterwards, the analysis done are detailed. In chapter 4, the results obtained, and discussed. Lastly, in chapter 5, the conclusions based on the results obtained is drawn. This paper closes with the limitations found throughout this work and some propositions of future work.

Chapter 2

Literature review

Previous to the elaboration of this thesis, an intense research was carried out in order to retrieve previous studies concerning fire management, including the role of helicopters, as well as the influence of weather in fire ignition and spread. Later on, the concept of flexibility was defined.

2.1 Fire Management

Fire Management is defined as the management of forest wildfire and its consequences on its social, economic and ecological, forest ecosystem scope (Martell, 2007). Typically, fire management programmes are developed by central authorities at country level, and are motivated, alongside to fire suppression and prevention, to attain a broader forest area and save natural reserves (Torres, 2016). Forest fire management divides itself broadly into two categories, prevention and suppression (Martell, 2001).

Fire prevention consists in all the activities that aimed to prevent wildfires from happening. It ranges from community education, fuel treatment to pre-suppression (Pacheco et al., 2014). Community education plays a major role in fire prevention, as it teaches people to avoid certain actions that may result in fire hazard, and raise awareness to the consequences of False Alarms (Pacheco, 2011). In addition, new measures and fines are being held in place that demand landowners to clean and trim their terrains (Fernandes, 2007). However, in Portugal, where a major slice of the forest is privately owned (93.4% (Mendes, 2006)), with most of them unknown or abandoned by the ageing population, poses a problem and leads to an increase in the fuel load and consequently, an increase in forest fire risk (Flannigan, 2008). Furthermore, fuel treatment can also be a part of fire management strategies. It aims to reduce fire likelihood to occur or spread, by modifying forest vegetation or fuel complexes (Martell, 2001). Fernandes and Botelho (2004) supports prescribed burning practice, as a strong prevention strategy, and points out its beneficial effects. Unfortunately, current fire management focus on fire suppression, tending to ignore land management issues, leading to a more fire-prone future and intensify the problem (Fernandes, 2013).

In addition, fire management systems, such as Wildland Fire Decision Support System (Pacheco et al., 2015), can be implemented in order to predict when and where those fires are likely to occurs,

rearranging the available resources to close proximity (Martell, 2001). Although, the high number of human caused ignitions can pose as a problem, on these predictions, Cunningham and Martell (1973) claims that these numbers could be distributed as a Poisson distribution. In Portugal, Catry et al. (2009) states that 85% ignitions were located in agricultural and urban–rural disperse areas, and only 15% occurred in forested or uncultivated areas, although it constitutes 50% of the country. Those systems and the decision making associated with initial attack operations classifies as the domain of skilled and experienced firefighters, as opposed to the inexperience and volunteer crews in Portugal (Comissão técnica Independente, 2017), and, unfortunately, there have been few attempts to develop decision-making to help them (Martell, 2001). Moreover, fire managers tend to not equip all their bases capable of coping with intense and infrequent fire demand but rather, they attempt to predict when and where such events will occur and re-deploy their resources from bases with higher demand (Martell, 2007).

When fire prevention is not enough, tactics of fire suppression are put in place. Fire suppression, is defined by all the actions to extinguish or contain a fire, from its moment of alert. The area burned and time to contain a fire are often used to obtain the performance of fire suppression and includes measures to detect fires at their initial stages, and intervene in the initial attack (IA) to contain fires before it burns over large areas, or minimise the damage caused by large fires. Man-power and equipment, more commonly denominated suppression effort, required to terminate a fire can be described in function of time since ignition, fire spread rate, fire line intensity and resources production time (Fernandes et al., 2016). Furthermore, the probability of the failure of the initial attack depends from fire danger rating, fuel hazard and forest type (Fernandes et al., 2016). In conclusion, fire suppression decreases burned area by reducing the number of potentially large fires through initial attack, and by decreasing the size of large fires through extended attack (EA) (Fernandes et al., 2016).

In their study, Pacheco et al. (2014) provides relevant information on the trade-off between prevention and suppression efforts. The premature abandonment of firefighters from mop-up routines, to intervene in the suppression of another fire poses as a problem, as rekindles can be prevent from occurring, by properly training firefighters in mop-up operations and active surveillance. Adding that fire crews could always be out of the headquarters, either fighting a fire or engaged in active surveillance and prevention (Pacheco et al., 2014, 2012), while Beighley and Hyde (2009) goes further by suggesting the creation of special brigades, properly trained for mop-up.

2.1.1 Fire life cycle

A fire ignition goes through several stages during its life cycles, requiring special care for each one. Martell (2001) describes as 5 distinct phases, has shown in figure 2.1. While Pacheco et al. (2014) complements it in figure 2.2, as it adds the different stages from the IA, EA and rekindles. It also points out the distribution of the available resources through false alarms and fires.

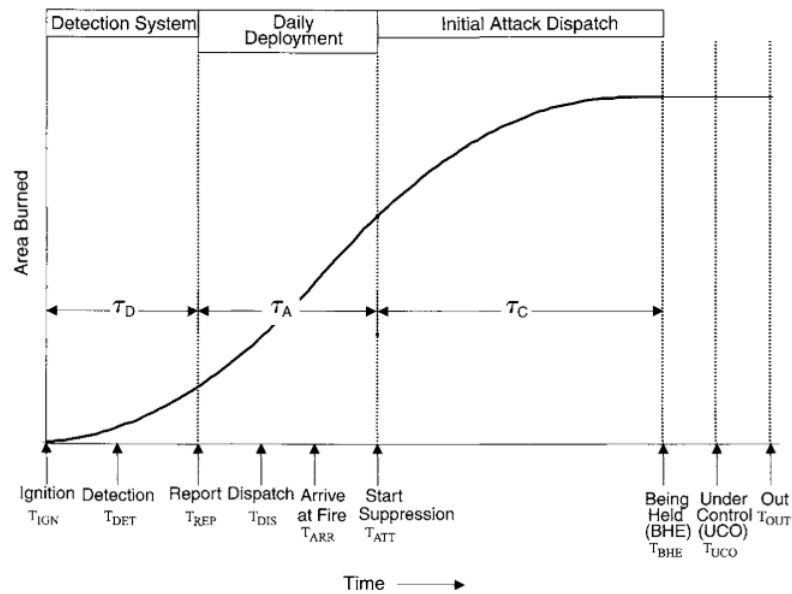


Figure 2.1: Fire life cycle according to Martell (2001)

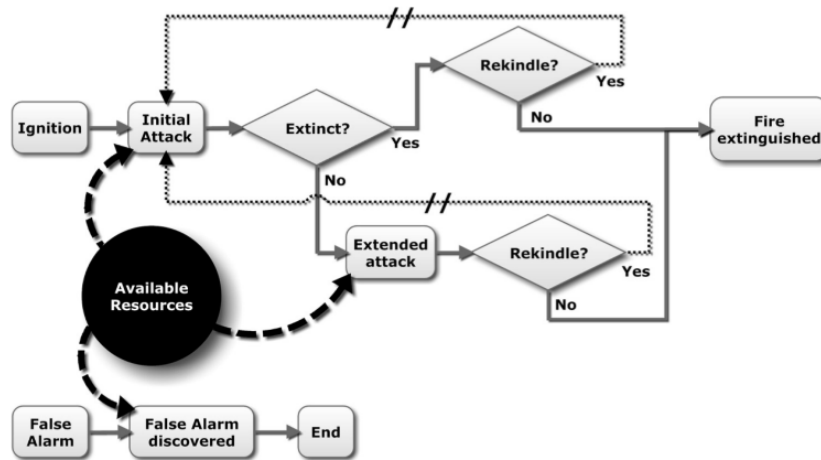


Figure 2.2: Fire life cycle according to Pacheco et al. (2014)

In Portugal, the first 90 minutes after an alert is issued concerning a new occurrence is considered the IA. The term occurrence must be used here, as it can be either a fire or a false alarm. This deploys a first intervention of the firefighting resources, in triangulation, typically composed by ground and aerial resources, in a strong and consistent approach. According to the *Diretiva Operacional Nacional* (DON) (Autoridade Nacional de Proteção Civil, 2017), if an available helicopter or plane is in the radius of operation should attend the fire. As a matter of fact, helicopters during the initial attack, proves to be more efficient (Marchi et al., 2014). In addition to the aerial resource, three firefighting vehicles from the three nearest fire departments must also be deployed.

When the crew arrives to the location, the designated leader must devise a plan for fire suppression based on the current fire behaviour, surrounding vegetation, values at risk, number and type of resources currently available, and the forecast weather (Martell, 2001), and decide if they will need more resources.

If the fire is not controlled within the first 90 minutes, the commander firefighter must warn the fire managers and it will be activated the EA. Additional resources are deployed, and it is verified an expansion of the perimeter, in addition, to an operational command post is set. The resources used in the initial attack are bound to recharge, especially the aerial resources. Therefore, a strong fast initial attack is followed by a solid and gradual increase of resources, at the EA, stabilising when the fire is considered contained. Then the number of resources continuously decreases as the fire is being under control and subsequently is declared out.

After the fire is under control, firefighters must stay behind in order to perform the fire mop-up, which means to monitors the area and eliminate and isolate every live combustion, with track machines or manual tools (Autoridade Nacional de Proteção Civil, 2009), and avoids future rekindles (Pacheco et al., 2014).

2.1.2 The role of helicopters

Helicopters have proven to be an extremely valid fire suppression mean, especially when used for the initial attack. However, the number of helicopters does not show a significant effect in terms of suppression effectiveness (Marchi et al., 2014), and that that the use of helicopters rather than trucks decreases the daily deployment window, (Martell, 2001). Aerial means can be used to drop water or special fire-spread-retarding chemicals on the fire (air tankers) while the initial attack crew is travelling to the fire. In addition, it can pose as a valid solution to transport crews to the perimeter of the fire. Germano et al. (2010) also argues that the use of aerial resources could monitor the forest and detect even earlier possible fires, or even assess the situation on ongoing fires.

2.1.3 The role of fire weather

Several studies showed that weather can play an important part when it comes to fire management and prevention. Using the Canadian Fire Weather Index System, Flannigan (2008) developed a statistical approach to estimate the monthly area burned and the number of fires per district, using meteorological variables and the forest Fire Weather Index (FWI) and other variables as predictors, obtaining highly significant regressions. It also states that the weather can influence ignitions, determine fuel moisture while wind contributes to fire growth. Note that FWI estimates the risk of wildfire, and Daily Severity Rating (DSR), rates the difficulty of controlling fires, based on the FWI, and gives a estimate of the effort required for fire suppression. Chow and Regan (2011) goes even further by considering weather conditions as a factor for the demand for resource allocation.

In Portugal, Viegas and Viegas (1994) has performed several studies that indicates that the rainfall from Winter and Early Spring contribute for the growth and development of vegetation, and

consequently increases the fuel during fire season, but on the other hand, precipitation during the Fire season has proven to slow down, and even repress the fire to ignite or spread. Unfortunately, the climates are changing, and seasons have become more and more uncertain (Carvalho et al., 2014), which also increases stress on vegetation, and consequently, larger and more damaging wildfires (Beighley and Hyde, 2009).

Although, Pereira et al. (2005) has identified the weather conditions, stated by Viegas and Viegas (1994), as particularly favourable to increasing wildfire, future fire occurrence seem to be more dependent on a number of human factors, rather than on climate change scenarios of temperature, humidity and wind. Therefore, education of population returns as an important solution for fire prevention, as stated previously section 2.1.

2.2 Flexibility

Flexibility can be describe "as a critical attribute of a system,(...) it is needed in order to cope with uncertainty and change, and implies an ability to change and adapt to a range of conditions"(Saleh et al., 2009). In other words, flexibility is the ability of a system to change when the initial requirements shift. In order to attain flexibility, a system must mimic the possibility of existence of decisions during its life span (Pacheco, 2018; Pacheco et al., 2014). Although, uncertainty can rise a lot of risks, it might bring a lot of opportunities, with different sources (Cardin et al., 2015). Saleh et al. (2009) describes flexibility as a multi-disciplinary concept, but later enlightens the reader about how flexibility can affect the decision making. Aiming to assess the flexibility of our system, it must be measurable. However, as pointed by D. Gupta (1998), in his studies of flexibility in manufacturing process, there is still not an agreement to how it can be measure, due to the fact that flexibility is not a direct result of physical attributes nor environmental characteristics. When evaluating possible outcomes for a project design, it is crucial to evaluate the flexibility, which consists in four parts: identifying the key performance indicators (KPI), analysing historical trends and their trend breakers and establishing the forecast accuracy (Torres, 2016).

Chapter 3

Data and Methods

This chapter begins by giving a brief overview of the area studied, in this case, Portugal, and completed with the suppression resources and how they are employed. Afterwards, it is explained how the provided data was treated and analysed, in addition to the methods and tools used.

3.1 Study site

Portugal is a South Eastern country situated in the Iberian Peninsula, with a total area of 92,212 km², where it is estimated that two thirds are considered forested areas, according to the Nature and Forest protection Institute *Instituto da Conservação da Natureza e das Florestas* (ICNF), in 2006, and 10 291 027 people, according to the National Statistic Institute. The country is divided in 18 districts, and those are divided in municipalities. The north and central coastal regions lodges a greater population density, in opposition to the rest of the territory which landscape consist on rural, agricultural and forest area. In addition, the effects of migration to the cities, originated to the abandonment of agriculture terrains and consequently an extensive area occupied by bush and dense forest (Gomes, 2006). Moreover, Carmo et al. (2011) states that the northern slopes are more sensitive to wildfires.

Portuguese forest has an important role in the country economy, and corresponds to over 500 millions of its Gross Value Added (GVA) (Instituto Superior de Agronomia, 2003) with the production of paper and cork. Eucalyptus and cork trees plantations are responsible for the sizeable production of these two goods, in addition to pine tree essential to the production of furniture. However, eucalyptus and pine trees represent a major fire hazard, as they are highly flammable (Gomes, 2006). Some studies even analysed moisture content of several fine fuels, including pine needles and eucalyptus leaves, and their relation to the average burn area, showing that there is a dependence between the moisture content of dead pine needles to average number of daily fires and burned area (Viegas and Viegas, 1991). Nonetheless, Portugal has the highest density of wild-fire ignitions among southern European countries, registering an average of 28,500 fire ignitions every year, with the average density of ignitions three times higher in Portugal than in Spain,

France, Italy and Greece combined (Catry et al., 2009). In addition, the average burned area has increased 48.8% over the last decade, between 2002-2011, alongside France (Marchi et al., 2014).

3.1.1 Portuguese fire suppression system

In Portugal, there are two major entities, the National Citizen Protection Authority - *Autoridade Nacional de Proteção Civil* (ANPC) and the ICNF, that work in order to create plans and reports, assess and evaluate risks regarding fire and firefighting management.

From the year 2006, as a result of a major reformulation in the Fire management policies in the country, ANPC must elaborate and publish the *Diretiva Operacional Nacional* (DON) that establishes the *Dispositivo Especial de Combate a Incêndios Florestais* (DECIF). This document details the number of resources, workforce, organised by seasons of fires, bases, among other important information for the year to come. From this document, there was retrieved some interesting information, in order to formulate some assumptions for this work. The DECIF states that the year is divided between 5 phases of fire hazard as shown in 3.1. During each period of the year, different tactics and resources are employed. For the purpose of this study, we will be focusing in the Charlie phase, as it represents the higher number of helicopter activity.

Table 3.1: Stages of fire hazard; Source: DECIF

Phase	Periods
ALFA	01 January to 14 May
BRAVO	15 May to 30 June
CHARLIE	01 July to 30 September
DELTA	01 October to 31 October
ECHO	01 November to 31 December

For the year in study, the cost of fire management policies corresponded to 110,8 millions euro (ICNF, 2013). Where the ratio between suppression and prevention policies was three times larger between the years 2013 and 2016 (Beighley and Hyde, 2018).

3.1.2 Resources management

The Portuguese government, aware of the consequences that forest fires poses, has at its disposal several resources for fire suppression. For the purpose of this dissertation, resources were divided in 4 main groups: aerial resources, separated by planes and helicopters - which will represent the main focus of this work - ground force, medical assistance, and others. By others, it is being referred to resources not directly linked to the fire suppression, but essential to help during and after an occurrence. The resources employed in 2013 are listed in Appendix A, by category, according to the ANPC dataset, in addition to the number of presences in occurrences and deployments. During the fire season, the ANPC can ask for reinforcements, that can be either national, divided between the army and private contracts, or international. For this dissertation, it will not be taken

in consideration the international help nor private resources. Regarding ground force resources, the most commonly used vehicles are the firefighting vehicles - *Veículo de Combate a Incêndios* (VCI), that include forest fighting vehicles - *Veículo Florestal de Combate a Incêndios* (VFCI) and smaller firefighting Vehicles - *Veículo Ligeiro de Combate a Incêndios* (VLCI), that can hold up to 4000 litres and 400 litres, respectively, and Rescue Vehicles. These are assisted by support vehicles like water tanks, such as *Veículo Tanque Tático Floresta* (VTTF), logistic, tactical command vehicles, among others. Lastly, other vehicles like track machines can be used to facilitate the access by fire or even create firebreaks (Autoridade Nacional de Proteção Civil, 2009). A special attention will be drawn to *Veículo de Comando e Comunicações* (VCOC), vehicle that aids with communication and operations. Alongside the ground force, aerial resources also play a major role in fire suppression, and are usually employed in the initial attack, but also for larger fires. Those can be fitted into two groups, airplanes and helicopters. Aerial resources offer a faster time of reaction, easier access to any area and can also be used to identify other fires during their missions. However, their high cost, which represents 50% to 65% of the suppression cost (Comissão técnica Independente, 2017; Beighley and Hyde, 2018), demands a careful management.

In this dissertation, the main focus will be the helicopters. ANPC argues that it can represent a very resourceful mean, as they can be used to drop water and in some case and used to transport teams. The use of fire retardant products has not yet been implemented in Portugal, but constitutes as one of the measures proposed by Comissão técnica Independente (2017). In addition, they can overfly dense forest and participate in rescue missions, as mentioned before. However, not all fires can be accessed by aerial resources, for instance, unfavourable flight conditions, dense smoke or even narrow passages. In addition, the use of aerial resources during the night, more specifically after the sunset and before dawn, is forbidden. Helicopters have their own classification, as they can be used for fire suppression, recognition missions, rescue missions, and other. For this work, the main focus will be on four types of helicopters, differentiated by their size: Small helicopters - *Helibombardeiros Ligeiros* (HEBL), Medium helicopters - *Helibombardeiros Médios* (HEBM), Larger helicopters - *Helibombardeiros Pesados* (HEBP) and military *Helicópteros das Forças Armadas* (HELIFA), which belong to the military. As established by the ANPC, the HEBL are used for the initial attack, while HEBP are used for extended attack and for fires at a greater distance than 70km. For the year of 2013, it was used 38 HEBL, 13 HEBM, 4 HEBP and 2 HELIFA.

In 2013, Portugal used 38 main operating bases, helipads, denominated *Centro de Meio aéreo* - CMA, which two were from the military. According to the ANPC, helicopters are assigned to a base and can later be reallocated to other helipads or even to alternative helipads. Nonetheless, the allocation of a helicopter requires that the new location has bedding and food facilities. In addition, this solution requires previous authorisation and preparations must be done in order to receive the vehicles and their crew. Furthermore, some helipad cannot receive more than one helicopter.

The independent group *AFOCELCA* also provides 3 more helipads, and, although they can also be pulled aside to fight fire, their locations were not taken into consideration in this study. The locations of helipads can be found on Appendix B in figure B.1, alongside their district and

municipality. They were also organised by their locations, as it will be later explained in 3.3.1. The map in figure 3.1 was created using their coordinates and their number, using *Rstudio*, function `plot`. Their x and y coordinates were outputted using a online tool¹ after the latitude and longitude provided by the Autoridade Nacional de Proteção Civil (2017). Using this representation, it was possible to divided the country into Thiessen Polygons, that were generated from the helipad location such that each polygon defines an area of influence around its helipad point, so that any location inside the polygon is closer to that helipad than any other (Croley and Hartmann, 1985).

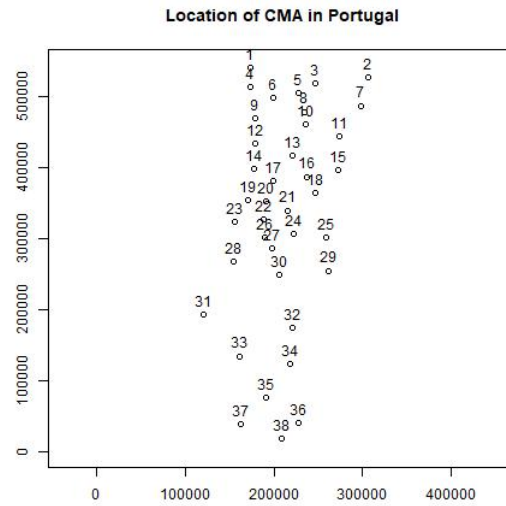


Figure 3.1: Locations of Helipads in Portugal, and ranked by their location explained in B

3.2 Datasets

The data provided consisted in two main datasets, which were linked by a third dataset, and a forth that adds information to the first one. The first dataset consisted in a list of all the Occurrences, hereinafter designated by *O2013*, while the second one, denominated *D2013* consisted on the Deployments and resources that were used by each occurrence. It is considered that the term occurrence for each ignition alert given that originated at least one deployment. There was no common identifier between both set of data, so the third one was needed to link both. A last database containing weather conditions at the time of ignition was linked to the *O2013* by an identifier code common to both. The deployment dataset was provided by *Autoridade Nacional de Proteção Civil* (ANPC), whilst the occurrence dataset was issued by the *Instituto da Conservação da Natureza e das Florestas* (ICNF). The Linking database (*L2013*) and the Meteorological database (*M2013*) was provided by Eng. Rui Almeida (ICNF). The identifier *2013* in each one of the dataset names was reference to the year of analysis of 2013. Later, it was found out that the repeated information, between *L2013* and *O2013* had some inconsistencies, regarding location,

¹<http://www.whoi.edu/marine/ndsf/utility/NDSFutility.html>

data and type of occurrence. This was ignored and it was used the *O2013*. The same happened with the repeated information in *D2013* and *O2013*, using the latter as reference. The last database *M2013* incorporated the information of *O2013*, with information about the weather, such as Temperature, Humidity, Wind, FWI, and DSR. Once again, the repeated information was ignored. This information was computed by taking in consideration the average mean of all the occurrences happening in simultaneous in a radius of five kilometres with the data of the closes weather station. It constitutes a pioneer approach, as it opposes the traditional information regarding only the closest weather station, and is currently in development. Additional dataframes such as *R2013* and *B2013* were also created containing the name and category of all the resource, and the helipads names and locations, respectively.

Before any type of analysis, it was mandatory to treat the data, therefore, it was used *RStudio software*® (<http://CRAN.R-project.org/>), and the language *R*, that allows statistical calculation, among others, and *Microsoft Excel* ®. In order to import and export the information, it was used the *readxl* package (Wickham and Bryan, 2018). All the dataframes that were created were saved in *csv* and *rds* format for further manipulation.

A brief inspection of the *D2013* was done, aiming to understand which information could be relevant to our study, and what could be retrieved. This dataset provided all the deployments, that could be differentiated from each occurrence to occurrence, by their ANPC Number. Then, it was analysed the *O2013*, that provided the x and y locations to ignitions, their date of alert and extinguishing, the type of fire (false alarm (FA), forest...) and the burned area. Regarding the type of fire, in the ICNF dataset, there were described as FA, forest, agriculture or *Queimada*, which is described as man-made fires used for the renewal of cattle grazing (Instituto Superior de Agronomia, 2006; Pacheco, 2011). In addition, there were binary variables regarding the distinction between rekindles (rkd), *queimadas*, FA, *fogacho* that is described as a fire with less than 1 hectare(ha) of burned area, forest fires, with more than 1 ha of burned area, and agricultural fires. All the occurrences were distinguished by their ICNF Code. The linking dataset contained the ICNF Code and respective ANPC number, along with location and type of occurrence.

The goal was to obtain a main occurrence database *OLDeM2013* as completed as it could be, including information such as number of deployments, number of vehicles used, along with other relevant information. This demanded a intense analysis of both database in order to obtain, for each occurrence, the presence of each mean by their classification, and the different number used. Secondly, it was realised that adding the *ICNF* database to the *ANPC* database was also significant, therefore it was created the *DLO2013* database. In addition, aiming to obtain the maximum number of information about each occurrence and their deployments, it was only took in consideration the occurrences present in both datasets. The following table 3.2 summarises the number of information that could be linked from one database to another, as well as the number of mismatches in the database, while in table 3.3 are the number of data without connection between the datasets.

Table 3.2: Available information per Database
(in bold the main databases)

Number of Occurrences in METEO	27,376
Number of Occurrences in ICNF	27,372
Number of Occurrences in ANPC	25,873
Number of Occurrences in Linking DB	24,774
Number of occurrences in OLDeM2013	23,136
Number of resources deployments in DLO2013	111,600

Table 3.3: Comparison of data between datasets

Without Connection					
	Linking DB	ICNF	Meteo	ANPC Occurrences	ANPC nor ICNF
METEO	1,527	4	–	x	x
ICNF	1,523	–	0	x	–
Linking DB	–	24	24	2,726	13
ANPC Occurrences	1,627	x	x	–	–

3.3 Methods

Aiming to assess the presence of a flexibility pattern, the provided data was manipulated and several methods were employed. These served as a mean to answer the questions presented on chapter 1, that helped assess the degree of flexibility.

3.3.1 Data Treatment

The first step, concerning data treatment, was to choose the right format of variables, treating dates as *POSIXct* to allow operations to be made, factors as factors, and so on. In addition, dates were also transformed to days of the year (1-366), using the function *yday* and the library *lubridate* (Grolemund and Wickham, 2011). This only assisted in our visualisation of the problem. Two new variables were created, concerning the number of the year day of the day of alert and the number of the year day of day of the deployment, originating from the day of alert of *O2013*, and the day of the departure from the station of the deployments *D2013*, respectively. When the day of departure was not specified, the day of arrival to the station was used. Even so, in some deployments it was not given any that information. Still regarding the *D2013*, the variables '*Duration of deployment*' and '*Time to action*' were computed, by taking in account the time between the departure and

arrival to their base or station, for each deployment and the time between the alert and the departure of a resources, respectively. This enable the identification of the resources that were used for initial or extended attack, and the duration of each intervention. For occurrences with helicopters, the '*Time to action*' were took in consideration and the smaller was declared as the time to action for a helicopter in the initial attack, '*Time to action IA*'. Regarding dates, it was also calculated the duration of each occurrence, by subtracting the date of extinction and date of alert. This enable the creation of a binary variable that assumed the value of 1 when the occurrence was declared extinct in less than 90 minutes. On account that the number of occurrences extinguish in 90 minutes was very small, a new threshold of 110 minutes was created, using the analogue method.

Then, all the information repeated on the datasets was tested to assess to see if they matched, using R to compare them. It was detected some inconsistencies between both datasets, but those were discards due to their residual size. The district discrepancy was presumed to the proximity from cities and where the alert was issued, as a occurrence might be reported by several people. Regarding date and time, the same supposition was made. In these cases, it was given priority to the information in the official ICNF dataset.

Some extra steps were also made to avoid future mistakes, such as comparison of the names given from database to database to locations and helipads. Those differed, sometimes, because of the Portuguese accent and auxiliary punctuation, and case sensitiveness. In addition, some databases had different names in the database, like Montijo helipad that was actually the military base *Base Aérea 6* (BA 6). Lastly, variables like District, Municipalities and helipads were treated as a factor, since there is a limited number of each.

As explained before, this study was only interested in occurrences that was possible to place the point of ignition, and that there was information about the deployments and resources employed. Hence, it was only took in consideration occurrences present in both databases. Therefore, a list was created connecting the occurrences available in both datasets, *O2013* and *D2013*, whit the help of *L2013*. The purpose of such list was to create an auxiliary dataframe containing the main identifiers in our databases, called *OL2013*.

Then, our *script* diverges, aiming to create the *OLDeM2013* and *DLO2013*, containing the occurrences and the deployments, respectively. First, the main focus was on the production of dataset *OLDeM2013*. In order to complement the information on *O2013*, it was needed to retrieve the shortest distance to the point of ignition to a helipad. This was the first calculated variable of our database. It was outputted by calculating the distance to each helipad, and choosing the shortest. In this case, it was not considered the military bases location, BA 11 and BA 6, and the *AFOCELCA* helipad locations. This originated four new variables in our *O2013* dataframe, consisting in the closest helipad, distance between the point of ignition, and the x and y coordinates of such base.

The next step led to the determination if a helicopter was used for the initial attack, as intended in the DECIF. For that, it was retrieved all the deployments of helicopters, and took in account the time to action. For those shorter than the 90 minutes, it was assign the number 1 to the variable '*Used during AI90*'. As explained before, the window for initial attack was enlarged

and 110 minutes were also considered, so the analogue method was applied for the creation of a '*Used during AI110*'. Following, it was summed for each occurrence the variable in question, and for the occurrences that had a sum different than 0, it was assigned the binary variable 1 to the variable '*Presence of Helicopters during IA90*'/'*Presence of Helicopters during IA110*', and 0 when the sum was 0. The same process was done, concerning the extended attack (EA), '*Presence of Helicopters during EA*'. For occurrences where there was no helicopters, this values were assign 0. Lastly, the shortest time to action of helicopters present was added to the occurrence in a variable '*Action time of first helicopter*'. Posterior, it was created a *script* in order to retrieve the number of deployments, resources, and people allocated to each occurrence. Due to the complexity of this cycle, it was created a different dataframe, containing only the ICNF Code and ANPC number, were it would be added the variables in question. Foremost, it was divided the resources by their category, creating a set of variables containing the resource code of each. it was divided in Aerial Resources (*ra*), Helicopters, (*rah*), Aerial Resources non helicopters (*rahn*), ground force resources (*rg*) and fundamental ground resources, (*rgf*). Also, the variable *d* and *rp* that stands for deployments and people, respectively, were created that contained the sum of the overall count of each occurrence. Related to this topic, the number of each different resource employed was also taken in account, identified by their license plate, alongside, the presence of each type of mean represented by a binary variable. The cycle was constructed, beginning by retrieving all the ANPC deployments containing the ANPC number provided. It would read row by row, placing each deployment in the respective category. The result was a dataframe containing each occurrence identified by their ANPC number and ICNF code, accompanying by the number of deployments, number of resources by each type, and how many distinct resources, and the presence or absence of each category. This concluded the treatment of the information that would later integrate our *OLDeM2013* database. The next step was to add to the *OL2013*, the closest helipad, the resources per fire, binary variable '*Presence of Helicopters during Initial Attack*' and lastly, the *M2013*, that did not required treatment. The opposite analysis was also done. The deployment database *D2013* was completed with data from *OLDeM2013*, originating *DLO2013*. The last step was to convert the binary variables and some variables with a limited number of outcomes into factors, such as '*Closest helipad*' or '*Type of Fire*'. A separate database including only the helicopter deployments was also subdivided, for further studies. The variables present *OLDeM2013* and *DLO* databases are presented in Appendix C and Appendix D, respectively.

3.3.2 Helicopter characterisation

In order to assess any pattern of flexibility, it was mandatory to analyse how the Helicopters were being used. For this it was created a calendar of each helicopter deployment, using only the *D2013*, throughout the year. This visual representation was developed using *Excel*®, and arrayed the daily deployments in different helipad, by each helicopter. It represented the perfect way to comprehend any visual pattern that could exist. This method allowed also to understand which helicopter interacted to which helipad. In addition, aiming to understand how the helicopters were being allocated, it was study the times of action of each helicopter deployment between their

departure from the station and the alert of the occurrence. This prompts an analysis, with the help of a histogram their time to action.

Proportion tests

A new analysis, regarding the characterisation of helicopters, was carried out aiming to understand the link of helicopter use to other factors. This allowed for the analysis of the helicopters used in False Alarms or in rekindles. This relationship was tested resorting to the two-proportions *z-test*. This test allows the comparison of two observed proportions, and detect if the probability of the presence of a helicopter has any relationship with the second observed proportion (Parternoster et al., 1986). The mathematical expression 3.1 equates this test, for large samples.

$$z = \frac{pa - pb}{\sqrt{\frac{pq}{na} + \frac{pq}{nb}}} \quad (3.1)$$

Where:

- pa represents the proportion observe in group A with size na ,
- pb represents the proportion observe in group B with size nb ,
- p and q represent the overall proportion.

By choosing a $\alpha = 0.05$, accepting a confidence interval of 95%, the value of $|z| < 1.96$ must be obtained, in order to conclude that the difference is not significant. This analysis was easily done with R command *prop.test* from the base R library (R Core Team, 2018).

Goodness-of-fit

Afterwards, an attempt to find any patterns was carried out, resorting to analysing the distributions of variables related to the different helipad and helicopters, using the *DLO2013*. For this analysis, the helicopters coming from AFOCELCA and Spain were removed and the period window was shorten to the critical period, that will be detailed bellow.

The goal of this analysis was to see if any variable fitted in one of the mathematical distributions. It was necessary to analyse the number of occurrences daily, the duration of the intervention and the straight line distance to target occurrence (SLDTO), in total, for each helicopter and for each helipad. The SLDTO was computed by calculating the distance from the helipad where the helicopter parted to the ignition point. Whilst the duration of the intervention was retrieve with the variable '*Duration of deployment*'. Additionally, aiming to arrange the data of the number of deployments per day, it was used the function *dcast* from the package *data.table* (Dowle and Srinivasan, 2018). This outputs the data in a matrix, where each row and column represents the different values of two variables. For this study, we created nine scenarios: - one for each of the three variables, time of deployment, SLDTO and number of deployments, for each of the three groups containing the analysed variables grouped by helicopters, by helipads and the total. Since

the number of deployments of these two variables are different, it could not save them in the same dataframe. Therefore, a dataframe was created for each using the *split* function from the base library (R Core Team, 2018), and later saving it in a *csv* file. This originated 95 *csv* files (57 helicopters and 38 helipads), for distances and another 95 *csv* files for duration of intervention.

Later, it was used the *software EasyFit®*(MathWave Technologis, = <http://www.mathwave.com>) This *software* allows to upload a series of data, and it will give several distributions that better fit - *goodness of fit* the dataset. It also computes the data in form of the histogram, several distributions and their parameters. *EasyFit®* also ranks all the distributions according to three different tests, Kolmogorov-Smirnov, Anderson Darling and Chi-squared. For this work, the distributions were ranked by the Kolmogorov-Smirnov, and were chosen the ones that were accepted by the three tests.

3.3.3 A *Logit* model for helicopters dispatching

In order to explain the presence of a helicopter in the occurrences, and the factors that may have influenced it, a *Logit* analysis was used, which consists on the transformation of a probability to odds, and later to log odds in order to obtain a broader scale (Williams et al., 2006). Therefore the Binomial *Logit* links a depend binary variable to the linear function of the independent variables. Moreover, for each increase of one unit of the independent variable, creates a increase of the output probability of the success of the dependent variable.

It also allows to represent the logistic regression in to a linear relationship with the predictor variables as follows:

$$\text{logit}(p) = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \dots + \beta_x x_x \quad (3.2)$$

$$p = \frac{\exp(\beta_0 + \beta_1 x_1 + \dots + \beta_x x_x)}{1 + \exp(\beta_0 + \beta_1 x_1 + \dots + \beta_x x_x)} \quad (3.3)$$

Several independent values selected from the *OLD2013* database were used, and several combinations of those values within several trials. Resorting to the *glm* function, from the base R package (R Core Team, 2018), the coefficients of the model in question were outputted. Later on, the *pR2* from the package *pscl* (Zeileis et al., 2008), was used to compute pseudo r-square measure for each model, that compares of the log-likelihood for the fitted model against the log-likelihood of a null/restricted model with no predictors.

In order to obtain the correlation between some of the variables, the function *cor* and the *corplot* were used, from the library *corplot* (Wei and Simko, 2017). This two functions enables the visual representation of correlation between a group of numerical variables.

3.3.4 Flexibility in the helicopter fleet

The last method implemented consisted in understanding if the fleet was allocated to each helipad according to the number and dimension of the fires in progress. This led to the creation of a three-dimensional matrix, containing the days and the closest helipad, as reference, and the number of occurrences and deployments, and respective standard deviation. This was then compared to a similar matrix, created based on the calendar created before Appendix H in figure H.1, containing the number of helicopters at each helipad throughout the year. This was using once again the *dcast* function (Dowle and Srinivasan, 2018). Furthermore, the standard deviation for each row and column was computed using the *rowSds* and *colSds*, respective, from the *fBasiscs* package (Wuertz et al., 2017). For a better understanding, it was plotted the matrix using *plotly* package (Sievert et al., 2017) to obtain online representation of the 3D map, as well as, the *Excel®* for the same purpose. Furthermore, the helipads were rearranged, taking in consideration their y coordinates in increasing order and ranked by numbers. The layout of the helipad in this manner created a stretch map of Portugal, as shown in 3.1.

Chapter 4

Results and Discussion

During this work, several results were produced aiming to respond to the questions proposed on chapter 1. In this chapter, it is presented the results obtained for the methods previously listed on chapter 3, alongside to the respective discussions. Please note that the reference to figures and tables in appendix in this chapter will only state the respective number (e.g. figure X.n).

From the initial datasets, *O2013* (9% of rekindles and 14% of False Alarms) and *D2013*, it was obtain a dataset containing 23,136 occurrences (10% of rekindles and 4% of False Alarms), that corresponded to 111,600 deployments. The median duration of each occurrence was of 153 minutes, and with a burned area of 6.8 hectares, as shown in table 4.1. The average distance from a point of ignition to the closest helipad was around 23km, with a maximum of 100km which is well of the range of the 70 km determined in the Autoridade Nacional de Proteção Civil (2012). All the descriptive statistic (mean, standard deviation, average, quartils,...) of the the continuous data in *OLDeM2013* is listed in Appendix E.

From this occurrences 1,418 (6%) were resolved in the first 90 minutes, and 4,511 (20%) in the first 110 minutes. From the 111,600 deployments analysed, retrieved from the 23,136 occurrences, 6,987 were flights of aerial resources, which mostly were carried out by helicopters (6,474 - 5.8% of *D2013*), in 5,013 occurrences (21.7% of *O2013*). Please note that the important number of deployments represents the number of times a resource left his station and comeback, and the number of drops was not taken in consideration, for instance, the VTTF which need to refill in nearby ponds or lakes. Concerning the 5,013 occurrences, helicopters were present in 4,307 (85.9%) during the first 90 minutes, i.e. IA.

Seeing that it was only considered 23,136 (84.5%), from the original 27,372, it was important to understand if the number of occurrences discarded was relevant. Therefore, it was took in consideration the occurrences in ICNF (*O2013*), in the database built (*OLD2013*), and the difference between each other *NL2013*, and analysed two variables, the duration of the occurrence and the burned area, and the type of occurrences, as shown in table 4.1. Comparing both *p25* and *p50* for both variables, in *O2013* and *OLD2013*, it becomes clear that they are very similar, so the database used seemed to be a significant sample. While doing this analysis, it was also noticed that some occurrences were closed several days after their alert, (some over 200 days). These occurrences

influenced the average of the duration of the occurrence. Additionally, a considerable number of the occurrences not study represent FA (64%), which might have been discarded and therefore not deployed a resource, which is corroborated by the median of 0 ha of burned area, in this case, but goes against the policy to consider every occurrence a fire until proven the opposite.

Table 4.1: Comparison of burned area, duration and types of occurrences, between the *O2013*, *OLD2013*, and *NL2013*

Database	Duration of fire (min)			Burned Area (ha)		
	O2013	OLD2013	NL2013	O2013	OLD2013	NL2013
Total	27,372	23,136	4,236	27,372	23,136	4,236
N	26,484	22,937	3,547	27,372	23,136	4,236
Missing	888	199	689	0	0	0
min	3	11	3	0	0	0
<i>p</i> 25	111	117	81	0.01	0.01	0
<i>p</i> 50	145	153	106	0.03	0.05	0
<i>p</i> 75	204	221	137	0.3	0.39	0.01
<i>p</i> 99	1,083	1,086	866	72.61	95.3	9.28
Average	266	257	321	5.88	6.8	0.82
sd	3,441	3,352	3,970	119.07	129.40	11.38
FA	3,728	1,014	2,714	14%	4%	64%
Rkd	2,504	2,416	88	9%	10%	2%
Agri.	3,834	3,573	261	14%	15%	6%
Fog.	15,446	14,625	821	56%	63%	19%
Inc.	3,845	3,505	340	14%	15%	8%
Queim.	519	419	100	2%	2%	2%

When analysing this data, it was realised that the duration of the occurrences had a important average compared to its median. Indeed, 28 occurrences in *O2013*, from which 17 present in *OLDeM2013*, that lasted over a week. When carefully analysing this list, in Appendix F, it was soon noticed that some of the extinction dates provided were bound to be a mistake. The longest occurrence in this list corresponded to approximately 8 months and was classified as a FA, alongside 10 other FA, as shown in table F.1. There is also a forest fire with a burned area inferior to 0.1 ha, which is bound to be a mistake since forest fires must have over 1 ha (Instituto Superior de Agronomia, 2006). In order to visualise the duration of FA, a histogram was created containing the duration of these type of incident. Following the histograms, a bar graph, accumulating all the occurrences that lasted over 360 minutes (6 hours) was plotted, resulting on F.1 and F.2, for *O2013* and *OLDeM2013*, respectively. Although, the majority of the occurrences was terminated before the 120 minutes mark, there are a significant number after that. It was assumed that the time stamps regarding the date of extinction were misleading.

Therefore, a new analysis was made regarding the duration of the occurrences in the three datasets but removing all the occurrences classified as FA, as shown in table 4.2. The new duration times seemed to have a dim skew to the right regarding *O2013* and *OLD2013*, except for *p75* and the average, while in the *NL2013*, the discrepancy seems to be much more important. Concerning the burned area, the opposite shifts are observed, in average as the FA being discarded translates in the annulment of occurrences with burned areas of zero. Consequently, by removing the FA the data regarding the duration and burned area seemed to make more sense. Additionally, it indicates that the sample *OLDeM2013* retrieved from the *O2013* is valid, since the number of occurrences left in *NL2013* are not relevant, as most represent FA with wrong dates or small fires.

Table 4.2: Comparison of burned area, duration, types of occurrences between the *O2013*, *OLD2013*, and *NL2013* without FA

Database	Duration of occurrences (min)			Burned Area (ha)		
	O2013	OLD2013	N2013	O2013	OLD2013	N2013
Total	23,644	22,122	1,522	23,644	22,122	1,522
N	23,603	22,090	1,513	23,644	22,122	1,522
Missing	41	32	9	0	0	0
min	9	11	9	0	0	0
<i>p25</i>	115	118	67	0.01	0.01	0.01
<i>p50</i>	151	154	100	0.05	0.05	0.0585
<i>p75</i>	210	213	146	0.5	0.44	1
<i>p99</i>	1,093	1,100	795	96	98.67	27.62
Average	226	230	173	6.8	7.11	2.29
sd	1,157	1,135	1,437	128.09	132.32	18.91
FA	0	0	0	0%	0%	0%
Rkd	2,504	2,416	88	11%	11%	6%
Agri.	3,834	3,573	261	16%	17%	16%
Fog.	15,446	14,625	821	65%	66%	54%
Inc.	3,845	3,505	340	16%	16%	22%
Queim.	519	419	100	2%	2%	7%

4.1 Helicopter characterisation

The first research questions formulated in chapter 1, regarding the characteristics of the helicopter management, unfolds in (i) where, (ii) when, (iii) how, and (iv) why are the helicopters used, and also, (v) if it is possible to fit the helicopters deployment.

(i) Where are the helicopters used?

This first question leads to the analysis of the variables "*number of occurrence*", "*burned area*", and their "*burned area per occurrence*" (quotient), by their closest helipad (Thiessen Polygon). To highlight the most significant data, it was taken in consideration the helipads that represented at least two thirds of the studied variable. The complete lists is shown in Appendix G.

Regarding the number of occurrences, shown in table 4.3, it becomes clear that more than a fifth of the occurrences occurred in the proximity of the Baltar helipad, and two thirds of the occurrences were closer to 7 helipads, close to one fifth. When taking in consideration only the occurrences where the helicopters were used, there are some slight shifts as shown in table 4.4. The names in bold represent the helipads common with the previous table. In this case, the Baltar retains the first place, but only with 12% of the occurrences. In addition, the use of helipads is more even out, as two thirds of the helicopter interventions corresponds to 10 different helipads, as opposed to the previous 7.

Table 4.3: Closer helipads to occurrences during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Freq.	Percent	Cum.
1	9	Baltar	4,166	23.40	23.40
2	6	Fafe	1,562	8.77	32.17
3	28	Pernes	1,548	8.69	40.86
4	1	Arcos Valdevez	1,356	7.61	48.48
5	12	Vale de Cambra	1,192	6.69	55.17
6	4	Braga	1,148	6.45	61.62
7	10	Armamar	691	3.88	65.50

Table 4.4: Closer helipads to occurrences with helicopter intervention during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Freq.	Percent	Cum.
1	9	Baltar	578	12.52	12.52
2	6	Fafe	397	8.60	21.13
3	1	Arcos Valdevez	384	8.32	29.45
4	12	Vale de Cambra	338	7.32	36.77
5	13	Viseu	261	5.66	42.43
6	10	Armamar	238	5.16	47.58
7	4	Braga	207	4.49	52.07
8	3	Vidago	206	4.46	56.53
9	14	Agueda	183	3.97	60.50
10	28	Pernes	163	3.53	64.03

An analogue analysis was also carried out regarding the total burned area. In the year 2013, during the Charlie phase, 151 267 hectares burned due to wildfires in *OLDeM2013*. The two thirds of the burned area are concentrated in 9 helipads, when taking in consideration the total occurrences (Table 4.5), which corresponds to the same number when taking in consideration only occurrences where there was the intervention of helicopters (Table 4.6). From both analysis, the list stays the same, but in a different order, with the exception of Baltar, for total occurrences, and Santa Comba Dão, for helicopter occurrences. Bornes and Arcos de Valdevez ranked on the first 3 in both analysis. It becomes appears that some helipads that are repeated, throughout the two comparisons, three for the number of total occurrences and four for the number of occurrences with helicopter intervention.

Table 4.5: Closest helipads to occurrences by burned Area during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned area	Percent	Cum.
1	7	Bornes	19,691.6	13.02	13.02
2	10	Armamar	13,603.9	8.99	22.01
3	1	Arcos Valdevez	13,356.2	8.83	30.84
4	13	Viseu	11,902.5	7.87	38.71
5	3	Vidago	11,256.9	7.44	46.15
6	11	Mêda	10,207.8	6.75	52.90
7	9	Baltar	9,000.5	5.95	58.85
8	5	Ribeira de Pena	7,754.3	5.13	63.98
9	8	Vila Real	7,262.4	4.80	68.78

Table 4.6: Closest helipads to occurrences by burned Area with helicopter intervention during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned area	Percent	Cum.
1	7	Bornes	19,591.7	15.12	15.12
2	13	Viseu	11,764.8	9.08	24.20
3	1	Arcos Valdevez	10,828.5	8.36	32.55
4	10	Armamar	10,489.3	8.09	40.65
5	11	Mêda	9,533.7	7.36	48.00
6	3	Vidago	8,805.2	6.79	54.80
7	5	Ribeira de Pena	7,232.2	5.58	60.38
8	17	Santa Comba Dão	7,020.3	5.42	65.80
9	8	Vila Real	6,139.9	4.74	70.53

Then, it was analysed the burned area by occurrences, associated to the proximity of each helipads, as shown in tables 4.7 and 4.8. It seems similar to the previous analysis of the burned area. Bornes, Mêda and Santa Comba Dão rank higher when taking in consideration this analysis,

regardless of the presence of helicopter. It is important to notice that the Baltar helipad is no long ranked in the first two thirds of this list, although it holds the higher number of occurrence. This might be associated with the fact that the area in which this helipad is a wildland urban interface (WUI) (Stewart et al., 2007), which contains both housing and wildland vegetation. Catry et al. (2009) claims the population density positively influence fire ignitions, adding that 98% occur near roads, nevertheless, WUI zones have less fuel, which might explain the small burned area per occurrence.

Table 4.7: Closest helipads to occurrences by burned Area by occurrence during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned Area by occurrence	Percent	Cum.
1	7	Bornes	115.83	23.44	23.44
2	11	Mêda	34.96	7.07	30.52
3	17	Santa Comba Dão	30.87	6.25	36.77
4	21	Pampilhosa da Serra	29.80	6.03	42.80
5	5	Ribeira de Pena	29.04	5.88	48.67
6	3	Vidago	23.50	4.76	53.43
7	8	Vila Real	22.48	4.55	57.98
8	2	Nogueira	22.29	4.51	62.49
9	13	Viseu	20.77	4.20	66.70

Table 4.8: Closest helipads to occurrences by burned Area by occurrence with helicopter intervention during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned Area by Occurrence	Percent	Cum.
1	7	Bornes	268.38	24.55	24.55
2	11	Mêda	69.59	6.37	30.92
3	17	Santa Comba Dão	67.50	6.18	37.09
4	21	Pampilhosa da Serra	59.35	5.43	42.52
5	2	Nogueira	54.93	5.03	47.55
6	5	Ribeira de Pena	54.38	4.97	52.52
7	18	Covilha	46.74	4.28	56.80
8	13	Viseu	45.08	4.12	60.92
9	10	Armamar	44.07	4.03	64.96
10	3	Vidago	42.74	3.91	68.87

In conclusion, joining tables 4.3 and 4.5, about one third the available helipads(13-34%), that covered over two thirds of the occurrences and burnt area.

(ii) When are the helicopters used?

Furthermore, it was created a visual representation of the helicopter deployments. The figure H.1 shows the whereabouts of each helicopter, represented by each row, in the different helipads, that are represented by different colours, during the days where helicopters were deployed. The first two rows represented the month and the day, respectively. The helicopters are referenced by their license plate, while the different helipads are represented by different colours. It is important to know that this table was draft by examining each movement, and taking in consideration where the helicopter departed that day. Meaning that, there is no certainty when the helicopter move from one helipads to another, before or during an occurrence, for example, the helicopter CS-HMN between the 14th and the 21st of may. It was also estimated that the helicopters were not used during interventions intervals. However, the point of ignition, the number of occurrences and deployments are not possible to obtain from this analysis, as it is not enough to draw any conclusion regarding the flexibility of the fleet.

This visual representation also evidences the fact that some helipad support and utilise several helicopters at the same time. The helicopters are roughly organised by the most amount of time spent in a location, alongside, to the smaller number of presences in different helipads. The first 14 helicopters were only deployed from one helipad while the latter changed their location over 5 times. The number of different helicopters present in each helipad and their number of fires was also extrapolated as shown in table H.1. The median for the number of helicopters per helipad was 2, as the average number of flights was 118. This representation also exposes that some helicopters have presences in different helipads that last only one day, two times, over 76 days, in the entire fleet, which might indicate some flexibility, and some helicopters that operate in two helipads in the same day (four times), as it suggests that the there was a high demand in a determinate place and period.

Although this study focuses on the Charlie Phase, from the 1st of July to the 30rd of September, a shorter period was took in consideration from the 7th of July to the 20th of September. This window had 76 days, and will be designated by "*critical period*" hereinafter. This interval was later used for most of the analysis and observed results. It was chosen since all the helicopters were used at this time, except the Air force helicopters and the helicopter operating with the license plate CS-HMK.

(iii) How are the helicopters used?

Another information relevant that emerge from the data manipulation was the interval between a occurrence date/time of alert and the date/time of departure of the helicopter from the helipad, denominated as '*Time to action*'. This information was compiled in a histogram that later one originated the figure 4.1, with respective frequencies percentages in table I.1. In this case, all the '*Time to action*' ranging from 115 to 10665 minutes (7.4 days) were aggregated. This served two purposes, one to allow a better visualisation of each class, and secondly understand the proportion of helicopters used for IA and EA. In this case, 115 minutes was chosen as it was over the 110

minutes window previously mention. It is important to stress that since the variable chosen represents the interval between the alert and the deployments, which might have occurred days after in case of fires where helicopters were employed during the extended attack.

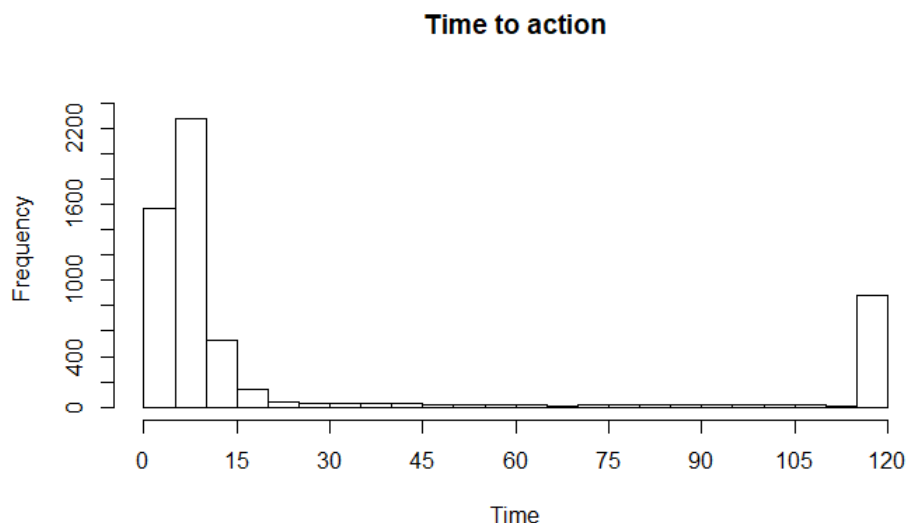


Figure 4.1: Helicopters time to action bar graph, made by the aggregating of intervals higher than 115 minutes

By analysing the data in table I.1, around 83.79% of the helicopters were used in the initial attack, i.e. the first 90 minutes. Increasing the window to 110 minutes, this number increases for 84.68%. This also constitutes as a sign that helicopters are being rightly used for the initial attack, therefore respecting the Autoridade Nacional de Proteção Civil (2012). Additionally, 15.32% of the helicopters were being used for over 115 minutes - EA.

(iv) Why are the helicopters used?

Next, it was analysed the reason for the helicopters used, during the "critical period", and to understand if there was a relationship between the presence of helicopters and other factors, using proportion tests to evaluate the presence of (a) False Alarms and (b) Rekindles. Later on, the (c) burnt area and the associated initial attack was also examined. Their results are summarised in 4.9, 4.10 and the 4.11, respectively.

a) Helicopters and false alarm

False Alarms occur when an alert has been given and resources are deployed believing it is a fire. It can be the result of mischief behaviour, or even the sight of smoke that does not constitute danger (Pacheco, 2011). As fire managers cannot ignore these calls and must treat it as a point of ignition until they can confirm it is a False Alarm, the procedure for this types of occurrences is the same. Therefore, we should expect that the number of helicopters in false alarms are the same. In this test

we get a p-value of 0.388, which is superior to the α used of 0.05. Therefore, the two portions are not statically significant. This result might indicate that helicopters are being deployed regardless of the fact that it is a FA. Deployments towards FA constitutes a waste in the fire management strategies, since resources are allocated for an unnecessary intervention, becoming unavailable for another occurrence, that might be real. Furthermore, each deployment is associated to a cost (Pacheco et al., 2014), in this case, vainly.

Table 4.9: Z-test for False Alarm

Presence of helicopters in False Alarm	167	False Alarms	674	Percentage	24.8%
Presence of helicopters in fires	3,884	Fires	14,739	Percentage	26.4%
X-squared	0.74532				
p-value	0.388				
95% confidence interval	-0.04988	0.01839135			

b) Helicopters and Rekindles

Rekindles occur when fires that were considered extinct becomes active again. This is the consequence of poorly executed mop-ups, premature consideration of the fire to be extinct, and sometimes of untrained firefighting teams (Fernandes et al., 2016; Beighley and Hyde, 2009). The test resulted in a small p-value, which is inferior to the α used. Thus, the two portions are statically significant. This might be a clue that helicopters are being preferably deployed for rekindles, as fire managers understand their risk and sensitivity to spread into large fires. Rekindles are also considered a major damper in the fire suppression as it represents a second fire, created by the fact that the first was not properly moped-up, and therefore, a second intervention and allocation of resources, associated to extra costs (Pacheco et al., 2014).

Table 4.10: Z-test for Rekindles

Presence of helicopters in Rekindles	623	Rekindles	1,937	Percentage	32.2%
Presence of helicopters in primary fires	3,261	Primary fires	12,802	Percentage	25.5%
X-squared	38.46				
p-value	$5.585E^{-10}$				
95% confidence interval	0.04447992	0.08933121			

c) Helicopters and burnt area

In an attempt to analyse if the burnt area was affected by the use of a helicopter. Helicopters were used in 26.4% of fires, which corresponded to burned area 87.2% of the total. This might point to that there is a managers concern, when allocating the available helicopters, to use them in fires that are becoming or are prone to become larger. Additionally, it was compared the number of

fires where the helicopters was and its burned area, before and after a time interval (between its alert and the deployment of the first helicopter). Several iterations, using different thresholds were tested. The results are shown in table 4.11, where "*Reaction time*" represents the interval between the fire alert and the deployment of the first helicopter.

Table 4.11: Comparison of burned area and the time of the helicopter intervention

Reaction time	Number		%		Burned Area		%	
	Before	After	Before	After	Before	After	Before	After
5	1,246	2,233	36%	64%	12,115	107,811	10%	90%
10	2,820	659	81%	19%	45,254	74,672	38%	62%
20	3,216	263	92%	8%	52,112	67,814	43%	57%
30	3,249	230	93%	7%	53,796	66,130	45%	55%
40	3,270	209	94%	6.0%	61,847	58,079	52%	48%
50	3,284	195	94%	5.6%	63,450	56,476	53%	47%
60	3,303	176	95%	5.1%	68,424	51,502	57%	43%
80	3,320	159	95%	4.6%	73,978	45,948	62%	38%
120	3,348	131	96%	3.8%	76,401	43,525	64%	36%
600	3,443	36	99%	1.0%	104,698	152,28	87%	13%
1,200	3,476	3	99.9%	0.1%	115,998	3,928	96.7%	3%
1,310	3,478	1	99.97%	0.0%	119,860	66	99.94%	0%

As the "*Reaction time*" progresses, alongside the number of fires with helicopters deployed before, the burned area increases, as opposed to fires with a deployment after the threshold. Also, it becomes clear that the proportions of helicopters used, in either time intervals is not proportional. This might point out that the earlier the helicopter is deployed, the more efficiently it can be used, and the decreases the burned area, as pointed out by Marchi et al. (2014), however, since the relationship is not linear, it might indicative that there are other factors that influence the burned area, as expected. In addition, this results might suggest that helicopters deployed within the first 30 minutes of fires are more effective.

In conclusion, regarding the justifications for the use of helicopters, there seems that helicopters are being deployed for initial attack, as devise in the Autoridade Nacional de Proteção Civil (2012), however, this might constitute a waste when being allocated for FA. Additionally, there is evidence that there is a decision rational favoured for the use of helicopters, e.g. fires with potential large areas, e.g. , rekindles cases, which constitutes a high risk. Nonetheless, rekindles and FA (790 occurrences/10%) represent a major waste, since they are occupying resources of other fires. As stressed in chapter 2, the use of helicopters in the beginning of IA proves to be very effective (Marchi et al., 2014).

(v) Deployment goodness-of-fit

In an attempt to understand how the helicopters were deployed, the (a) SLDTO (i.e. straight line distance to target occurrence), the (b) number of daily deployments and of (c) duration of flight were grouped and organised by their total, by helicopters and by helipads. Figures 4.2, 4.4 and 4.5 show the histograms of the total distributions regarding the number of deployments per day, the SLDTO by all the helicopters and the time of flight, respectively, during the critical period. The best fitted distribution were plotted. For each total set of data, it was ranked the best fitting distribution, according to Kolomogorov-Smirnov test, and chosen the distributions not rejected by the other two tests (Anderson-Darling and Chi-Squared). Later, some helipads and some helicopters were tested, in order to determine if each variable could be fitted using the same distributions. In Appendix J, several examples are shown. The goal of this analyse is to identify the best fitting distributions for future simulation of the helicopter fleet.

a) Straight line distance to target occurrence

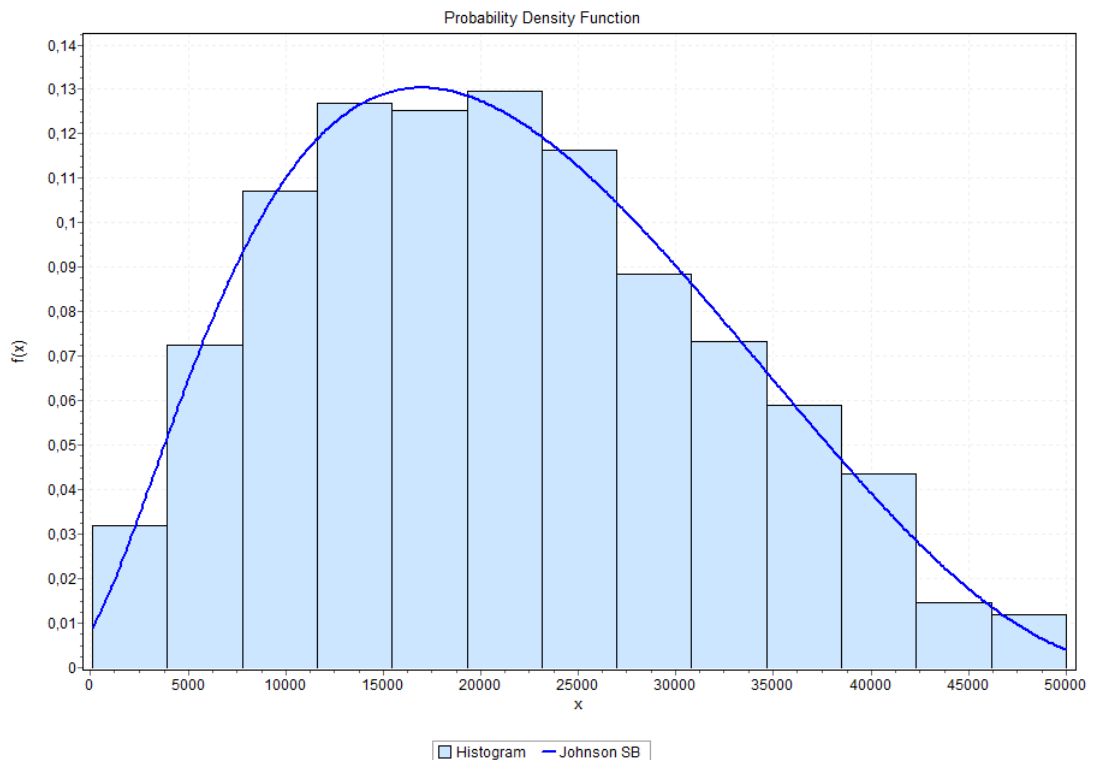


Figure 4.2: Distribution of SLDTO

The SLDTO by the helicopters followed a Johnson SB distribution. This distribution was found to be the best fitting for our data, according to Kolomogorov-Smirnov test. Moreover, the SLDTO fitted a large number of distributions, as opposed to the other variables, so it was also study which of the distributions accepted by Kolomogorov-Smirnov were also accepted by Anderson-Darling

test. In this case, Johnson SB, Pert, Kumaraswamy, and Gen. Gamma (4P) were accepted by both tests, as shown in figure 4.12, while Beta distribution was only accepted by Kolomogorov-Smirnov.

Table 4.12: Results for SLDTO goodness-of-fit distributions

Distribution	Kolmogorov Smirnov	Anderson Darling	Chi-Squared
Johnson SB	Not rejected by all	Not rejected by all	Rejected over $\alpha = 0.5$
Pert	Not rejected by all	Not rejected by all	Rejected by all
Kumaraswamy	Rejected at $\alpha = 0.2$	Rejected at $\alpha = 0.2$	Rejected over $\alpha = 0.02$
Gen. Gamma (4P)	Rejected at $\alpha = 0.2$	Rejected over $\alpha = 0.05$	Rejected by all
Beta	Rejected over $\alpha = 0.1$	Rejected by all	Rejected by all
Weibull (3P)	Rejected over $\alpha = 0.05$	Rejected over $\alpha = 0.01$	Rejected by all
Gen. Extreme Value	Rejected over $\alpha = 0.01$	Rejected by all	Rejected by all
Rayleigh	Rejected over $\alpha = 0.01$	Rejected by all	Rejected by all

In table J.1, it is demonstrated the best fitting distributions by the order they are ranked according to Kolomogorov-Smirnov, as well as their parameters and the tests regarding several confident intervals. Since our objective was to understand if the helicopters shared similar distributions to the total SLDTO data, it was took in consideration previous listed fitting distributions.

Bearing in mind these tests, it was chosen some helicopters and helipads to understand the individual cases followed the distribution fitted by the total. For that, it was considerate the sum and mean of all the helicopters and helipads and chose our sample. The results are shown in tables J.2 and J.3. This test was more detailed because the SLDTO seemed to output the best results regarding the fact that it might followed a distribution. Johnson SB, a transformation of the normal distribution., that was previously regarded as the best fitting distribution for the overall SLDTO, is indeed a good distribution for most of the helipads picked, and to all the helicopters picked. It can also be pointed out that Beta, a classical distribution, seems to fit all of the helicopters chosen, and some of the helipads. Nonetheless, Ferreira de Zezere helipad can not be fitted in any of the best fitting distributions of the overall distance. Some examples are shown in Appendix J.

b) Daily deployments

The number of deployments per day follows a Uniform distribution, according to the Kolomogorov-Smirnov, but rejected by Anderson-Darling (figure 4.3). By observing the plotted histogram, it becomes clearer that the distribution is not uniform. The second suggestion of the goodness of fit was negative Binomial that was not rejected by both tests at $\alpha = 0.01$ and $\alpha = 0.02$. As the proposed goodness of fit did not represented the data, it was transformed the variable into continuous. The figure 4.4 represents the same distribution, but taking in consideration that the number of deployments are continuous. The Beta distribution only ranked 3rd on Kolomogorov-Smirnov, but was

chosen, since the previous fits were reject by the other two tests. The 12 best fitting distributions are represented on table 4.13.

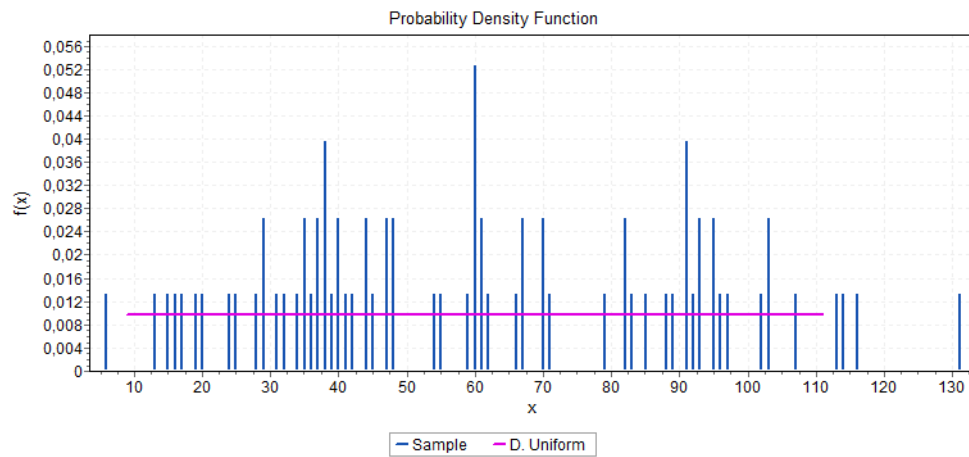


Figure 4.3: Distribution of the number of deployments per day

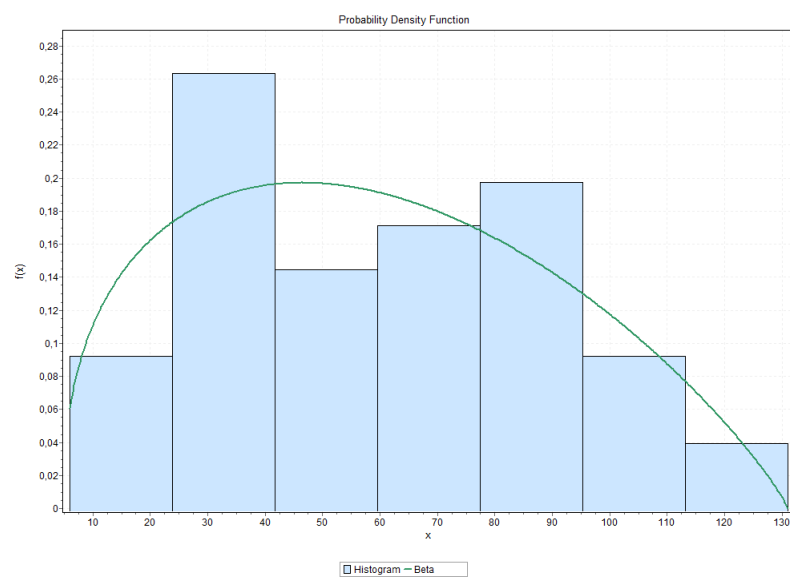


Figure 4.4: Distribution of the number of deployments per day, regarded as continuous

Table 4.13: The best 12 results for the number of daily deployments goodness of fit distributions

Distribution	Kolmogorov Smirnov	Anderson Darling	Chi-Squared
Beta	Not rejected by all	Not rejected by all	Not rejected by all
Log-Pearson 3	Not rejected by all	Not rejected by all	Not rejected by all
Rayleigh	Not rejected by all	Not rejected by all	Not rejected by all
Weibull	Not rejected by all	Not rejected by all	Not rejected by all
Error	Not rejected by all	Not rejected by all	Not rejected by all
Gen. Extreme Value	Not rejected by all	Not rejected by all	Not rejected by all
Erlang (3P)	Not rejected by all	Not rejected by all	Not rejected by all
Burr (4P)	Not rejected by all	Not rejected by all	Not rejected by all
Rayleigh (2P)	Not rejected by all	Not rejected by all	Not rejected by all
Gen. Gamma (4P)	Not rejected by all	Not rejected by all	Not rejected by all
Gen. Gamma (3P)	Not rejected by all	Not rejected by all	Not rejected by all
Lognormal	Not rejected by all	Not rejected by all	Not rejected by all

Afterwards, it was analysed the number of deployments by helipad and by helicopters. Once again, the discrete data was not satisfyingly fitted, so, it was once again transformed to continuous. When taking in consideration the helipads, most seemed to follow a distribution, although there was not a consensus in all - the most recurrent was the Gen. Pareto. However, some helipads such as Bornes did not fit any distribution, according to Kolmogorov-Smirnov, and where rejected at high in most according to Anderson-Darling test, or Pombal that was only accepted by distributions according to Anderson-Darling test or Chi-squared. Regarding the helicopters, the number of movements seemed to be more limited in terms of the distributions that could be used to fit it. There was no recurrent distribution, throughout the fleet, and the number of accepted distribution was scarce. An important number helicopters such as D-HOOK, D-HDAN and OE-XHP did not fit any distribution, according to Kolmogorov-Smirnov. The most used helicopters, CS-HID, and the *p75* I-LIGU seemed to follow a Johnson distribution, as shown in figure J.16 and J.17. Therefore, the total number of movements and by helipad follows can be fitted, into some general distributions, but not when taken in consideration each helicopters. In this case, they needed to be analysed individually.

c) Duration of flight

The duration of flights concerning all the data do not follow any type of distribution. Some iterations were also carried out in an attempt to trim the extremes of our data, to no avail. Nonetheless, by analysing only by helicopters and helipads, some seemed to follow a distribution, provided higher confidence intervals. Concerning helicopters, Dagum seemed to be the wider accepted

regarding Kolomogorov-Smirnov test, and Gen. Extreme Value for Anderson-Darling test. Although it was not always the case. Some exception, like I-AMVN and OE-XBC seemed to have defined distribution, accepted at all the provided α and accepted by both tests. Regarding the helipads, the same unsatisfactory results remained. There was a scarce number of data that could be consensual distributed, therefore, it was needed to analyse each case. Helipads such as Seia followed Gen. Pareto, not rejected by any of tests, while Vila Real did not, and followed rather a Gen. Extreme Value.

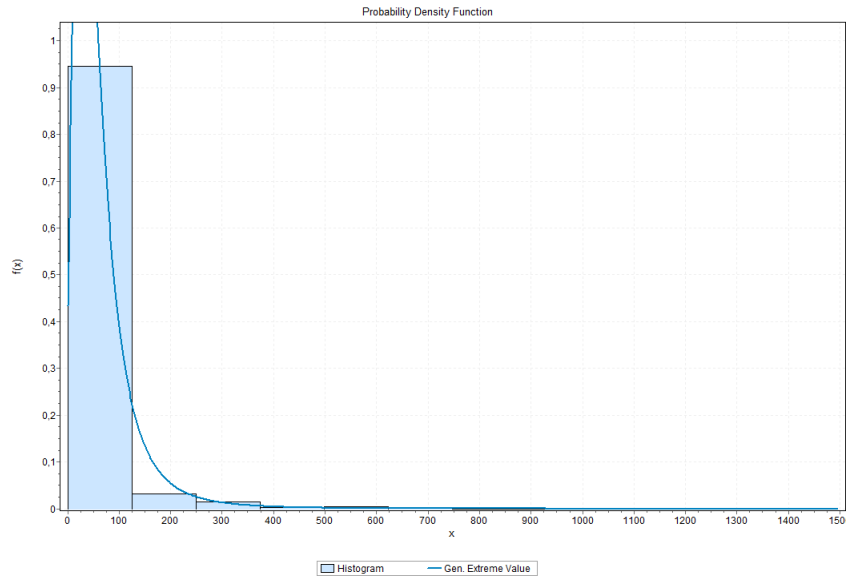


Figure 4.5: Distribution of the time of flight per deployment

The distributions for some of the tested cases and respective goodness of fit are exhibit in Appendix J. The number of deployments and SLDTO can be fitted in some distributions, however, for the the case of the number of deployments, it is not consensual. For further work, it could be estimated the travelled distance, and the time in the scene, as this takes in consideration the distance to the occurrence and the interval between the departure and arrival to the helipads, respectively. It is also important to understand that these variables are related. As the number of deployments is influenced by the availability, and the time of flight and the SLDTO are both related. So if two of this variables can be fitted, the others derive from it, however it would be needed to estimate a coefficient for the SLDTO as it only represents one way, and does not account for movements near the site.

4.2 A Logit model for helicopters dispatching

In order to study the decision to allocate a helicopter to an occurrence, and the factors that may have influenced it, a *Logit* model was used. For the purpose of this analysis, it was only considered the critical period previously defined. The approach used to create a statistically significant regression was to test each variable with the dependent value, helicopter presence. Therefore, variables

were grouped in families, according to their representation, as presented on Appendix K. Prior to the analyse of all the regressions, their correlation was tested, in order to avoid deceitful results. In Appendix K, the correlation between the presence of helicopters and family groups is shown. As expected, FWI and DSR are highly correlated, since DSR is calculated through FWI, therefore, it can be used either one for the analysis. The same conclusions were drawn regarding the Forested burned area and total burned area. A simple model, controlling for one or two variables of each family was created.

Table 4.14: *Logit* model referring to the decision to deploy a helicopter with a pseudo R-squared of 0.314 (i.District with Aveiro as baseline)

Coefficients	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-3.065	0.172	-17.854	< 2.2E-16	***
Temperature	0.018	0.005	3.339	8.40E-04	***
DSR	-0.010	0.003	-3.073	2.12E-03	**
Forested spaces	0.001	0.001	1.814	6.96E-02	.
Ground resources	0.739	0.017	42.328	< 2.2E-16	***
Fundamental ground resources deployment	-0.461	0.019	-24.041	< 2.2E-16	***
VCI (=Yes)	0.458	0.087	5.282	1.28E-07	***
Fires over 1ha (=Yes)	-0.507	0.069	-7.399	1.37E-13	***
i.District.Beja	-1.557	0.229	-6.786	1.15E-11	***
i.District.Braga	-0.386	0.098	-3.935	8.33E-05	***
i.District.Bragança	-0.498	0.169	-2.949	3.19E-03	**
i.District.Castelo	-3.381	0.218	-15.495	< 2.2E-16	***
i.District.Coimbra	-1.383	0.146	-9.465	< 2.2E-16	***
i.District.Évora	-0.856	0.237	-3.605	3.12E-04	***
i.District.Faro	-0.928	0.180	-5.152	2.58E-07	***
i.District.Guarda	-0.407	0.143	-2.844	4.46E-03	**
i.District.Leiria	-2.127	0.176	-12.119	< 2.2E-16	***
i.District.Lisboa	-6.068	0.419	-14.485	< 2.2E-16	***
i.District.Portalegre	-0.625	0.250	-2.499	1.24E-02	*
i.District.Porto	-0.771	0.086	-9.009	< 2.2E-16	***
i.District.Santarém	-1.138	0.141	-8.085	6.24E-16	***
i.District.Setúbal	-2.599	0.232	-11.208	< 2.2E-16	***
i.District.Viana	-0.238	0.104	-2.294	2.18E-02	*
i.District.Vila Real	0.575	0.107	5.391	7.00E-08	***
i.District.Viseu	0.283	0.098	2.892	3.83E-03	**

The analysis of the *logit* in table 4.14 produce has a R-squared of 0.314. It shows that all of the variables are significant. As to the fire weather variables, the temperature increase of one degree seem to have a positive effect on the presence of the helicopters (50.4%), as opposed to the DSR, which its increase might lead to unfavourable flight conditions, due to the smoke and high flames, and therefore, less likely to be attended by an helicopter. The forested burned area which might suggest that helicopters are preferably deployed for forested areas, rather than agricultural areas. Forest fires, with burned areas superior to 1 *ha*, supports the previous claims, as helicopters used

in IA tend to have a smaller burned areas, therefore, helicopters might not being used in fires with large areas. As opposed, it seems that the number of deployments of fundamental ground force resources impacts negatively the use of helicopters, since a high number of deployments seems to be linked to large fires, supporting the previous claims. On the other hand, a positively impact of the presence of firefighting vehicles supports the Autoridade Nacional de Proteção Civil (2012) that states that during the initial attack, three firefighting vehicles and one helicopter should be allocated to the occurrence (Autoridade Nacional de Proteção Civil, 2012), allied to the number of different resources employed. Furthermore, it suggests that the presence of a *VCI*, increase the probability of a helicopter attend a fire of 61,2%. Lastly, the factorial variables of the districts show somewhat a level of significance, which was taken in consideration in an attempt to create a level of fuel proxy. However, their order of magnitude seems to show some disparity.

The use of district variables as fuel proxy is debatable, as the fuels (type and cover) is not constant thought out the entire district, and the same fuel can be found in several districts. Therefore, a second model was made by removing this variable. In table 4.15, the output of the result of one of the iterations made, which increases the level of significance for the burned area, while maintaining the variables of fire weather, resources and deployments previously considered. The fires with a large burned area over 1 *ha* was substituted by the opposite and rekindles. Both fire weather, ground resources, fundamental ground resources deployments, presence of *VCI* and forested spaces kept their directional variation, but slightly decreases their value. While fires with less than 1 *ha* of burned area are more likely to have the presence of helicopters, as expected (Instituto Superior de Agronomia, 2006; Pacheco, 2011). In addition, it confirms the previous finding that helicopters are preferably being deployed to rekindles (64% more likely).

Table 4.15: *Logit* model with a pseudo R-squared 0.235 without a fuel proxy

Coefficients	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-3.578	0.160	-22.302	< 2.2E-16	***
Temperature	0.017	0.005	3.418	0.0006	***
DSR	-0.012	0.003	-4.042	5.30E-05	***
Forested Spaces	0.001	0.000	2.231	0.0257	*
Ground resources	0.563	0.014	40.466	< 2.2E-16	***
Fundamental ground resources deployment	-0.323	0.018	-17.754	< 2.2E-16	***
<i>VCI</i> (=Yes)	0.512	0.084	6.118	9.45E-10	***
Fires less than 1 <i>ha</i> (=Yes)	0.190	0.048	3.964	7.38E-05	***
Rekindles (=Yes)	0.600	0.061	9.880	< 2.2E-16	***

In the regression chosen, fire weather might influence the presence of helicopter, since, it influences the number of daily occurrences and their behaviour (Chow and Regan, 2011; Pereira et al., 2005; Viegas and Viegas, 1994). Additionally, the positive influence of the presence of *VCI* with helicopters might be explained, once again, that helicopters are being used in the initial attack, since, according to Autoridade Nacional de Proteção Civil (2012), the initial attack is composed

by three *VCI* and one helicopter. Furthermore, helicopters seemed to be present in helicopters with smaller burned area, and less number of deployments, which supports the claims of Marchi et al. (2014) and its effectiveness. Lastly, helicopters are more likely to be deployed to forested areas, rather than agricultural areas.

4.3 Flexibility in the helicopter fleet

Finally, it was important to study if the fleet was allocated to each helipad according to the number and dimension of the fires in progress. This led to the creation and plotting of a three-dimensional matrix, as shown in figure 4.6, which, represents the number of occurrences closer to the helipad, by day and figure 4.7 which only shows the ones where a helicopter was used. In z there is the frequency of the variable in study, while, x represents the days of the critical period and y the number of the helipad. Please bare in mind that the number of helipad represents a simplification of the location of the helipads in the country, where 1 equates to the helipad further in north, and 38 for south, as described in Appendix B. Different scales for z were used, as the magnitude is not the same.

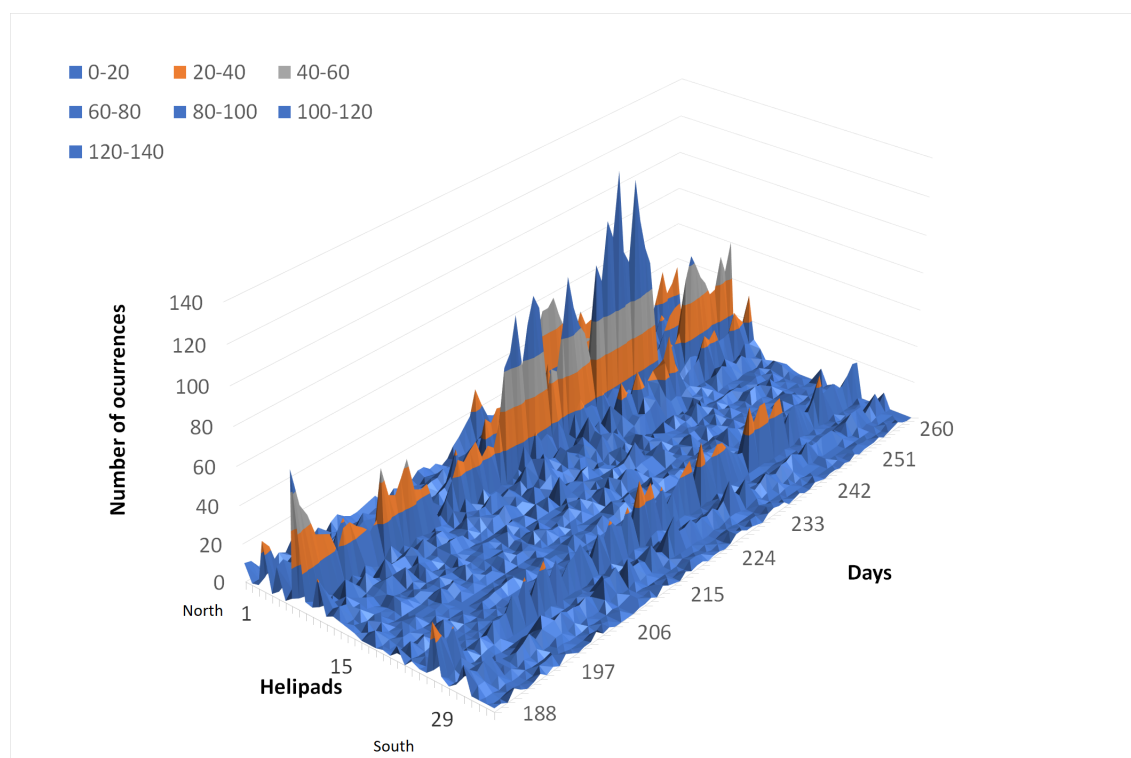


Figure 4.6: Three-dimensional matrix of Number Occurrences

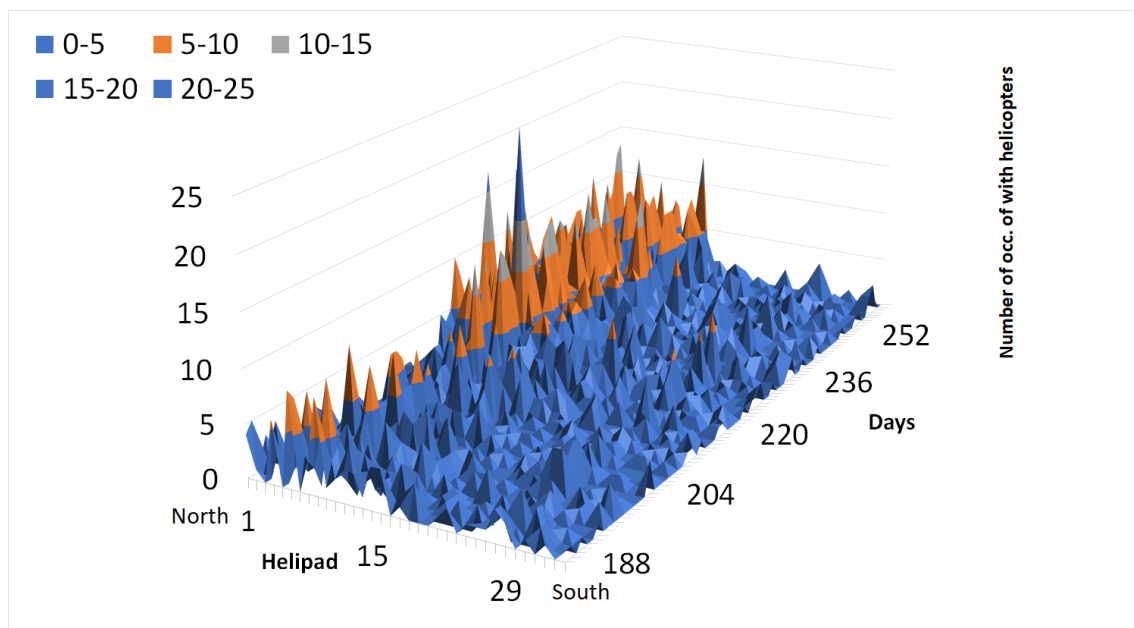


Figure 4.7: Three-dimensional matrix of Number Occurrences with Helicopter Presence

At a first glance, it becomes clear that the two graphical representations do not overlap. This was already proven by the analyse of the data, as there are occurrences that helicopters do not intervene. Nonetheless, it evidences that there is a uneven distribution of the number of occurrence by helipad and by day. In addition, figure 4.7 seems to be more uniform, which might indicate that helicopters are being used locally, and not attending the areas where the number of occurrences is higher.

Figure 4.6 also indicates a high number of occurrences in the north of the country, around helipad 1 and 9, in addition to base 28, in the south. This was also evidence by table 4.3 and 4.4.

An analogue analysis was also computed for the burned area, the overall deployments, helicopter deployments, and number of different helicopters used, taking in consideration the day of the deployment, for each occurrence was also made, and can be seen in Appendix L. The burned area seemed to concentrate in the northern region, and during a 20 day period, (around 12th of August and the 5th of September), as it was also pointed out in figure 4.6. The same peaks are replicated in the number of helicopter flights, although it is not observable in the number of different helicopters used. Meaning that the same helicopters were just being exhaustively used. Additionally, when comparing the number of occurrences and the number of occurrences with helicopters, it is clearer that there is a much even dispersion of the latter. This is a result that there are helicopters being used since they are available, as intended, off course, but not in the areas with large demand.

This representation, despite being very useful, has a lot noise. Thus, a second iteration of the two graphs were made, by cutting the base for a clearer view. This allowed to ignore all the low values, and create a threshold. It varied from representation from representation and it was chosen, by successive iterations, in order to retrieve a clean view. The results are shown below, in figures

4.8 and 4.9.

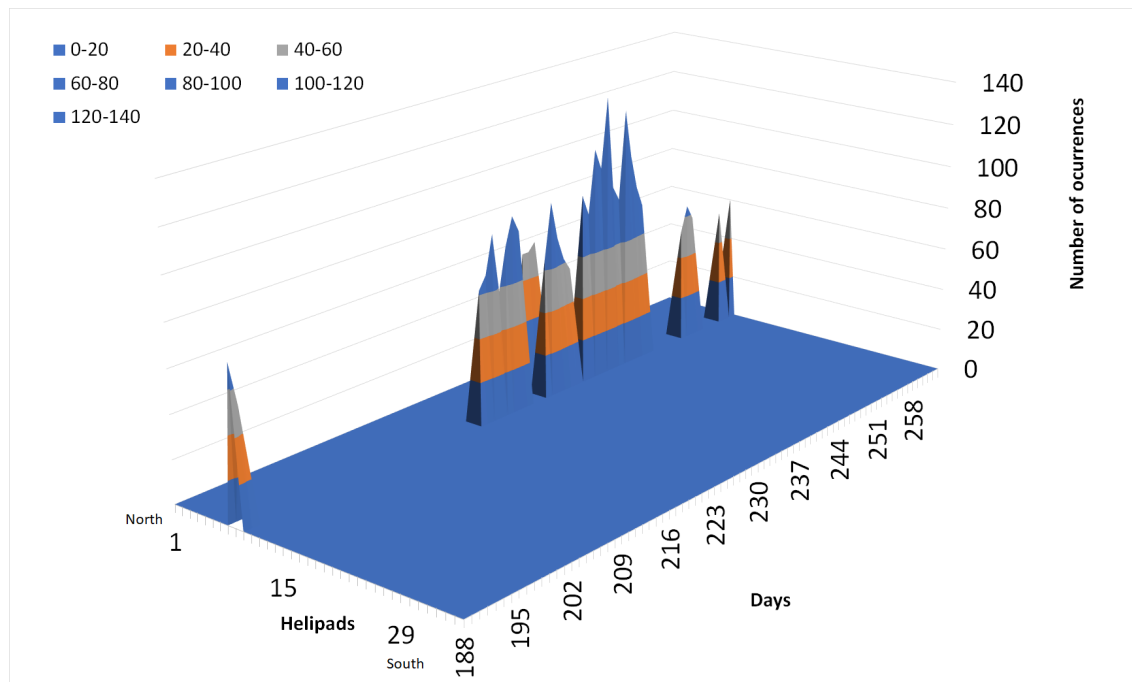


Figure 4.8: Three-dimensional matrix of number occurrences superior to 50 occurrences

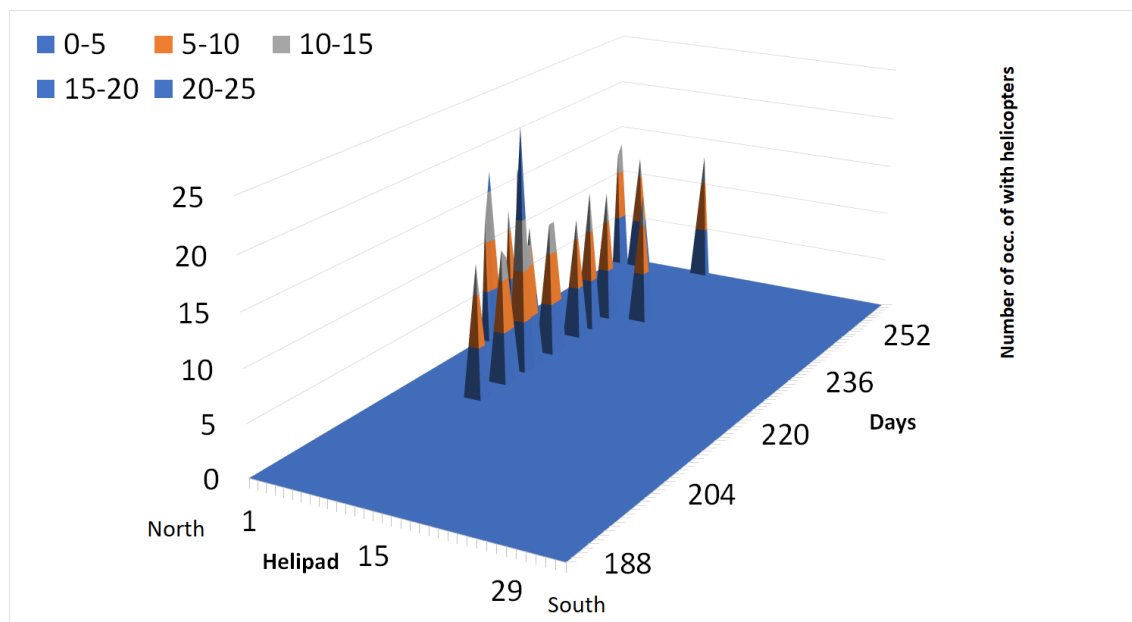


Figure 4.9: Three-dimensional matrix of Number Occurrences with helicopter intervention superior to 12 deployments

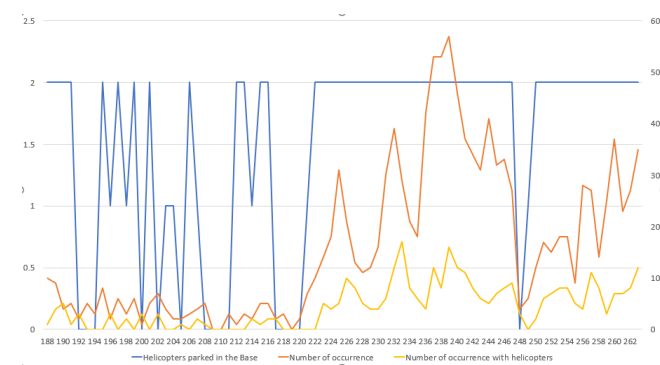
We can differentiate in both graphics that helipads 1, 9 and 12 show demand peaks, in several occasions throughout the year. This can be corroborate by analysing the standard deviations present in Appendix M, as it shows the variation of the dispersion of our data and point out which

of the helipad can be interested to be analysed. Looking at the helipads standard deviations, helipad 1, 6, 9 and 12 represent a good sample as they present a significant variation, in the 7 analysis plotted. They represent, respectively, helipad Arcos de Valdevez, helipad Fafe, helipad Baltar and helipad Vale de Cambra. This led to the creation of a two dimensional graphic, where it would be demonstrated the number of occurrences, the number of occurrences with helicopter presence and the number of helicopters in that helipad during the year. This last variable was retrieved from the visual representation the different movements of helicopters over the helipads during the year, present in Appendix H in figure H.1.

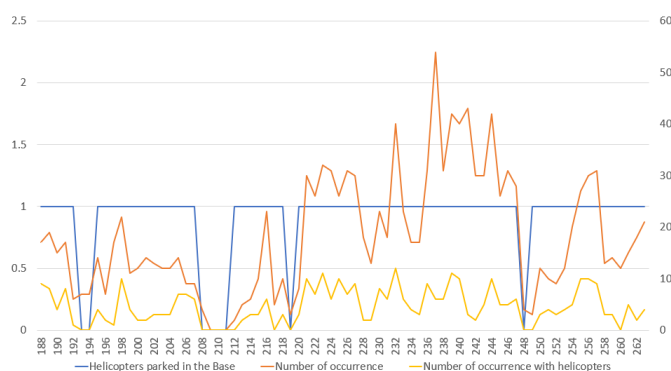
The same analysis was also made regarding the days, where it was analysed the day 232, 242 and 245, that correspond to 20th August, 30th August and 2nd of September, respectively, as shown in figures 4.11.

By joining the variation of these three variables in a same graph, as shown in figures 4.10 and 4.11, it becomes even clearer that they do not overlap. These two representation are non-other than sections dissected from the previous representations, in the y axis, and the x axis, respectively. Taking in consideration the figures 4.10, it is evident that the number of helicopters allocated to each base are not being adjusted accordingly to the number of occurrences in close proximity. By comparing, figures 4.10(a) and 4.10(c), where the latter shows a higher number of occurrences, the first has two helicopters in the majority of the interval of time being considered. Moreover, in figure 4.10(d), the allocation of a second helicopter does not overlap to the highest peak of occurrences during that period.

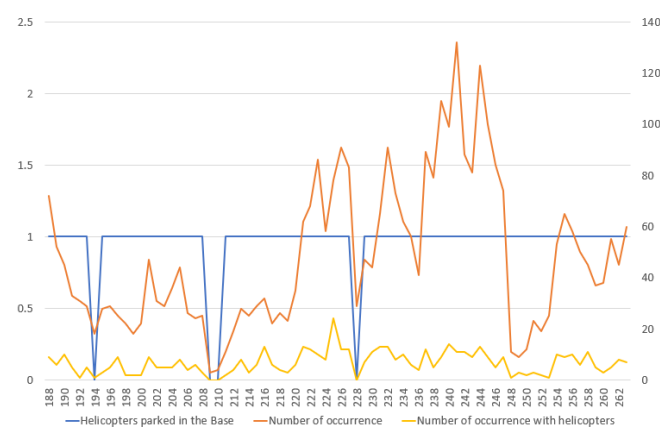
It is also confirmed by observing in figure 4.11, where, even though there is residual activity in helipads from 15 to 28, there are helicopters allocated to those places. Regarding the days, the variation between the number of occurrence and number of helicopters seems to overlap more. These graphical representations constitutes as one more piece of evidence that the fleet is not being flexibly managed. Please take note that the scale of the number of occurrences, with or without helicopters is different, as it translates different magnitudes. Additionally, as mention before, the analysis done in Appendix H was made taking in consideration the deployments made, so the fact that there are some values that reach zero, it only means that no helicopters dispatched that day.



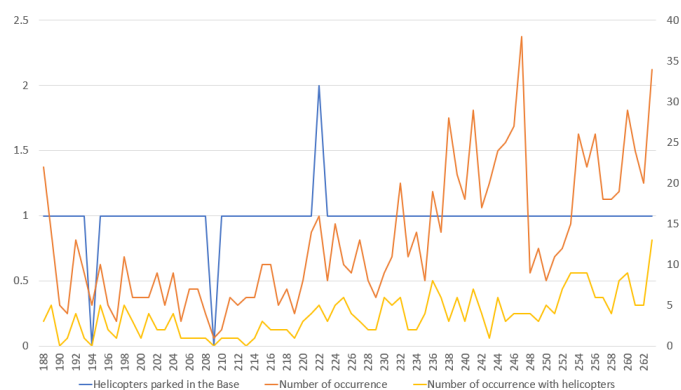
(a)



(b)

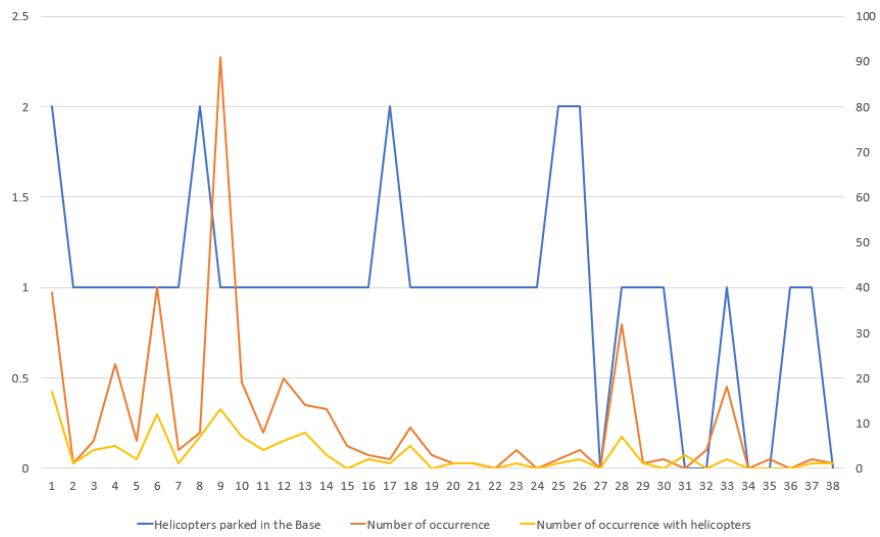


(c)

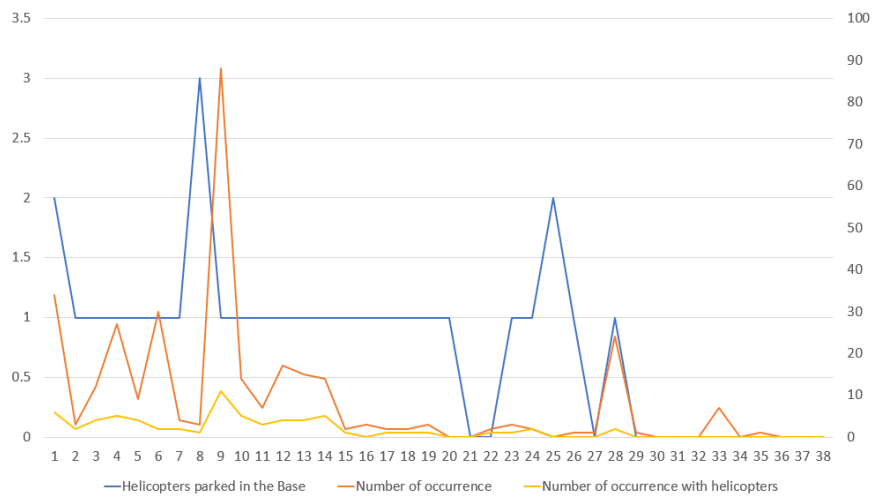


(d)

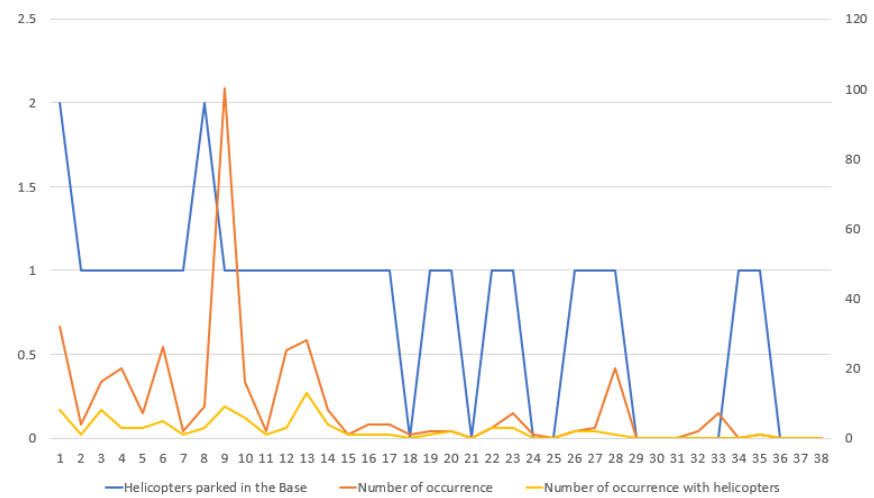
Figure 4.10: Number of occurrences versus the number of helicopters in the helipads of (a) Arcos de Valdevez; (b) Fafe; (c) Baltar; and, (d) Vale de Cambra.



(a)



(b)



(c)

Figure 4.11: Number of occurrences versus the number of helicopters (a) for the day 232; (b) for the day 242; and, (c) for the day 245;

Chapter 5

Conclusion

5.1 Conclusion

This research aimed to describe how the firefighting helicopter fleet was used and assess if it was being flexibly managed. The concept of flexibility is defined as the ability of a system to change when the initial requirements shift. These are the results of the uncertainty of the system, in our case, the occurrences location, beginning and hazard. According to Marchi et al. (2014), helicopters have proven to be an extremely valid fire suppression mean, but their high operating cost (Beighley and Hyde, 2018) demands a careful management. Several conclusions drawn by other authors, and analysed in the literature review, also are consistence with results of this research, e.g. Marchi et al. (2014) about the helicopters effectiveness and Pacheco et al. (2012); Beighley and Hyde (2018) for rekindle hazardenouss. This prompt the formulation of three major questions, which led to the characterisation of helicopters use, consequent explanation of factors that made the helicopter intervention, and lastly, if there was evidence of flexibility in the use of the helicopter fleet. For the purpose of this research, it was considerate as a case study the occurrences in Portugal during the year of 2013 - which accounts for 23,136 occurrences(22% with helicopters), and their associated 111,600 deployments.

An extensive work regarding the data available was carried out. In Portugal, the available information is separated between two datasets, containing the occurrences and the deployments respectively. Therefore, both databases need to be treated, in order to merge them with useful information regarding the occurrences and deployments. The final result was a main occurrence dataset containing the type of fire, date and time information, location, action times, burned area, number of deployments, categorised by type, number of different resources, categorised by type, in addition to information about closest helipad, presence of helicopter in IA/EA, amongst other. ICNF and ANPC should merge or link their databases, in order to avoid inconsistencies like the ones retrieved before, additionally to a more accurate data, for instance, equipping vehicles with trackers that could track the deployment arrival and departure of the station.

Regarding the characterisation of helicopters, it was focus on the period between 7th of July to the 20th of September since it represented the peak of the helicopter fleet utilisation. Concerning

the helipads, over two thirds of the occurrence and burned area is covered by around one third of the available helipads. Additionally, it was concluded that helicopters are being equally deployed to false alarm and fires. This represents a major waste of this resource (Pacheco et al., 2014), since fire managers cannot distinguish a false alarm from a fire when they receive their alert. Moreover, there were found evidences that helicopters are being preferably used in rekindles, as fire managers understand their dangers, and highlights the waste that rekindles represent (Pacheco et al., 2012). In addition, it was analysed the relationship between the reaction time of deployment and the burned area, where it was concluded that helicopters deployed in the beginning of the initial attack (30 minutes), seemed to be more efficient, as pointed out by Marchi et al. (2014). The fact that rekindles and fires with a potential for large burned area tend to have more helicopters, might indicate a rational in the deployment decision taken.

Furthermore, in an attempt to understand if the helicopter fleet management is able to be simulated, the distributions of time and SLDTO (i.e. straight line distance to occurrence), alongside the number of daily deployments were retrieved. The number of total deployments during the critical period could be best fitted through a Beta distribution. The SLDTO, by helipads and by helicopters, follows a Johnson SB distribution, which approaches a normal distribution. This contributes for the modelling with simulation of the helicopter suppression system. However, the flight times did not follow any type of distribution when considered as a total. It is also important to understand that these variables are influenced by the same factors, and they are related. However, since the number of deployments is influenced by the availability, and the time of flight and the SLDTO are both related, if two of this variables can be fitted, the others could derive from it.

Regarding the factors that might explain the operational decision of the use or not a helicopters in occurrence, it was used a *logit* model. Variables were distinguish by the burned area, the deployments, fire weather, fuel proxy, occurrence and resources. The use of district variables for proxies is debatable, as the fuel (type and cover) is not constant thought out the entire district, and the same fuel can be found in several districts. Additionally, the positive influence of VCI with helicopters might indicate, that helicopters are being used in the initial attack as devised in Autoridade Nacional de Protecção Civil (2012), in addition to a high number of ground resources. However, helicopters are less likely to be used in large fires, alongside a high number of deployments of fundamental ground force. In addition, helicopters are preferably used for forested areas, rather than agricultural areas.

Lastly, the variation of the number of occurrence against the number of helicopters is a strong indication that the fleet is not being manage with flexibility. It was observed that the demand created by the rising number of occurrences is not met by the number of helicopters close to the fire. During the critical period, it becomes clear that the number of helicopters allocated to each base are not being adjusted accordingly to the number of occurrences in close proximity. Eventually, the decision to allocate helicopters in some helipad less busy might be biased by political pressures. This research contribution could be used as clues for future studies regarding the helicopter fleet management and also for the further analysis of other years, confirming or not our results, which suggests that in 2013 there was no flexibility in the helicopter fleet management.

5.2 Limitations and future work

Regarding the limitations of this work, it was not taken into consideration the windows that helicopters could be operated, nor the human limitations of the helicopter crews. Moreover, the simultaneous number of occurrences was not considered. As pointed, the data provided seemed to have some inconsistencies, for instance, the duration of FA, and others, and deficiencies in the linkage between the databases. Additionally, the lack of variables like fuel type and fuel cover, posed as a problem in order to obtain fuel proxy. Moreover, the lack of contact with field professionals, posed as a problem for the author to understand the full scope of fire management and decisions.

Other regression models could be used in order to better understand the influence of the helicopters and its use. It would also be interesting to analogise with several factors, such as, burnt area, duration of fire, and the success of the initial attack, i.e. understand if such factors were the reason to bring a helicopter. In future analysis, the variables described in the limitations not taken into account should be considered as they impose constraints, or could bring more significant data. Secondly, aiming to mitigate the problems with the data provided, with the help of advanced statistical methods, more occurrences could have been linked between both datasets. Finally, after this analysis, an approach in order to simulate the helicopter fleet use by predicting fire ignition, and with the understanding of the Fire Weather condition.

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Appendix A

List of resources used in 2013 and their classification

Table A.1: Aerial resources, without helicopters

Aerial Resource			
Code	Name	Number of deployments	Presences in occurrences
AVBM	Avião Bombardeiro Médio	379	144
AVBP	Avião Bombardeiro Pesado	124	34
ARCO	Avião de Reconhecimento e Coordenação	3	3
AVIÕES_FA	Aviões Forças Armadas	1	1
IE AERONAUTICA CIVIL BASE	Base Aeronáutica Civil	6	6

Table A.2: Helicopters

Helicopters			
Code	Name	Number of deployments	Presences in occurrences
HEBL	Helibombardeiro Ligeiro	4852	4027
HEBM	Helibombardeiro Médio	1382	1216
HEBP	Helibombardeiro Pesado	230	162
HELICÓPTEROS_FA	Helicóptero Forças Armadas	10	9

Table A.3: Ground resources

Ground Resource			
Code	Name	Number of deployments	Presences in occurrences
AUTOTANQUE_ÁGUA	Autotanque Água	1	1
CNAF	Corpo Nacional Agentes Florestais	118	93
ESF	Equipas Sapadores Florestais	2593	1990
GAUF	GAUF	275	66
GGM	Gerador até 15Kw	3	3
HUMC	Humano	5975	4837
Maquina de rasto	Maquina de rasto	245	163
MÁQUINA_RASTO_D4	MÁQUINA_RASTO_D4	1	1
MÁQUINA_RASTO_D6	MÁQUINA_RASTO_D6	3	2
MÁQUINAS RASTO	Máquinas Rasto	7	6
MTBB	Motobomba	42	35
MBGD	Motobomba G.D	7	7
MTSR	Motoserra	57	30
PORTA_MÁQUINAS	Porta Máquinas	2	1
VETA	Veículo com Equipamento Técnico de Apoio	1045	806
VCOC	Veículo de Comando e Comunicações	206	190
VCOT	Veículo de Comando Tático	7629	4281
VGEO	Veículo de Gestão Estratégica e Operações	2	2
VPCC	Veículo de Planeamento, Comando e Comunicações	30	30
VECI	Veículo Especial de Combate a Incêndios	1425	1207
VFCI	Veículo Florestal de Combate a Incêndios	32973	15839
VLCI	Veículo Ligeiro de Combate a Incêndios	17893	10661
VRCI	Veículo Rural de Combate a Incêndios	8702	5888
VEÍCULO TÁTICO	Veículo Tático	0	0
VEÍCULO TÁTICO LIGEIRO	Veículo Tático Ligeiro	34	13
VEÍCULO TÁTICO MÉDIO	Veículo Tático Médio	22	6
VEÍCULO TÁTICO PESADO	Veículo Tático Pesado	20	9
VTGC	Veículo Tanque Grande Capacidade	2190	1588
VTTF	Veículo Tanque Tático Florestal	497	439
VTTR	Veículo Tanque Tático Rural	1524	1268
VTTU	Veículo Tanque Tático Urbano	8011	5794
VEÍCULO TÁTICO	Veículo Tático	5390	4925
Veículo_Técnico	Veículo Técnico	0	0
VUCI	Veículo Urbano de Combate a Incêndios	1281	1124
VC ANPC	Veículos ANPC	310	211
VCO	Veículos de Comando Operacional	7	6
VSCI	Veículos de Socorro e Combate a incêndios	12	12
VOPE	Veículos Motorizados Específicos	1213	778
VOE	Veículos para Operações Específicas	4	4

Table A.4: Medical assistance resources

Medical Assistance			
Code	Name	Number of deployments	Presences in occurrences
ABCI	Ambulância de Cuidados Intensivos	19	17
ABSC	Ambulância de Socorro	551	361
INEM	Ambulância de Socorro - INEM	13	13
ABTD	Ambulância de Transporte de Doentes	266	180
ABTM	Ambulância de Transporte Múltiplo	1408	530
SBV	Ambulância Suporte Básico de Vida	14	9
SIV	Ambulância Suporte Imediato de Vida	18	17
HESA	Helicóptero de Socorro e Assistência	141	111
HELI-INEM	Helicóptero Emergência Médica	3	3
UMIPE	Unidade Móvel de Intervenção	7	7
	Psicológica de Emergência		
VSAM	Veículo de Socorro e Assistência Médica	18	16
VTSD	Veículo Transporte Simples Doentes	6	5
VTSA	Veículos Técnicos de Socorro e Assistência	0	0
VMER	Viatura Médica de Emergência e Reanimação	31	27

Table A.5: Other types of resources

Others			
Code	Name	Number of deployments	Presences in occurrences
AUTOCARRO_FA	Autocarro_FA	6	1
BSRP	Botes de Socorro e Resgate Pneumáticos	1	1
BRM-VL	Busca Resgate em Montanha	2	2
COM	Comandante Operacional Municipal	2	2
VAME	Veículo de Apoio a Mergulhadores	8	8
VAPA	Veículo de Apoio Alimentar	33	30
VALE	Veículo de Apoio Logístico Especial	0	0
VPMT	Veículo de Proteção Multiriscos Tático	1	1
VSAE	Veículo de Socorro e Assistência Especial	9	9
VSAT	Veículo de Socorro e Assistência Tático	73	70
VTPG	Veículo de Transporte de Pessoal Geral	95	78
VTPL	Veículo de Transporte de Pessoal Ligeiro	34	29
VTPP	Veículo de Transporte de Pessoal Pesado	13	12
VTPT	Veículo de Transporte de Pessoal Tático	1234	875
VE	Veículo Escada	4	4
VEÍCULO_SINALIZAÇÃO _ASSISTENCIA	Veículo Sinalização e Assistência	18	18
VTPP	Veículo Tático de Transporte de Pessoal	10	10
VAVT	Veículos de Apoio Logístico -Viaturas de Transporte	1	1
VTEC_COMUNIC	Veículos Técnicos Redes Comunicações	6	6
VTEC_ELETRIC	Veículos Técnicos Redes Eléctricas	58	58
VIC	Viatura de Intervenção em Catástrofe	4	4

Appendix B

Helipad in 2013

Table B.1: Helipads location in 2013 - order by their location from north to south

#	Helipad	x	y	District	Municipality
1	Arcos Valdevez	174162	539985	Viana do Castelo	Arcos de Valdevez
2	Nogueira	306254	526408	Bragança	Bragança
3	Vidago	247064	518186	Vila Real	Chaves
4	Braga	174111	513020	Braga	Braga
5	Ribeira de Pena	227395	504201	Vila Real	Ribeira de Pena
6	Fafe	199519	498473	Fafe	Fafe
7	Bornes	298000	486947	Bragança	Macedo de Cavaleiros
8	Vila Real	234591	478501	Vila Real	Vila Real
9	Baltar	178729	468949	Porto	Paredes
10	Armamar	236543	460340	Viseu	Armamar
11	Mêda	274278	443780	Guarda	Mêda
12	Vale de Cambra	178860	433627	Aveiro	Vale de Cambra
13	Viseu	220494	416997	Viseu	Viseu
14	Águeda	176945	397510	Aveiro	Águeda
15	Guarda	272381	395911	Guarda	Guarda
16	Seia	237306	387141	Guarda	Seia
17	Santa Comba Dão	199840	380972	Viseu	Santa Comba Dão
18	Covilha	246873	364461	Castelo Branco	Covilhã
19	Cernache	171415	354191	Coimbra	Coimbra
20	Lousã	190654	352755	Coimbra	Lousã
21	Pampilhosa da Serra	215630	339780	Coimbra	Pampilhosa da Serra
22	Figueiró	187867	327066	Leiria	Figueiró dos Vinhos
23	Pombal	155810	324224	Leiria	Pombal
24	Proença-a-Nova	222198	306887	Castelo Branco	Proença-a-Nova
25	Castelo Branco	259317	301839	Castelo Branco	Castelo Branco
26	Ferreira do Zêze	189614	301372	Santarém	Ferreira do Zezere
27	Sardoal	197592	285945	Santarém	Sardoal
28	Pernes	154382	267605	Santarém	Santarém
29	Portalegre	261282	255005	Portalegre	Portalegre
30	Ponte de Sôr	206481	248816	Portalegre	Ponte de Sor
31	BA6	121303	193325	Setúbal	Montijo
32	Évora	221171	173937	Évora	Évora
33	Grândola	161206	134812	Setúbal	Grândola
34	BA11	217843	123546	Beja	Beja
35	Ourique	191569	76266	Beja	Ourique
36	Cachopo	228286	40916	Faro	Tavira
37	Monchique	162772	39318	Faro	Monchique
38	Loulé	208812	18306	Faro	Loulé

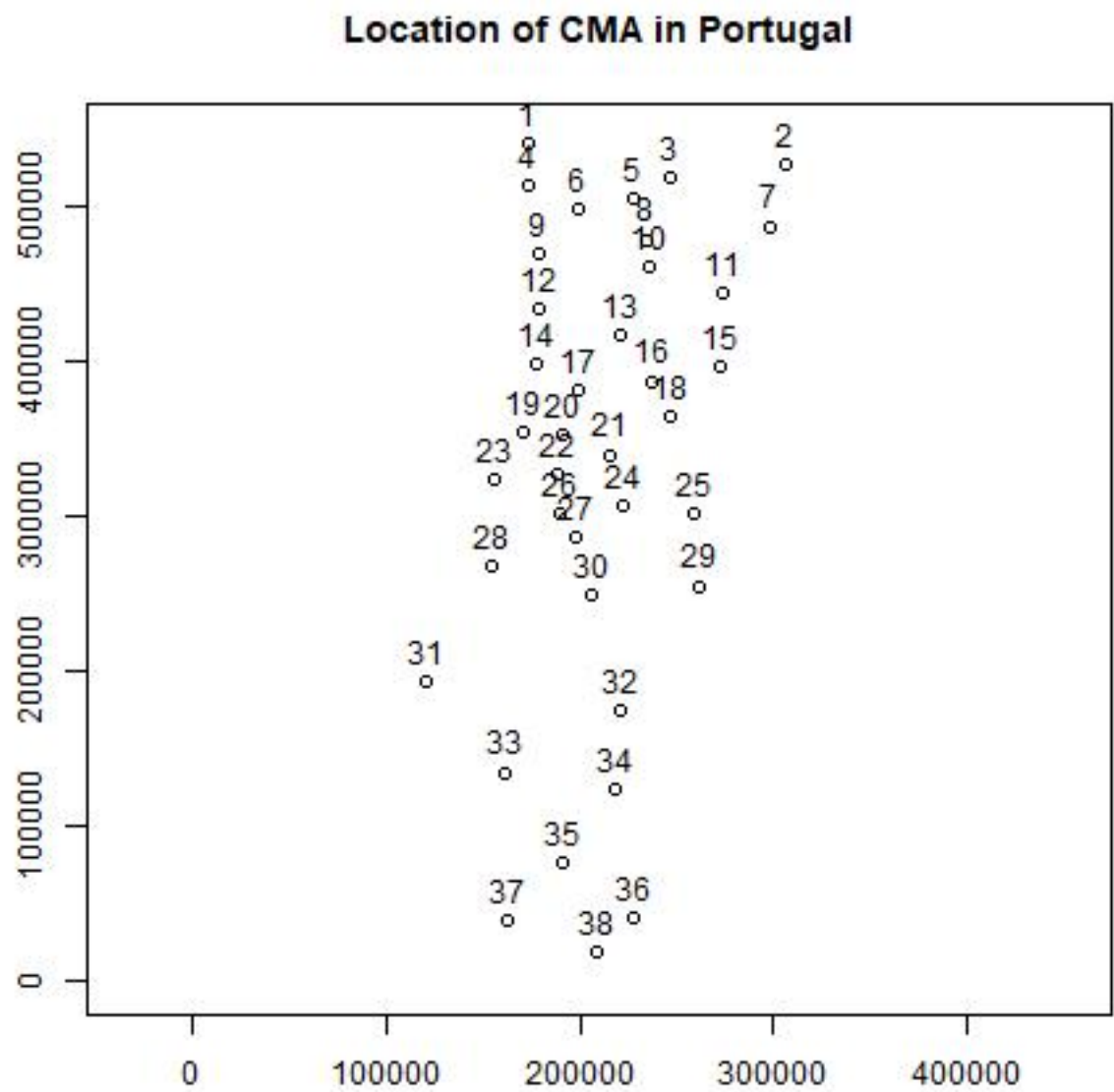


Figure B.1: Location of helipad with caption in table B.1

Appendix C

Variable description of *OLDeM*

Table C.1: *OLDeM2013* Variables

Name	Type	O2013	D2013	B2013	M2013	Details
ICNF Code	chr	X				
ANPC Code	num		X			
District	factor	X				
Municipality	factor	X				
Date of Alert	POSIXct	X				
Day of Alert	num	X				Calculated using lubridate function yday
Date Extinction	POSIXct	X				
x	num	X				
y	num	X				
Closest helipad	factor	X		X		Calculated by obtaining the shortest distance between every helipad(x,y) and fire(x,y)
x from closest helipad	num	X		X		
y from closest helipad	num	X		X		
Distance to closest helipad	num	X		X		
ReationTime	num	X	X			Shortest interval between the alert and first helicopter deployment
Type	chr	X				
Rekindle	factor	X				
<i>Queimada</i>	factor	X				
False Alarm	factor	X				
<i>Fogacho</i>	factor	X				
Fire	factor	X				
Presence of VLCI	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VFCI	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VTTF	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VCOC	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VCI	factor		X			Calculated by grouping every movement in ANPC Database
Number of deployments	num		X			Calculated by grouping every movement in ANPC Database

Name	Type	O2013	D2013	B2013	M2013	Details
Number of flights	num		X			Calculated by grouping every movement in ANPC Database
Number of helicopter flights	num		X			Calculated by grouping every movement in ANPC Database
Number of non helicopter flights	num		X			Calculated by grouping every movement in ANPC Database
Number of Ground movements	num		X			Calculated by grouping every movement in ANPC Database
Number of Fundamental Ground Movements	num		X			Calculated by grouping every movement in ANPC Database
Presence of Fundamental vehicles	factor		X			Calculated by grouping every movement in ANPC Database
Number of distinct aerial resources	num		X			Calculated by grouping every movement in ANPC Database
Number of distinct helicopters	num		X			Calculated by grouping every movement in ANPC Database
Number of distinct ground force means	num		X			Calculated by grouping every movement in ANPC Database
Number of distinct fundamental ground force means	num		X			Calculated by grouping every movement in ANPC Database
Number of people	num		X			Calculated by grouping every movement in ANPC Database
Used of Helicopter for initial attack (90)	factor	X	X			Calculated by grouping every movement in ANPC Database
Used of Helicopter for initial attack (110)	factor	X	X			Calculated by grouping every movement in ANPC Database
Used of Helicopter for extended attack	factor	X	X			Calculated by grouping every movement in ANPC Database
Average Temperature	num				X	
Average Humidity	num				X	
Average Wind	num				X	
Average FW	num				X	
Average DSR	num				X	
Burned Planted Forest Area	num	X				
Burned agricultural Area	num	X				
Burned Planted Forest+Shrubs Area	num	X				
Burned Shrub area	num	X				
Burned Total Area	num	X				
Success (90)	factor	X				
Success (110)	factor	X				

Appendix D

Variable description of *DLO*

Table D.1: *DLO2013* Variables

Name	Type	O2013	D2013	B2013	M2013	Details
ICNF Code	chr	X				
ANPC Code	num		X			
District	factor	X				
Municipality	factor	X				
Date of Alert	POSIXct	X				
Day of Alert	num	X				Calculated using lubridate function yday
Date Extinction	POSIXct	X				
x	num	X				
y	num	X				
Closest helipad	factor	X		X		Calculated by obtaining the shortest distance between every helipad(x,y) and fire(x,y)
x from closest helipad	num	X		X		
y from closest helipad	num	X		X		
Distance to closest helipad	num	X		X		
ReationTime	num	X	X			Shortest interval between the alert and first helicopter deployment
Date of Depart of Entity	POSIXct		X			
Date of Arrival of Entity	POSIXct		X			
Time of action	num		X			Difference between Date of Alert and the Departure of each Movement
Day of movement	num		X			Calculated using function yday from lubridate database
Time of movement	num		X			Difference between Date of Departure and the Arrival of each Movement
Number of people	num		X			
MeanCode	chr		X			
License Plate	chr		X			
Operacional Code	chr		X			
Code	chr		X			
Name	chr		X			
Corporation name	chr		X			
OperatingCode	chr		X			
Type	chr	X				
Rekindle	factor	X				
Queimada	factor	X				

Name	Type	O2013	D2013	B2013	M2013	Details
False Alarm	factor	X				
<i>Fogacho</i>	factor	X				
Fire	factor	X				
Presence of VLCI	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VFCI	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VTTF	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VCOC	factor		X			Calculated by grouping every movement in ANPC Database
Presence of VCI	factor		X			Calculated by grouping every movement in ANPC Database
Number of deployments	num		X			Calculated by grouping every movement in ANPC Database
Number of flights	num		X			Calculated by grouping every movement in ANPC Database
Number of helicopter flights	num		X			Calculated by grouping every movement in ANPC Database
Number of non helicopter flights	num		X			Calculated by grouping every movement in ANPC Database
Number of Ground movements	num		X			Calculated by grouping every movement in ANPC Database
Number of Fundamental Ground Movements	num		X			Calculated by grouping every movement in ANPC Database
Presence of Fundamental vehicles	factor		X			Calculated by grouping every movement in ANPC Database
Number of distinct aerial resources	num		X			Calculated by grouping every movement in ANPC Database
Number of distinct helicopters	num		X			Calculated by grouping every movement in ANPC Database
Number of distinct ground force means	num		X			Calculated by grouping every movement in ANPC Database
Number of distinct fundamental ground force means	num		X			Calculated by grouping every movement in ANPC Database
Number of people	num		X			Calculated by grouping every movement in ANPC Database
Used of Helicopter for initial attack (90)	factor	X	X			Calculated by grouping every movement in ANPC Database
Used of Helicopter for initial attack (110)	factor	X	X			Calculated by grouping every movement in ANPC Database
Used of Helicopter for extended attack	factor	X	X			Calculated by grouping every movement in ANPC Database
Average Temperature	num				X	
Average Humidity	num				X	
Average Wind	num				X	
Average FW	num				X	
Average DSR	num				X	
Burned Planted Forest Area	num	X				
Burned agricultural Area	num	X				
Burned Planted Forest+Shrubs Area	num	X				
Burned Shrub area	num	X				
Burned Total Area	num	X				
Success (90)	factor	X				
Success (110)	factor	X				

Appendix E

Descriptive Statistics

Table E.1: Meaning of variables used

Variable Name	Meaning	Variable Name	Meaning
hpD	Distancie to closest HP	Duration	Duration of occurence
IgnDay	Day of alert	d	Deployment
hiaal	Action time of helicopter	da	Aerial deployment
fwTEMP	Temperature	dh	Helicopter Deployment
fwHR	Humidity	dhn	Non-helicopter Deployment
fwWIND	Wind	dg	Ground Deployment
fwFWI	FWI	dgf	Fundamental ground Deployment
fwDSR	DSR	ra	Number of distinct aerial deployment
baPltF	Forested burned area	rah	Number of distinct helicopter deployment
baSrub	Burned Area of Shrubs	rahn	Number of distinct non-helicopter deployment
baAgri	Agricultural burned area	rg	Number of distinct ground deployment
baFSpace	Forested area and shrubs burned	rgf	Number of distinct fundamental ground deployment
baTotal	Total burned area	rp	Number of persons

Table E.2: Descriptive Statistics of *OLDeM2013*, used in table K.1, with explanation of variables in table E.1

variable	N	missing	mean	sd	min	p1	p25	p50	p75	p99	max
Duration	22 937	199	257	3 352	11	69	117	153	212	1 086	349 641
IgnDay	23 136	0	213	46	2	61	187	226	244	286	314
hpD	23 136	0	22 793	18 863	102	2 270	11 432	17 355	25 420	86 002	98 510
d	23 136	0	5	12	1	1	1	3	5	38	638
da	23 136	0	0	1	0	0	0	0	0	3	49
dh	23 136	0	0	1	0	0	0	0	0	3	30
dhn	23 136	0	0	1	0	0	0	0	0	3	30
dg	23 136	0	4	9	0	1	1	2	5	32	469
dgf	23 136	0	2	4	0	0	1	1	3	15	152
ra	23 136	0	0	1	0	0	0	0	0	3	17
rah	23 136	0	0	1	0	0	0	0	0	2	8
rahn	23 136	0	0	0	0	0	0	0	0	0	9
rg	23 136	0	4	5	0	1	1	2	4	22	146
rgf	23 136	0	2	2	0	0	1	1	2	10	39
rp	23 136	0	18	47	0	2	5	10	19	140	2 485
hiaal	4 488	18 648	23	97	0	0	5	7	9	565	1 884
fwTEMP	23 133	3	27	6	2	12	24	28	31	38	100
fwHR	23 133	3	41	16	8	15	29	38	51	84	100
fwWIND	23 133	3	9	6	0	0	3	7	10	28	93
fwFWI	23 133	3	31	13	0	1	22	32	39	64	217
fwDSR	23 133	3	13	9	0	0	6	13	18	42	88
baPltF	23 136	0	2	54	0	0	0	0	0	23	5 989
baSrub	23 136	0	4	94	0	0	0	0	0	50	11 723
baAgri	23 136	0	0	8	0	0	0	0	0	2	514
baFSpace	23 136	0	6	126	0	0	0	0	0	88	13 706
baTotal	23 136	0	7	129	0	0	0	0	0	96	14 136

Table E.3: Descriptive statistics of continuous variables separated by Charlie phase

Charlie	variable	N	mean	sd	min	p1	p25	p50	p75	p99	max
No	Duration	5 289	229	4 509	11	39	110	140	188	520	326 490
No	IgnDay	5 329	156	55	2	37	122	154	177	293	314
No	hpD	5 329	26 618	20 830	138	2 346	12 843	19 533	32 363	87 569	97 742
No	d	5 329	3	4	1	1	1	2	4	18	100
No	da	5 329	0	0	0	0	0	0	0	1	5
No	dh	5 329	0	0	0	0	0	0	0	1	5
No	dhn	5 329	0	0	0	0	0	0	0	1	5
No	dg	5 329	3	4	0	1	1	2	4	16	90
No	dgf	5 329	2	2	0	0	1	1	2	9	45
No	ra	5 329	0	0	0	0	0	0	0	1	4
No	rah	5 329	0	0	0	0	0	0	0	1	3
No	rahn	5 329	0	0	0	0	0	0	0	0	2
No	rg	5 329	3	3	0	1	1	2	3	13	44
No	rgf	5 329	2	1	0	0	1	1	2	7	18
No	rp	5 329	11	15	0	2	5	7	13	65	331
No	hial	359	12	32	0	1	5	7	10	178	488
No	fwTEMP	5 329	23	6	2	9	18	22	28	35	100
No	fwHR	5 329	44	16	8	15	31	42	55	86	100
No	fwWIND	5 329	11	7	0	0	7	10	14	32	93
No	fwFWI	5 329	21	14	0	0	10	18	32	55	75
No	fwDSR	5 329	8	8	0	0	2	5	13	32	57
No	baPltF	5 329	0	4	0	0	0	0	0	7	136
No	baSrub	5 329	1	5	0	0	0	0	0	7	228
No	baAgri	5 329	0	3	0	0	0	0	0	3	132
No	baFSpace	5 329	1	7	0	0	0	0	0	16	285
No	baTotal	5 329	1	8	0	0	0	0	0	20	285
Yes	Duration	17 648	266	2 917	60	78	120	157	220	1 272	349 641
Yes	IgnDay	17 807	230	24	182	183	214	234	247	269	273
Yes	hpD	17 807	21 648	18 078	102	2 262	11 075	16 760	24 323	85 043	98 510
Yes	d	17 807	5	13	1	1	1	3	6	43	638
Yes	da	17 807	0	1	0	0	0	0	1	4	49
Yes	dh	17 807	0	1	0	0	0	0	1	3	30
Yes	dhn	17 807	0	1	0	0	0	0	1	3	30
Yes	dg	17 807	5	10	0	1	1	3	5	37	469
Yes	dgf	17 807	2	4	0	0	1	1	3	17	152
Yes	ra	17 807	0	1	0	0	0	0	1	3	17
Yes	rah	17 807	0	1	0	0	0	0	1	2	8
Yes	rahn	17 807	0	0	0	0	0	0	0	0	9
Yes	rg	17 807	4	5	0	1	1	3	5	23	146
Yes	rgf	17 807	2	2	0	0	1	1	3	10	39
Yes	rp	17 807	20	53	1	2	5	11	21	161	2 485
Yes	hial	4 129	24	101	0	0	5	7	9	589	1 884
Yes	fwTEMP	17 804	28	5	11	19	25	28	32	38	100
Yes	fwHR	17 804	40	16	8	15	29	37	50	83	100
Yes	fwWIND	17 804	8	5	0	0	3	7	10	25	61
Yes	fwFWI	17 804	34	12	0	6	26	34	41	64	217
Yes	fwDSR	17 804	15	9	0	1	9	14	19	43	88
Yes	baPltF	17 807	3	61	0	0	0	0	0	30	5 989
Yes	baSrub	17 807	5	107	0	0	0	0	0	67	11 723
Yes	baAgri	17 807	0	9	0	0	0	0	0	2	514
Yes	baFSpace	17 807	8	144	0	0	0	0	0	120	13 706
Yes	baTotal	17 807	8	147	0	0	0	0	0	129	14 136

Appendix F

False Alarms

Table F.1: List of occurrence longer than one week in *O2013*, where linked refers to their linking to *OLDeM2013*

ICNF Code	Alert Date	Extintion Date	Duration	BaTotal	Type	Linked
TM1131201	21/09/2013 17:36	22/05/2014 11:57	349 641	0.0	False Alarm	Y
TM1131311	07/10/2013 19:40	22/05/2014 12:10	326 490	0.0	False Alarm	Y
DM213506	01/06/2013 07:38	16/09/2013 08:55	154 217	0.0	False Alarm	N
DM213855	27/06/2013 21:55	07/09/2013 17:52	103 497	0.0	False Alarm	N
DM2131623	08/07/2013 16:20	07/09/2013 18:01	88 001	0.0	False Alarm	N
BL1132126	11/09/2013 12:15	21/10/2013 01:50	57 035	0.0	False Alarm	N
BL1131087	21/08/2013 00:25	29/09/2013 08:00	56 675	1345.6	Forested	Y
BL213446	28/07/2013 17:15	04/09/2013 17:10	54 775	0.1	Forested	N
BL1131057	20/08/2013 16:46	26/09/2013 01:35	52 429	0.0	Forested	Y
TM113794	24/08/2013 16:40	28/09/2013 21:00	50 720	1696.0	Forested	Y
DM2136350	21/09/2013 05:37	25/10/2013 17:39	49 742	0.0	False Alarm	N
BL1131265	26/08/2013 11:35	29/09/2013 18:14	49 419	289.9	Forested	Y
BL1131168	23/08/2013 14:16	26/09/2013 02:45	48 329	0.5	Forested	Y
BL1131180	24/08/2013 03:05	26/09/2013 03:40	47 615	0.8	Forested	Y
BL1131190	24/08/2013 13:17	26/09/2013 02:28	46 931	0.5	Forested	Y
BL113762	11/08/2013 16:48	13/09/2013 00:51	46 623	0.2	Forested	Y
BL1131286	27/08/2013 02:01	26/09/2013 02:35	43 294	181.8	Forested	Y
DM2133022	12/08/2013 05:05	08/09/2013 15:08	39 543	0.3	Forested	Y
BL113542	23/07/2013 14:19	18/08/2013 05:06	36 947	14.0	Forested	Y
DM2133197	14/08/2013 03:55	08/09/2013 17:00	36 845	0.0	False Alarm	N
DM2133155	13/08/2013 21:14	07/09/2013 18:50	35 916	0.0	False Alarm	N
BL1131535	02/09/2013 10:17	26/09/2013 02:33	34 156	0.1	Forested	Y
BL113387	14/05/2013 22:35	06/06/2013 01:08	31 893	0.0	<i>Queimada</i>	Y
BL213233	01/07/2013 20:39	23/07/2013 10:20	31 121	0.0	False Alarm	N
BL113447	11/07/2013 14:30	30/07/2013 03:03	26 733	0.0	False Alarm	Y
BL1132127	23/09/2013 00:41	11/10/2013 01:54	26 053	0.0	False Alarm	N
DM2133799	21/08/2013 16:00	07/09/2013 18:59	24 719	0.0	False Alarm	N
RO2131534	23/08/2013 12:30	06/09/2013 10:24	20 094	0.0	Forested	Y

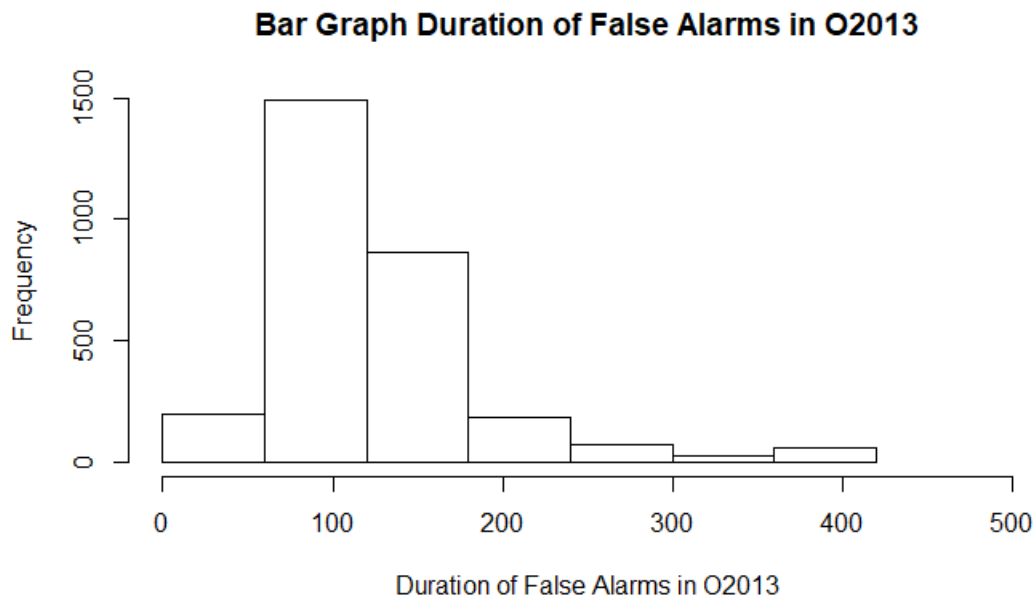


Figure F.1: Bar graph representing the duration of False Alarms in *O2013*, with accumulation of occurrences after 360 minutes

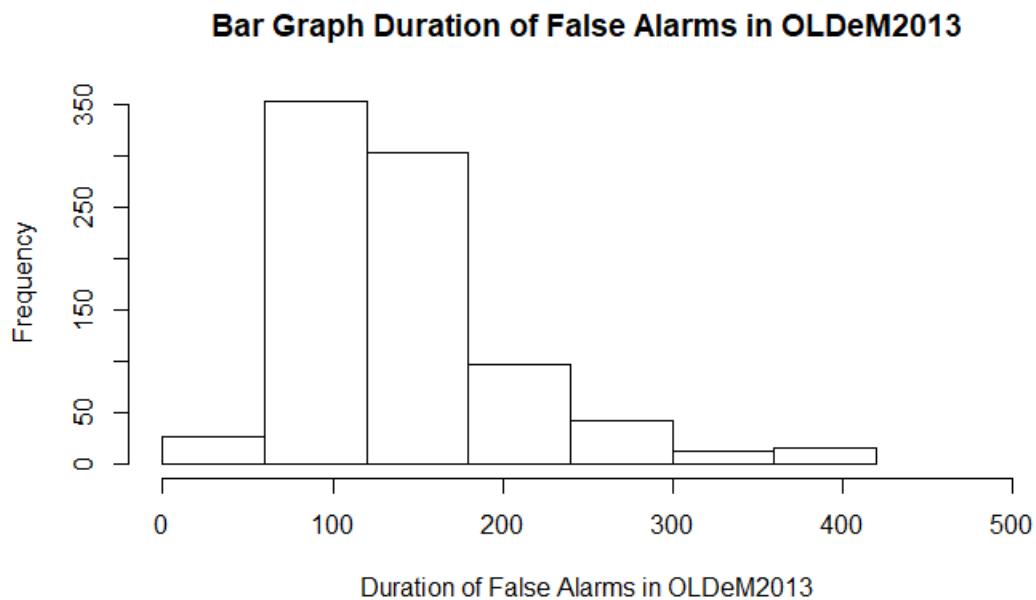


Figure F.2: Bar graph representing the duration of False Alarms in *OLDeM2013*, with accumulation of occurrences after 360 minutes

Appendix G

Analysis of the occurrence to the closest helipad

Table G.1: Closest helipad to occurrences during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Freq.	Percent	Cum.
1	9	Baltar	4,166	23.40	23.40
2	6	Fafe	1,562	8.77	32.17
3	28	Pernes	1,548	8.69	40.86
4	1	Arcos Valdevez	1,356	7.61	48.48
5	12	Vale de Cambra	1,192	6.69	55.17
6	4	Braga	1,148	6.45	61.62
7	10	Armamar	691	3.88	65.50
8	33	Grandola	671	3.77	69.26
9	13	Viseu	573	3.22	72.48
10	14	Agueda	546	3.07	75.55
11	3	Vidago	479	2.69	78.24
12	8	Vila Real	323	1.81	80.05
13	11	Meda	292	1.64	81.69
14	5	Ribeira de Pena	267	1.50	83.19
15	23	Pombal	239	1.34	84.53
16	19	Cernache	231	1.30	85.83
17	16	Seia	230	1.29	87.12
18	17	Santa Comba Dao	228	1.28	88.40
19	18	Covilha	201	1.13	89.53
20	32	Evora	194	1.09	90.62
21	20	Lousa	185	1.04	91.66
22	2	Nogueira	175	0.98	92.64
23	7	Bornes	170	0.95	93.60
24	15	Guarda	161	0.90	94.50
25	35	Ourique	123	0.69	95.19
26	38	Loule	115	0.65	95.84
27	26	Ferreira do Zezere	101	0.57	96.41
28	37	Monchique	93	0.52	96.93
29	22	Figueiro	92	0.52	97.44
30	29	Portalegre	91	0.51	97.96
31	27	Sardoal	91	0.51	98.47
32	25	Castelo Branco	76	0.43	98.89
33	30	Ponte de Sor	57	0.32	99.21
34	24	Proenca-a-Nova	55	0.31	99.52
35	21	Pampilhosa da Serra	44	0.25	99.77
36	36	Cachopo	41	0.23	100.00
		<i>Total</i>	<i>17,807</i>	<i>100.00</i>	

Table G.2: Closest helipad to occurrences with helicopter intervention during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Freq.	Percent	Cum.
1	9	Baltar	578	12.52	12.52
2	6	Fafe	397	8.60	21.13
3	1	Arcos Valdevez	384	8.32	29.45
4	12	Vale de Cambra	338	7.32	36.77
5	13	Viseu	261	5.66	42.43
6	10	Armamar	238	5.16	47.58
7	4	Braga	207	4.49	52.07
8	3	Vidago	206	4.46	56.53
9	14	Agueda	183	3.97	60.50
10	28	Pernes	163	3.53	64.03
11	8	Vila Real	149	3.23	67.26
12	11	Meda	137	2.97	70.23
13	5	Ribeira de Pena	133	2.88	73.11
14	16	Seia	105	2.28	75.38
15	17	Santa Comba Dao	104	2.25	77.64
16	15	Guarda	89	1.93	79.57
17	23	Pombal	76	1.65	81.21
18	7	Bornes	73	1.58	82.80
19	18	Covilha	73	1.58	84.38
20	20	Lousa	68	1.47	85.85
21	2	Nogueira	68	1.47	87.32
22	19	Cernache	61	1.32	88.65
23	26	Ferreira do Zezere	58	1.26	89.90
24	32	Evora	57	1.24	91.14
25	27	Sardoal	49	1.06	92.20
26	22	Figueiro	45	0.98	93.17
27	37	Monchique	45	0.98	94.15
28	35	Ourique	40	0.87	95.02
29	38	Loule	37	0.80	95.82
30	25	Castelo Branco	36	0.78	96.60
31	33	Grandola	36	0.78	97.38
32	29	Portalegre	36	0.78	98.16
33	24	Proenca-a-Nova	28	0.61	98.76
34	21	Pampilhosa da Serra	22	0.48	99.24
35	30	Ponte de Sor	19	0.41	99.65
36	36	Cachopo	16	0.35	100.00
		<i>Total</i>	<i>4,615</i>	<i>100.00</i>	

Table G.3: Closest helipad to occurrences by burned Area during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned area	Percent	Cum.
1	7	Bornes	19,691.6	13.02	13.02
2	10	Armamar	13,603.9	8.99	22.01
3	1	Arcos Valdevez	13,356.2	8.83	30.84
4	13	Viseu	11,902.5	7.87	38.71
5	3	Vidago	11,256.9	7.44	46.15
6	11	Mêda	10,207.8	6.75	52.90
7	9	Baltar	9,000.5	5.95	58.85
8	5	Ribeira de Pena	7,754.3	5.13	63.98
9	8	Vila Real	7,262.4	4.80	68.78
10	17	Santa Comba Dão	7,039.0	4.65	73.43
11	6	Fafe	6,320.2	4.18	77.61
12	14	Águeda	4,080.9	2.70	80.31
13	2	Nogueira	3,901.5	2.58	82.89
14	18	Covilha	3,436.5	2.27	85.16
15	16	Seia	3,367.0	2.23	87.38
16	4	Braga	3,148.7	2.08	89.46
17	12	Vale de Cambra	3,043.9	2.01	91.48
18	15	Guarda	2,522.4	1.67	93.14
19	35	Ourique	1,828.5	1.21	94.35
20	23	Pombal	1,521.2	1.01	95.36
21	21	Pampilhosa da Serra	1,311.3	0.87	96.23
22	28	Pernes	1,302.8	0.86	97.09
23	29	Portalegre	988.4	0.65	97.74
24	30	Ponte de Sôr	590.1	0.39	98.13
25	37	Monchique	485.2	0.32	98.45
26	20	Lousã	469.0	0.31	98.76
27	32	Évora	458.8	0.30	99.06
28	22	Figueiró	426.5	0.28	99.35
29	33	Grândola	333.1	0.22	99.57
30	36	Cachopo	214.0	0.14	99.71
31	19	Cernache	104.4	0.07	99.78
32	24	Proença-a-Nova	99.7	0.07	99.84
33	27	Sardoal	99.4	0.07	99.91
34	25	Castelo Branco	60.4	0.04	99.95
35	26	Ferreira do Zêzere	46.1	0.03	99.98
36	38	Loulé	31.6	0.02	100.00
<i>Total</i>			<i>151,266.9</i>	<i>100.00</i>	

Table G.4: Closest helipad to occurrences by burned Area with helicopter intervention during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned area	Percent	Cum.
1	7	Bornes	19,591.7	15.12	15.12
2	13	Viseu	11,764.8	9.08	24.20
3	1	Arcos Valdevez	10,828.5	8.36	32.55
4	10	Armamar	10,489.3	8.09	40.65
5	11	Mêda	9,533.7	7.36	48.00
6	3	Vidago	8,805.2	6.79	54.80
7	5	Ribeira de Pena	7,232.2	5.58	60.38
8	17	Santa Comba Dão	7,020.3	5.42	65.80
9	8	Vila Real	6,139.9	4.74	70.53
10	9	Baltar	5,119.1	3.95	74.48
11	14	Águeda	4,018.7	3.10	77.59
12	2	Nogueira	3,735.5	2.88	80.47
13	6	Fafe	3,438.3	2.65	83.12
14	18	Covilha	3,411.7	2.63	85.75
15	16	Seia	3,276.3	2.53	88.28
16	12	Vale de Cambra	2,822.2	2.18	90.46
17	15	Guarda	2,471.9	1.91	92.37
18	4	Braga	1,878.5	1.45	93.82
19	23	Pombal	1,513.0	1.17	94.98
20	21	Pampilhosa da Serra	1,305.6	1.01	95.99
21	35	Ourique	846.0	0.65	96.65
22	29	Portalegre	836.8	0.65	97.29
23	28	Pernes	642.8	0.50	97.79
24	20	Ponte de Sôr	568.3	0.44	98.23
25	37	Monchique	478.9	0.37	98.60
26	20	Lousã	445.0	0.34	98.94
27	22	Figueiró	418.2	0.32	99.26
28	36	Cachopo	209.7	0.16	99.42
29	32	Évora	197.5	0.15	99.58
30	33	Grândola	144.1	0.11	99.69
31	24	Proença-a-Nova	97.8	0.08	99.76
32	27	Sardoal	95.9	0.07	99.84
33	19	Cernache	95.0	0.07	99.91
34	25	Castelo Branco	55.4	0.04	99.95
35	26	Ferreira do Zêzere	40.3	0.03	99.98
36	38	Loulé	21.6	0.02	100.00
		<i>Total</i>	<i>129,590</i>	<i>100.00</i>	

Table G.5: Closest helipad to occurrences by burned area by occurrence during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned Area by occurrence	Percent	Cum.
1	7	Bornes	115.83	23.44	23.44
2	11	Mêda	34.96	7.07	30.52
3	17	Santa Comba Dão	30.87	6.25	36.77
4	21	Pampilhosa da Se	29.80	6.03	42.80
5	5	Ribeira de Pena	29.04	5.88	48.67
6	3	Vidago	23.50	4.76	53.43
7	8	Vila Real	22.48	4.55	57.98
8	2	Nogueira	22.29	4.51	62.49
9	13	Viseu	20.77	4.20	66.70
10	10	Armamar	19.69	3.98	70.68
11	18	Covilha	17.10	3.46	74.14
12	15	Guarda	15.67	3.17	77.31
13	35	Ourique	14.87	3.01	80.32
14	16	Seia	14.64	2.96	83.28
15	29	Portalegre	10.86	2.20	85.48
16	30	Ponte de Sôr	10.35	2.10	87.58
17	1	Arcos Valdevez	9.85	1.99	89.57
18	14	Águeda	7.47	1.51	91.08
19	23	Pombal	6.36	1.29	92.37
20	36	Cachopo	5.22	1.06	93.43
21	37	Monchique	5.22	1.06	94.48
22	22	Figueiró	4.64	0.94	95.42
23	6	Fafe	4.05	0.82	96.24
24	4	Braga	2.74	0.56	96.79
25	12	Vale de Cambra	2.55	0.52	97.31
26	20	Lousã	2.54	0.51	97.82
27	32	Évora	2.37	0.48	98.30
28	9	Baltar	2.16	0.44	98.74
29	24	Proença-a-Nova	1.81	0.37	99.11
30	27	Sardoal	1.09	0.22	99.33
31	28	Pernes	0.84	0.17	99.50
32	25	Castelo Branco	0.80	0.16	99.66
33	33	Grândola	0.50	0.10	99.76
34	26	Ferreira do Zêze	0.46	0.09	99.85
35	19	Cernache	0.45	0.09	99.94
36	38	Loulé	0.27	0.06	100.00
			494	100.00	

Table G.6: Closest helipad to occurrences with helicopter intervention by burned area by occurrence during Charlie Phase

(rank)	Id.	Nearest Helipad (CMA)	Burned Area by occurrence	Percent	Cum.
1	7	Bornes	268.38	24.55	24.55
2	11	Mêda	69.59	6.37	30.92
3	17	Santa Comba Dão	67.50	6.18	37.09
4	21	Pampilhosa da Se	59.35	5.43	42.52
5	2	Nogueira	54.93	5.03	47.55
6	5	Ribeira de Pena	54.38	4.97	52.52
7	18	Covilha	46.74	4.28	56.80
8	13	Viseu	45.08	4.12	60.92
9	10	Armamar	44.07	4.03	64.96
10	3	Vidago	42.74	3.91	68.87
11	8	Vila Real	41.21	3.77	72.64
12	16	Seia	31.20	2.85	75.49
13	30	Ponte de Sôr	29.91	2.74	78.23
14	1	Arcos Valdevez	28.20	2.58	80.81
15	15	Guarda	27.77	2.54	83.35
16	29	Portalegre	23.25	2.13	85.47
17	14	Águeda	21.96	2.01	87.48
18	35	Ourique	21.15	1.93	89.42
19	23	Pombal	19.91	1.82	91.24
20	36	Cachopo	13.11	1.20	92.44
21	37	Monchique	10.64	0.97	93.41
22	22	Figueiró	9.29	0.85	94.26
23	4	Braga	9.07	0.83	95.09
24	9	Baltar	8.86	0.81	95.90
25	6	Fafe	8.66	0.79	96.69
26	12	Vale de Cambra	8.35	0.76	97.46
27	20	Lousã	6.54	0.60	98.06
28	33	Grândola	4.00	0.37	98.42
29	28	Pernes	3.94	0.36	98.78
30	24	Proença-a-Nova	3.49	0.32	99.10
31	32	Évora	3.47	0.32	99.42
32	27	Sardoal	1.96	0.18	99.60
33	19	Cernache	1.56	0.14	99.74
34	25	Castelo Branco	1.54	0.14	99.88
35	26	Ferreira do Zêzere	0.70	0.06	99.95
36	38	Loulé	0.58	0.05	100.00
		<i>Total</i>	<i>1,093.08</i>	<i>100</i>	

Appendix H

Helicopter by deployments by helipad

Table H.1: Number of different helicopter per helipad and number of flights

Helipad	Different operating helicopter	Number of flights
Arcos Valdevez	5	413
Santa Comba Dão	5	257
Castelo Branco	4	396
Fafe	4	136
Ferreira do Zêze	4	125
Pampilhosa da Se	4	147
Águeda	3	362
Braga	3	269
Guarda	3	156
Monchique	3	155
Ribeira de Pena	3	202
Vale de Cambra	3	203
Vila Real	3	60
BA11	2	50
Baltar	2	126
Bornes	2	27
Cachopo	2	101
Cernache	2	167
Covilha	2	75
Figueiró	2	154
Grândola	2	103
Ponte de Sôr	2	52
Portalegre	2	276
Proença-a-Nova	2	102
Sardoal	2	240
Seia	2	33
Vidago	2	118
Viseu	2	297
BA6	1	58
Armamar	1	51
Évora	1	3
Lousã	1	90
Mêda	1	12
Nogueira	1	34
Ourique	1	22
Pernes	1	17
Pombal	1	16

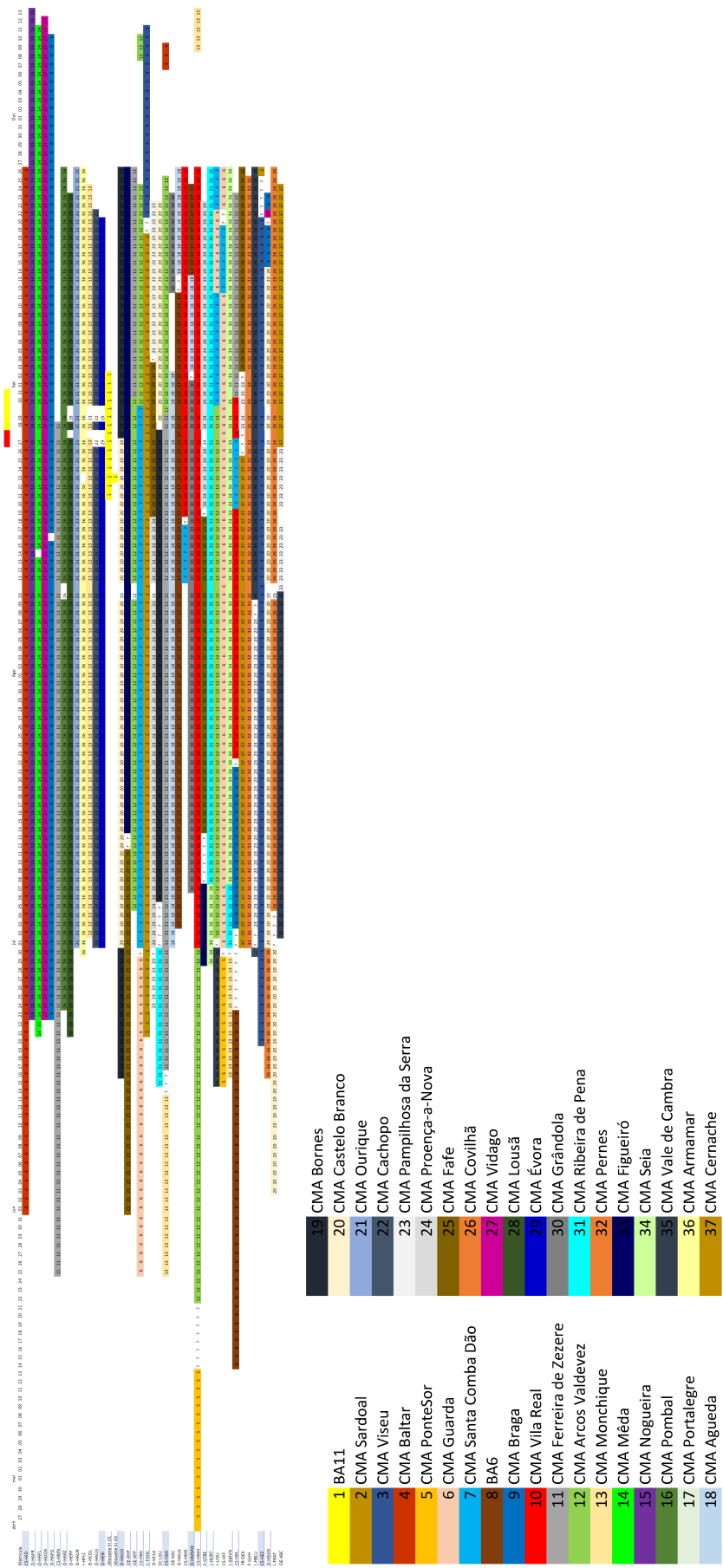


Figure H.1: Calendar of the intervention of helicopters (please enlarge the figure in the pdf)

Note that there are only represented 37 helipads, since Loulé helipad only served, during the year of 2013, as a base for medical assistance helicopters, which are not addressed in this research.

Appendix I

Time to action bar graph

Table I.1: Frequency and percentage of interval for dispatching a helicopter, accumulating after 115 minutes

Minutes	Density	Frequency	Accumulative Density	Accumulative Frequency
0	27.38%	1,576	27.38%	1,576
5	39.62%	2,281	67.00%	3,857
10	9.19%	529	76.19%	4,386
15	2.38%	137	78.57%	4,523
20	0.78%	45	79.35%	4,568
25	0.57%	33	79.92%	4,601
30	0.42%	24	80.34%	4,625
35	0.42%	24	80.75%	4,649
40	0.42%	24	81.17%	4,673
45	0.30%	17	81.47%	4,690
50	0.36%	21	81.83%	4,711
55	0.30%	17	82.13%	4,728
60	0.35%	20	82.47%	4,748
65	0.12%	7	82.60%	4,755
70	0.28%	16	82.87%	4,771
75	0.23%	13	83.10%	4,784
80	0.23%	13	83.32%	4,797
85	0.24%	14	83.57%	4,811
90	0.23%	13	83.79%	4,824
95	0.26%	15	84.05%	4,839
100	0.24%	14	84.30%	4,853
105	0.24%	14	84.54%	4,867
110	0.14%	8	84.68%	4,875
115	15.32%	882	100.00%	5,757

Appendix J

Goodness-of-fit

Distribution	Parameters	Statistic	p-value	α	0.2	0.1	0.05	0.02	0.01
				Critical Value	0,01521	0,01734	0,01925	0,02152	0,02309
Johnson SB	$\gamma = 0,53142$ $\delta = 1,1732$ $\lambda = 59612,0$ $\zeta = -2884,7$	0,00964	0,74046	Reject?	No	No	No	No	No
Pert	m=17774,0 a=-935,49 b=56651,0	0,01189	0,47882	Reject?	No	No	No	No	No
Kumaraswamy	$\alpha_1=1,7928$ $\alpha_2=3,7124$ a=-245,29 b=55495,0	0,01563	0,17418	Reject?	Yes	No	No	No	No
Gen. Gamma (4P)	k=3,2695 $\alpha = 0,50413$ $\beta = 32528,0$ $\gamma = -137,44$	0,0165	0,1317	Reject?	Yes	Yes	No	No	No
Beta	$\alpha_1=1,8221$ $\alpha_2=2,4951$ a=81,933 b=49998,0	0,01892	0,05602	Reject?	Yes	Yes	No	No	No
Weibull (3P)	$\alpha = 2,2349$ $\beta = 25416,0$ $\gamma = -1344,7$	0,02123	0,02226	Reject?	Yes	Yes	Yes	No	No
Gen Extreme Value	k=-0,16063 $\sigma = 9994,7$ $\mu = 16781,0$	0,02216	0,01489	Reject?	Yes	Yes	Yes	Yes	No
Rayleigh	$\sigma = 16884,0$	0,02241	0,0133	Reject?	Yes	Yes	Yes	Yes	No

Table J.1: Best fitting distributions of the SLDTO of the helicopters

Distribution CMA	Johnson SB	Pert	Kumaraswamy	Gen.Gamma(4P)	Beta	Widbull (3P)	Gen. Extreme Value	Rayleigh	
Ferreira de Zézere	✗	✗	✗	✗	✗	✗	✗	✗	Larger Mean
Castelo Branco	✓ $\gamma=0,19431$ $\delta=0,9624$ $\lambda=70268,0$ $\xi=5832,1$	✗	✓ (except 0,2; 0,1) $\alpha_1=1,05$ $\alpha_2=1,15$ $a=11594,0$ $b=68175,0$	✓ $\kappa=6,0227$ $\alpha=0,18803$ $\beta=51524,0$ $\gamma=11450,0$	✓ (except 0,2) $\alpha_1=1,2864$ $\alpha_2=1,5345$ $a=11594,0$ $b=68175,0$	✓ (except 0,2; 0,1) $\alpha=2,1555$ $\beta=34248,0$ $\gamma=7752,1$	✓ (except 0,2) $\kappa=-0,24136$ $\sigma=14775,0$ $\mu=32457,0$	✓ (except 0,2; 0,1) $\sigma=30380,0$	Larger Mean
Baltar	✓ $\gamma=1,5786$ $\delta=1,9834$ $\lambda=84254,0$ $\xi=-10534,0$	✓ (except 0,2) $m=12706,0$ $a=326,38$ $b=47561,0$	✓ (except 0,2) $\alpha_1=1,7505$ $\alpha_2=7,1539$ $a=0,03794$ $b=60191,0$	✓ $\kappa=2,85$ $\alpha=0,52452$ $\beta=25173,0$ $\gamma=204,58$	✓ (except 0,2) $\alpha_1=1,8486$ $\alpha_2=3,595$ $a=326,38$ $b=47561,0$	✓ $\alpha=2,007$ $\beta=19216,0$ $\gamma=-598,66$	✓ $\kappa=-0,14786$ $\sigma=8106,0$ $\mu=12820,0$	✓ (except 0,2) $\sigma=13559,0$ $\gamma=-568,91$	Smaller Mean, Larger Sum
Arcos de Valdevez	✓ (except 0,2) $\gamma=0,36982$ $\delta=0,74081$ $\lambda=36775,0$ $\xi=2289,2$	✗	✗	✗	✗	✗	✗	✗	Smaller Mean, Larger Sum
Vila Real	✗	✗	✗	✓ $\kappa=0,5304$ $\alpha=7,0608$ $\beta=815,72$ $\gamma=0,81187$	✗	✓ (except 0,2; 0,1; 0,05) $\alpha=1,4023$ $\beta=38150,0$ $\gamma=1775,0$	✓ $\kappa=0,17944$ $\sigma=16131,0$ $\mu=23655,0$	✗	Larger Sum
Grandola	✓ $\gamma=0,01418$ $\delta=1,6281$ $\lambda=81959,0$ $\xi=-14753,0$	✓ $m=26451,0$ $a=1655,0$ $b=49933,0$	✓ $\alpha_1=1,1134$ $\alpha_2=1,0866$ $a=1655,0$ $b=49933,0$	✓ $\kappa=4,8137$ $\alpha=0,3861$ $\beta=41006,0$ $\gamma=-772,79$	✓ $\alpha_1=1,7778$ $\alpha_2=1,7201$ $a=1655,0$ $b=49933,0$	✓ $\alpha=3,2211$ $\beta=36941,0$ $\gamma=-6998,6$	✓ $\kappa=-0,27909$ $\sigma=11749,0$ $\mu=21890,0$	✓ $\sigma=20795,0$	Smaller Sum
Proença-a-Nova	✓ $\gamma=-1,758$ $\delta=1,922$ $\lambda=11451,0$ $\xi=8197,0$	✓ $m=16084,0$ $a=4932,2$ $b=62692,0$	✓ $\alpha_1=1,05$ $\alpha_2=1,15$ $a=4932,2$ $b=62692,0$	✓ $\kappa=0,91556$ $\alpha=6,2599$ $\beta=3063,1$ $\gamma=-1006,5$	✓ $\alpha_1=1,7771$ $\alpha_2=4,3584$ $a=4932,2$ $b=62692,0$	✓ $\alpha=1,828$ $\beta=20219,0$ $\gamma=3931,6$	✓ $\kappa=-0,07329$ $\sigma=8347,3$ $\mu=17682,0$	✓ $\sigma=17500,0$	Smaller Sum

Table J.2: Results of distributions of helipads regarding best fitting distribution

Distribution Helicopter	Johnson SB	Pert	Kumaraswamy	Gen.Gamma(4P)	Beta	Widbull (3P)	Gen. Extreme Value	Rayleigh	
CS-HM	✓ $\gamma=0,92405$ $\delta=0,95877$ $\lambda=2,1573E+5$ $\xi=620,28$	✓ (except 0,2) $m=52650,0$ $a=11732,0$ $b=1,8517E+5$	✗	✓ $\kappa=3,2393$ $\alpha=0,25664$ $\beta=1,2043E+5$ $\gamma=11732,0$	✓ $\alpha1=0,97669$ $\alpha2=2,0632$ $a=11732,0$ $b=1,8517E+5$	✓ $\alpha=1,3043$ $\beta=61416,0$ $\gamma=10932,0$	✓ $\kappa=-0,01211$ $\sigma=33801,0$ $\mu=48807,0$	✓ $\sigma=54190,0$	Larger Mean, Larger Sum
CS-HMN	✓ $\gamma=0,00247$ $\delta=0,78144$ $\lambda=1,7192E+5$ $\xi=-7108,5$	✓ (except 0,2; 0,1;0,05) $m=74100,0$ $a=16586,0$ $b=1,5951E+5$	✓ $\alpha1=1,05$ $\alpha2=1,15$ $a=16586,0$ $b=1,5951E+5$	✓ (except 0,2; 0,1) $\kappa=6,006$ $\alpha=0,12124$ $\beta=1,3617E+5$ $\gamma=16586,0$	✓ $\alpha1=0,82876$ $\alpha2=1,168$ $a=16586,0$ $b=1,5951E+5$	✓ (except 0,2) $\alpha=1,4336$ $\beta=72178,0$ $\gamma=12589,0$	✓ $\kappa=-0,29064$ $\sigma=43059,0$ $\mu=63777,0$	✓ (except 0,2) $\sigma=62833,0$	Larger Mean
OE-XHP	✓ $\gamma=1,6053$ $\delta=1,2654$ $\lambda=60929,0$ $\xi=-1149,5$	✓ (except 0,2; 0,1; 0,05) $m=10111,0$ $a=3107,7$ $b=39195,0$	✗	✓ $\kappa=2,488$ $\alpha=0,30287$ $\beta=25759,0$ $\gamma=3107,7$	✓ $\alpha1=0,94081$ $\alpha2=2,1666$ $a=3107,7$ $b=39195,0$	✓ $\alpha=1,2444$ $\beta=11498,0$ $\gamma=3040,3$	✓ $\kappa=0,01709$ $\sigma=6493,2$ $\mu=9931,7$	✓ (except 0,2) $\sigma=11004,0$	Smaller Sum
CS-HID	✓ $\gamma=1,5786$ $\delta=1,9834$ $\lambda=84254,0$ $\xi=-10534,0$	✓ (except 0,2) $m=12706,0$ $a=326,38$ $b=47561,0$	✓ (except 0,2) $\alpha1=1,7505$ $\alpha2=7,1539$ $a=0,03794$ $b=60191,0$	✓ $\kappa=2,85$ $\alpha=0,52452$ $\beta=25173,0$ $\gamma=204,58$	✓ (except 0,2) $\alpha1=1,8486$ $\alpha2=3,595$ $a=326,38$ $b=47561,0$	✓ $\alpha=2,007$ $\beta=19216,0$ $\gamma=-598,66$	✓ $\kappa=-0,14786$ $\sigma=8106,0$ $\mu=12820,0$	✓ (except 0,2) $\sigma=13127,0$	Smaller Mean, Larger Sum
I-HPLC	✓ $\gamma=0,34093$ $\delta=1,0539$ $\lambda=47399,0$ $\xi=3178,8$	✓ $m=22173,0$ $a=4864,8$ $b=48513,0$	✗	✓ $\kappa=4,0051$ $\alpha=0,39932$ $\beta=30681,0$ $\gamma=4618,3$	✓ $\alpha1=1,8885$ $\alpha2=2,4926$ $a=4864,8$ $b=48513,0$	✓ $\alpha=2,328$ $\beta=22977,0$ $\gamma=3331,5$	✓ $\kappa=-0,18623$ $\sigma=8953,8$ $\mu=19926,0$	✗	Larger Sum
I-HBLU	✓ $\gamma=0,74108$ $\delta=1,0313$ $\lambda=55515,0$ $\xi=-2827,6$	✗	✗	✗	✓ $\alpha1=1,2496$ $\alpha2=2,1725$ $a=551,71$ $b=46324,0$	✓ $\alpha=1,6461$ $\beta=19295,0$ $\gamma=-479,33$	✓ $\kappa=-0,08275$ $\sigma=9259,2$ $\mu=12187,0$	✗	Smaller Mean
C-HFAC	✓ $\gamma=0,27132$ $\delta=0,66768$ $\lambda=37996,0$ $\xi=1438,3$	✓ (except 0,2; 0,1; 0,05) $m=17293,0$ $a=802,7$ $b=36352,0$	✓ $a1=1,05$ $a2=1,15$ $a=802,7$ $b=36352,0$	✓ $\kappa=8,8117$ $\alpha=0,10415$ $\beta=34609,0$ $\gamma=802,68$	✓ $\alpha1=1,0736$ $\alpha2=1,206$ $a=802,7$ $b=36352,0$	✓ $\alpha=1,9289$ $\beta=21037,0$ $\gamma=-946,74$	✓ $\kappa=-0,14862$ $\sigma=9497,3$ $\mu=13472,0$	✓ $\sigma=14140,0$	Smaller Sum
D-HCOL	✓ $\gamma=0,04339$ $\delta=2,1016$ $\lambda=66272,0$ $\xi=-8113,2$	✓ $m=24952,0$ $a=7698,8$ $b=41295,0$	✓ $\alpha1=1,1133$ $\alpha2=1,0867$ $a=7698,8$ $b=41295,0$	✓ $\kappa=4,0185$ $\alpha=0,62947$ $\beta=26376,0$ $\gamma=4583,7$	✓ $\alpha1=2,1544$ $\alpha2=2,0818$ $a=7698,8$ $b=41295,0$	✓ $\alpha=3,4087$ $\beta=25259,0$ $\gamma=2014,7$	✓ $\kappa=-0,29173$ $\sigma=7610,5$ $\mu=22057,0$	✓ (except 0,2; 0,1) $\sigma=19706,0$	Smaller Sum

Table J.3: Results of distributions of helicopters regarding best fitting distribution

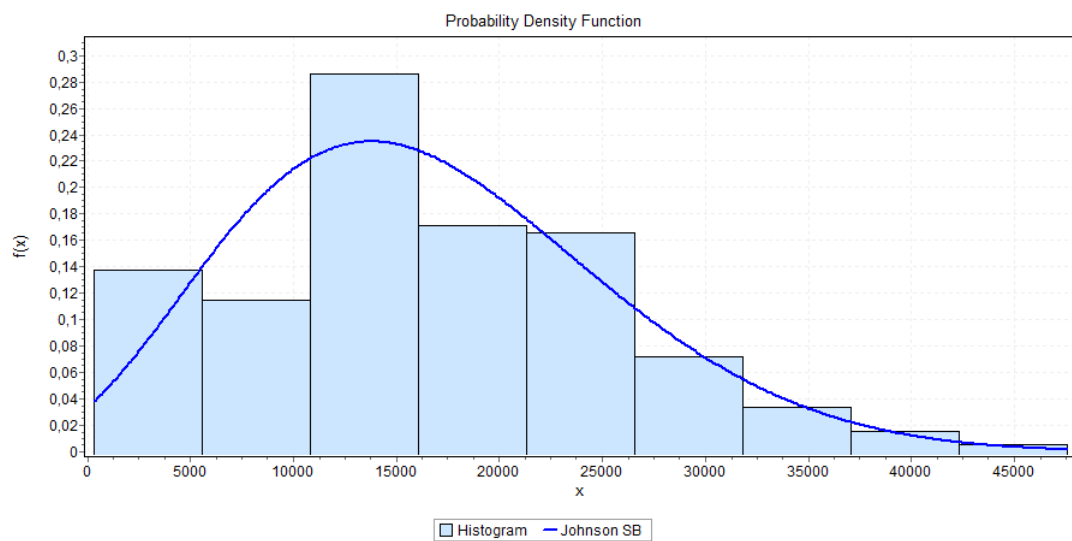


Figure J.1: Distribution of SLDTO by helicopters in Baltar helipad

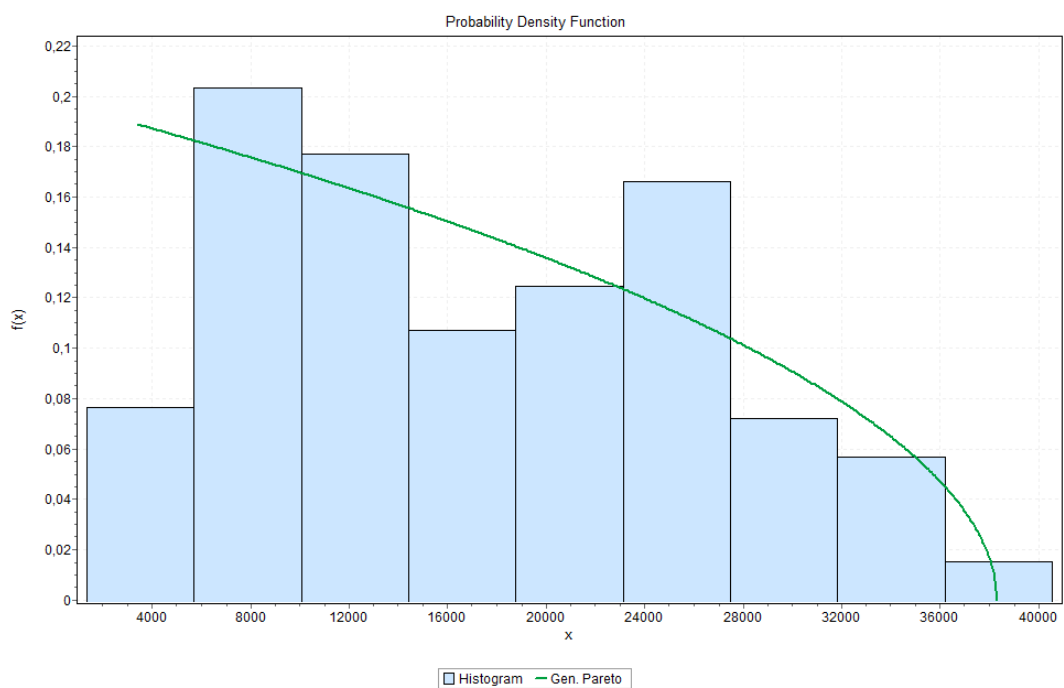


Figure J.2: Distribution of SLDTO by helicopters in Arcos de Valdevez helipad

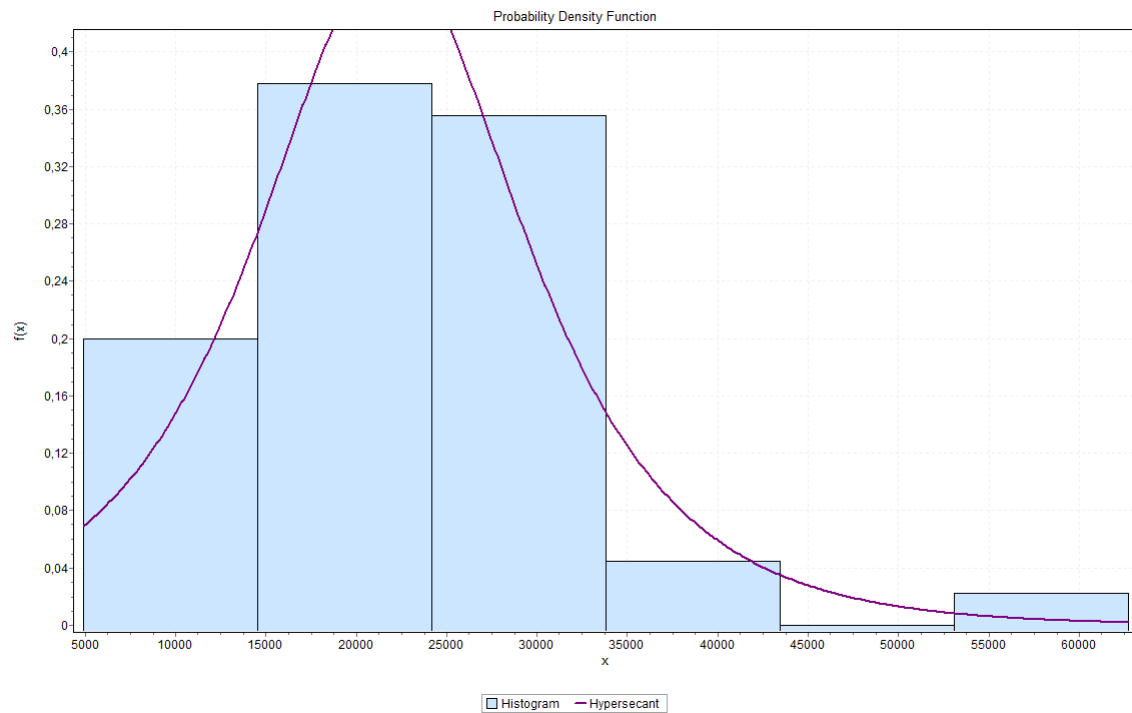


Figure J.3: Distribution of SLDTO by helicopters in Proença-a-nova helipad

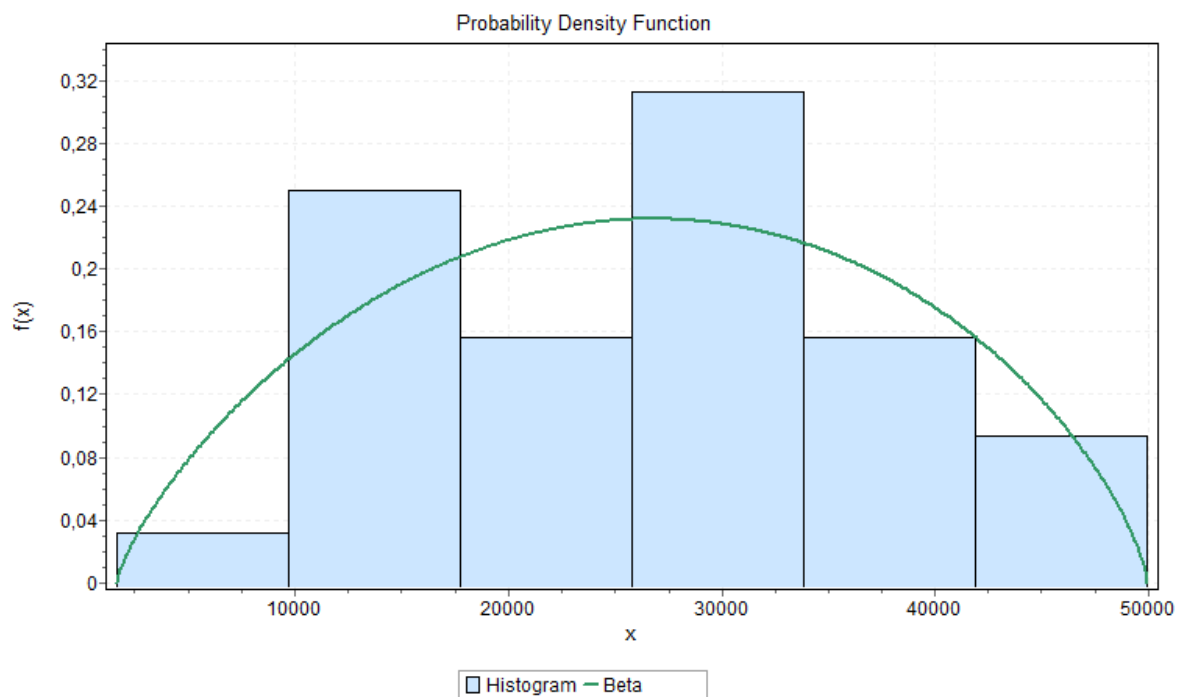


Figure J.4: Distribution of SLDTO by helicopters in Grândola helipad

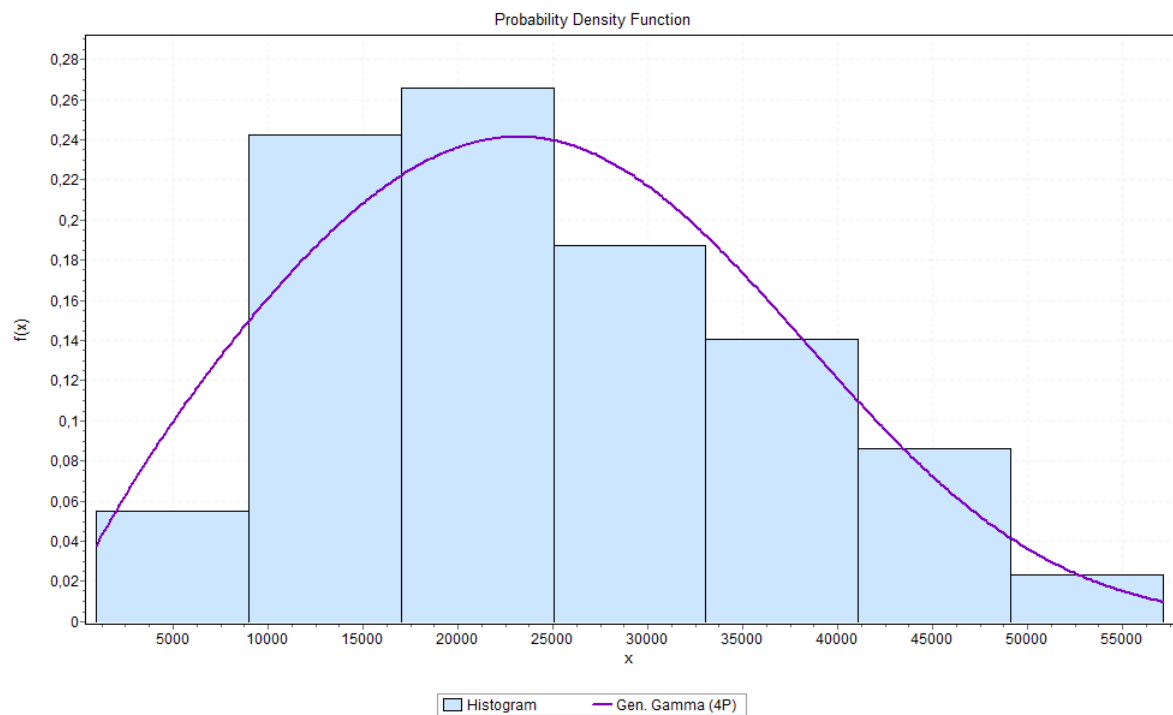


Figure J.5: Distribution of SLDTO by helicopters in Bornes helipad

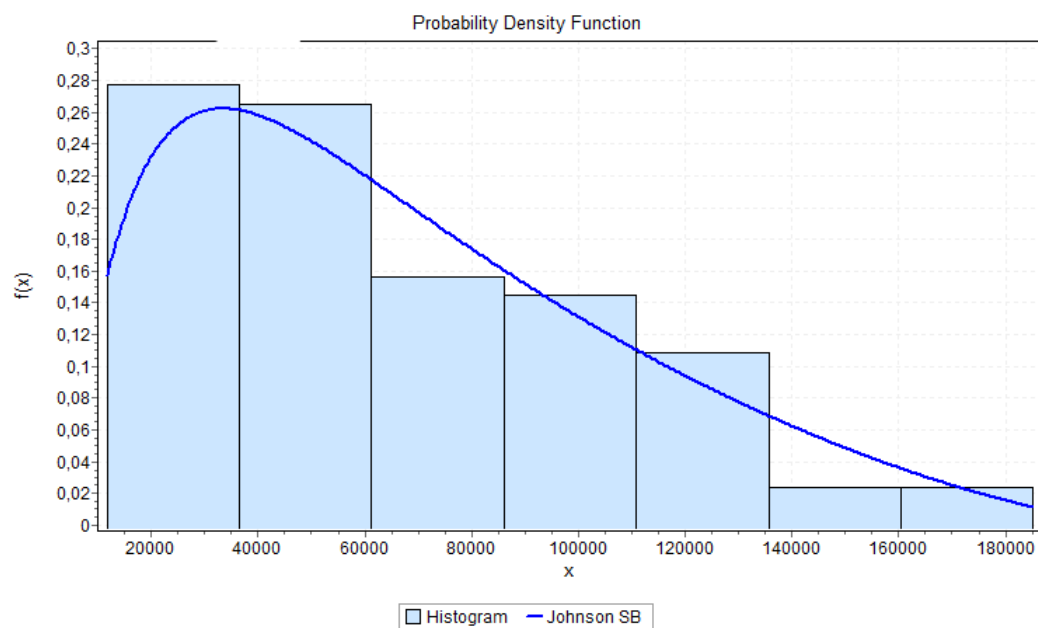


Figure J.6: Distribution of SLDTO by CS-HM

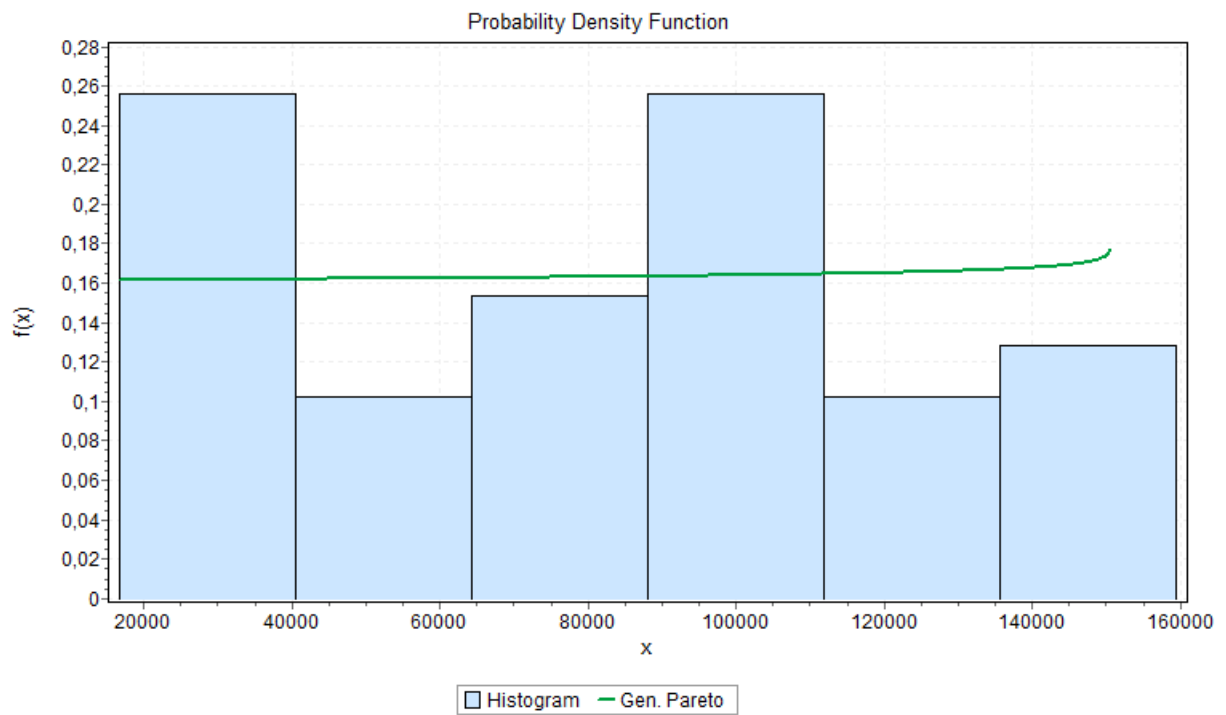


Figure J.7: Distribution of SLDTO by CS-HMN

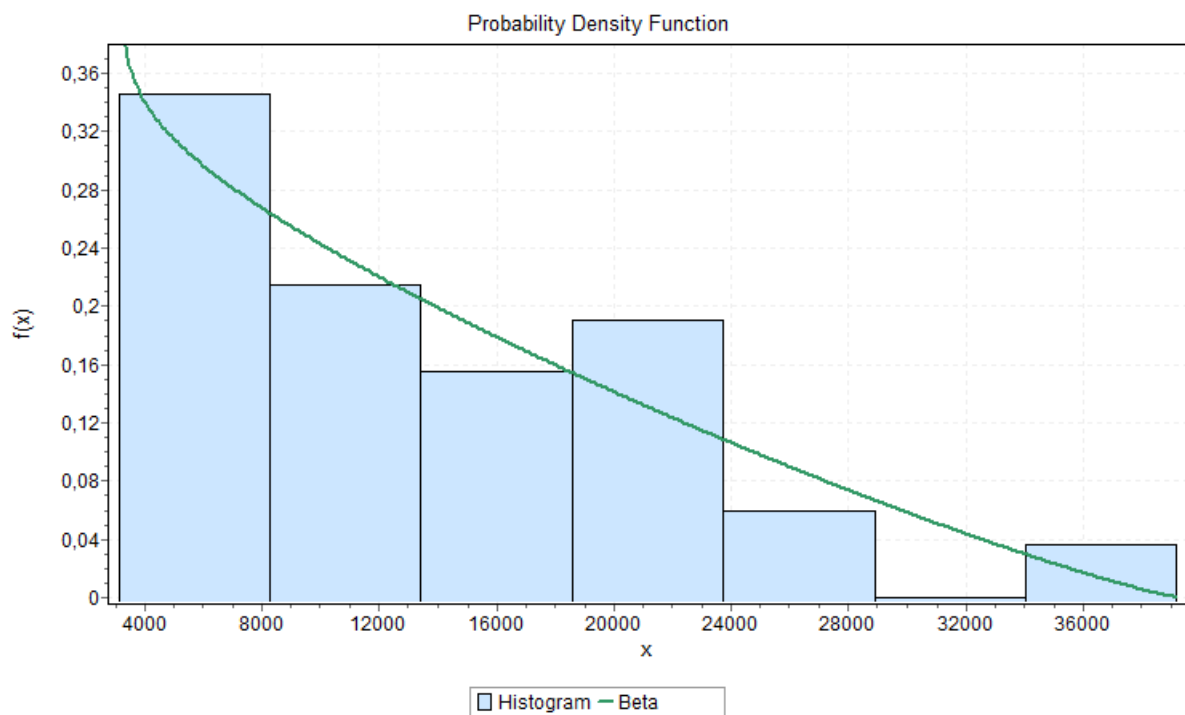


Figure J.8: Distribution of SLDTO by OE-XHP

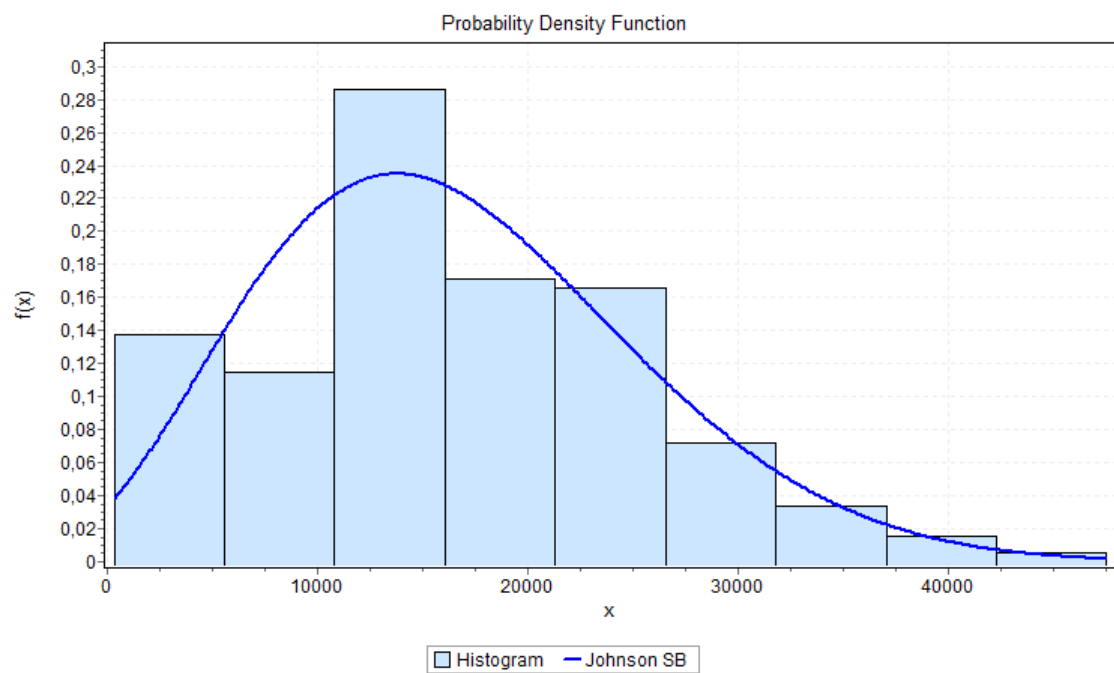


Figure J.9: Distribution of SLDTO by CS-HID

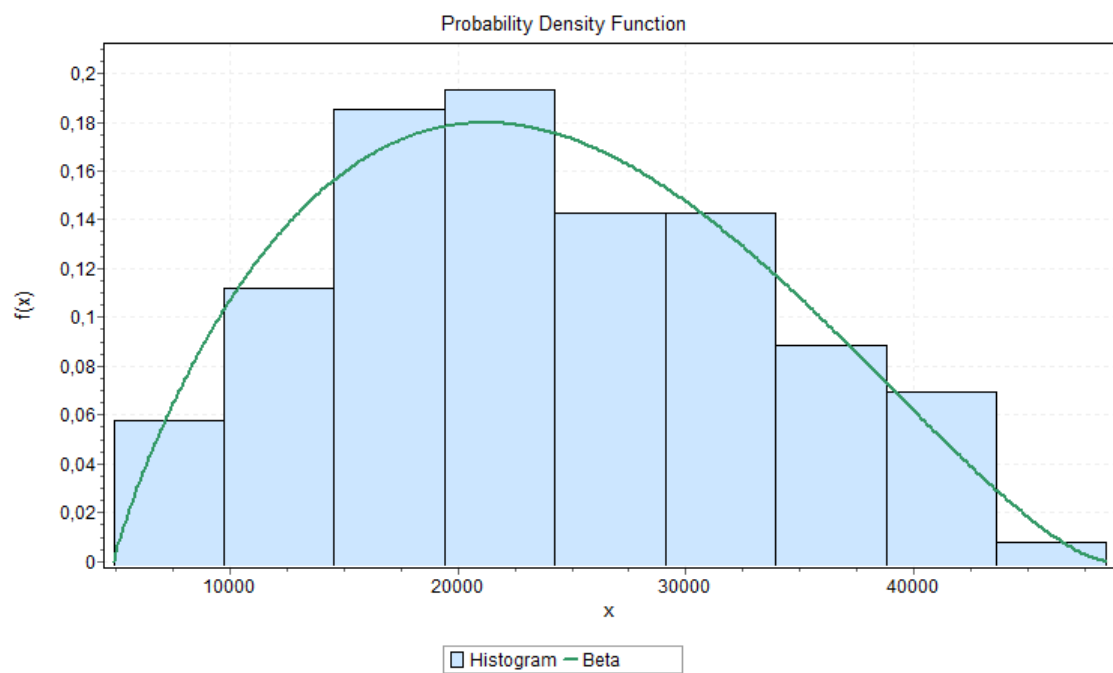


Figure J.10: Distribution of SLDTO by H-IPLC

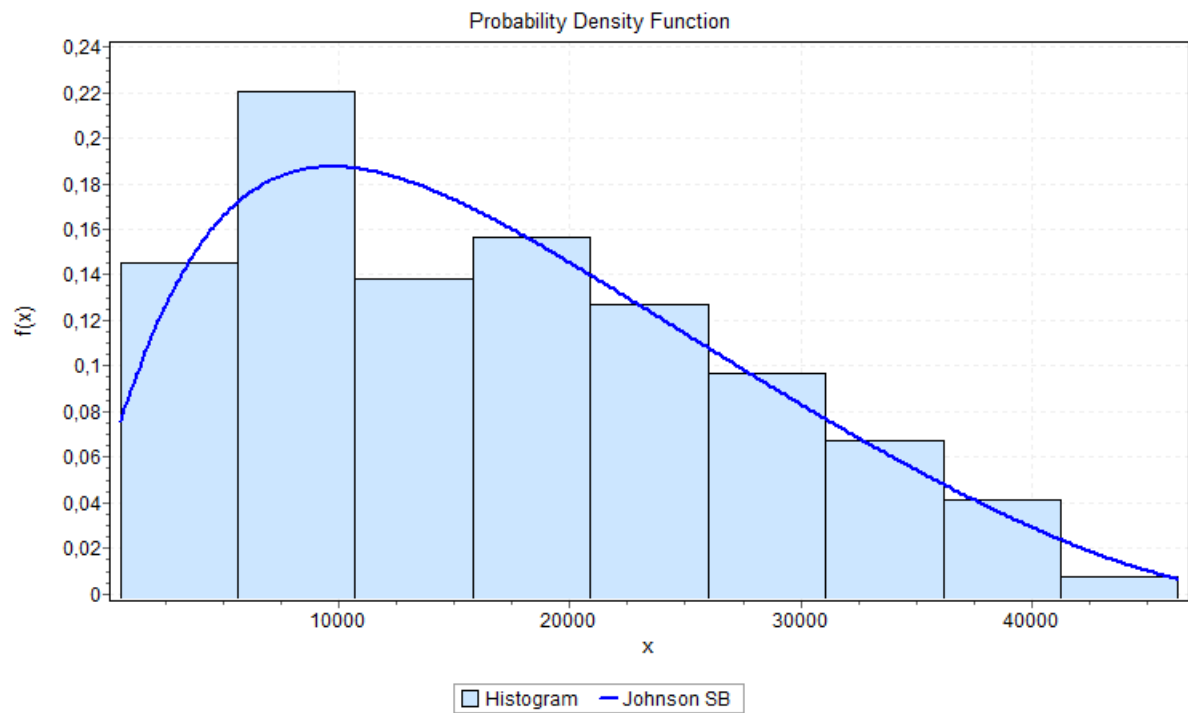


Figure J.11: Distribution of SLDTO by I-HBLU

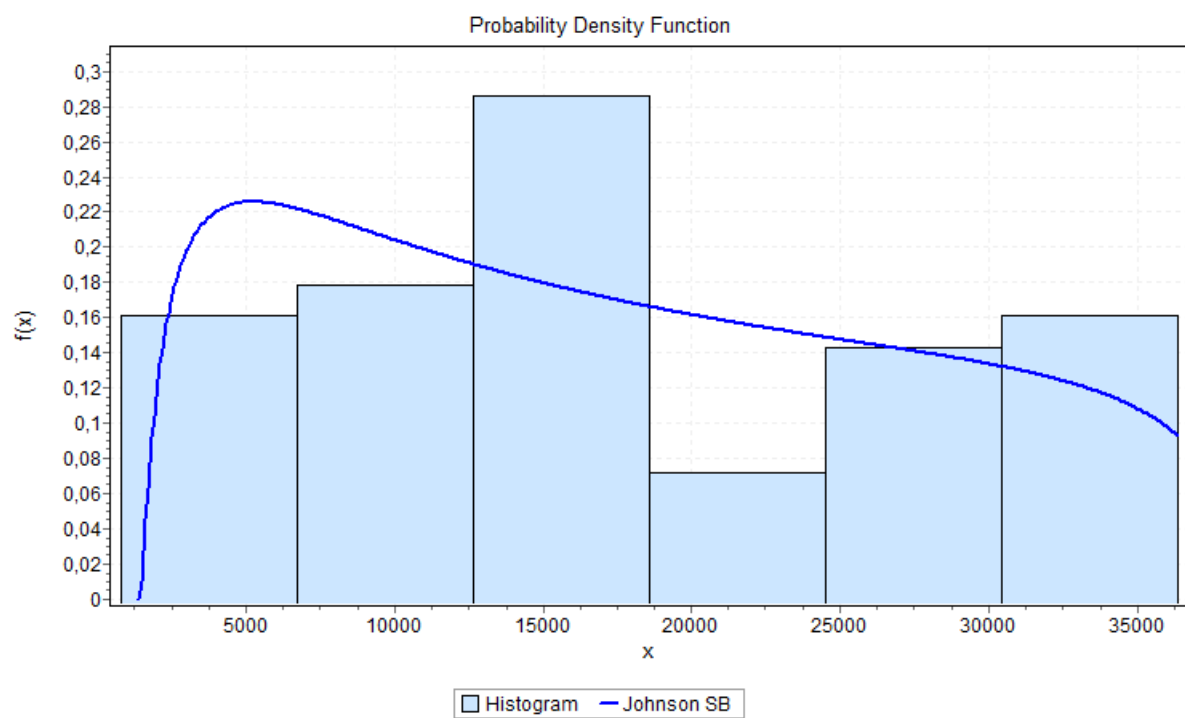


Figure J.12: Distribution of SLDTO by C-HFAC

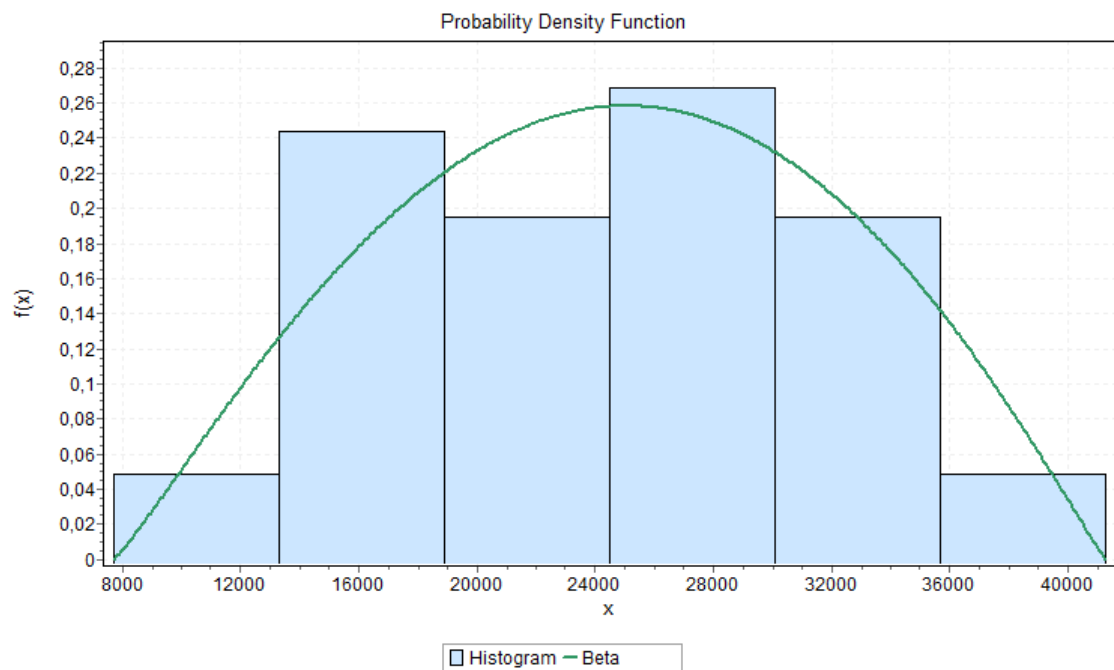


Figure J.13: Distribution of SLDTO by D-HCOL

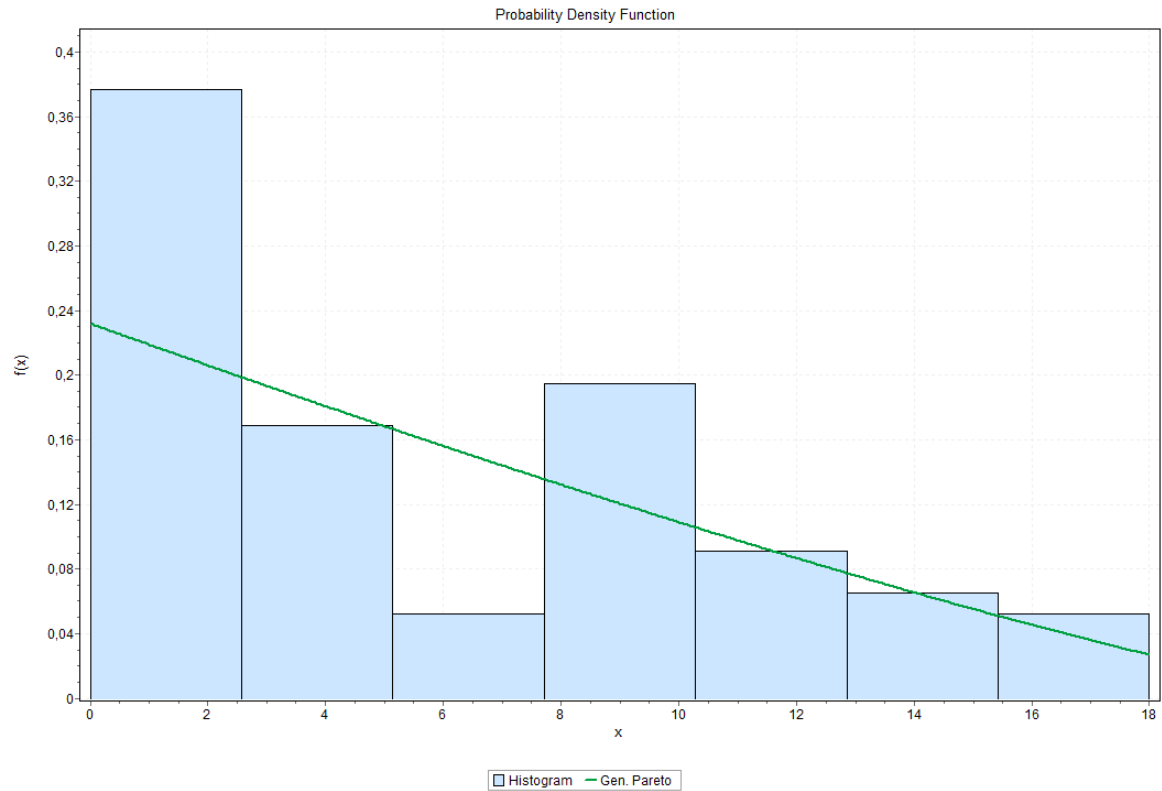


Figure J.14: Distribution of number of deployments per day in Arcos de Valdevez helipad

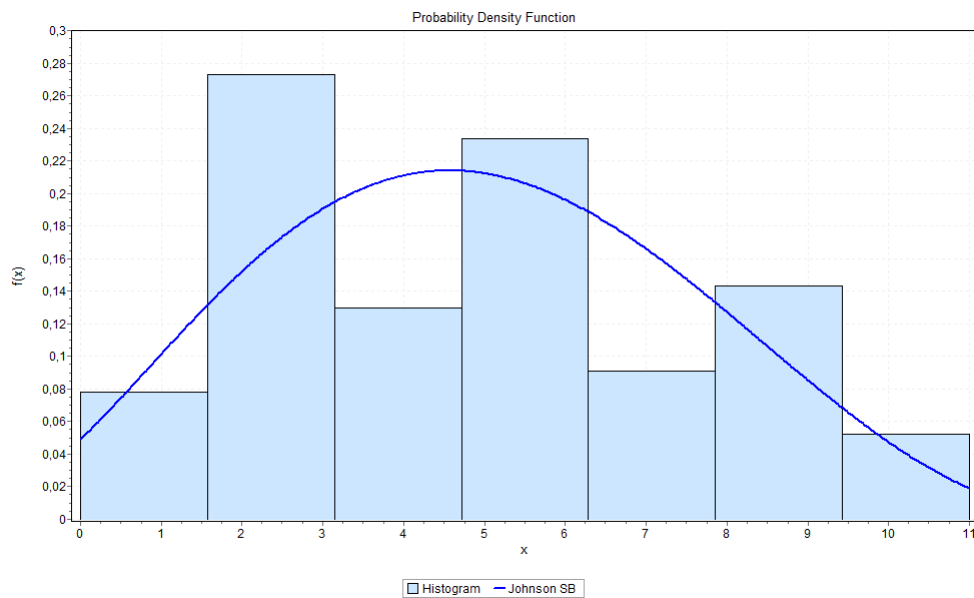


Figure J.15: Distribution of number of deployments in Baltar

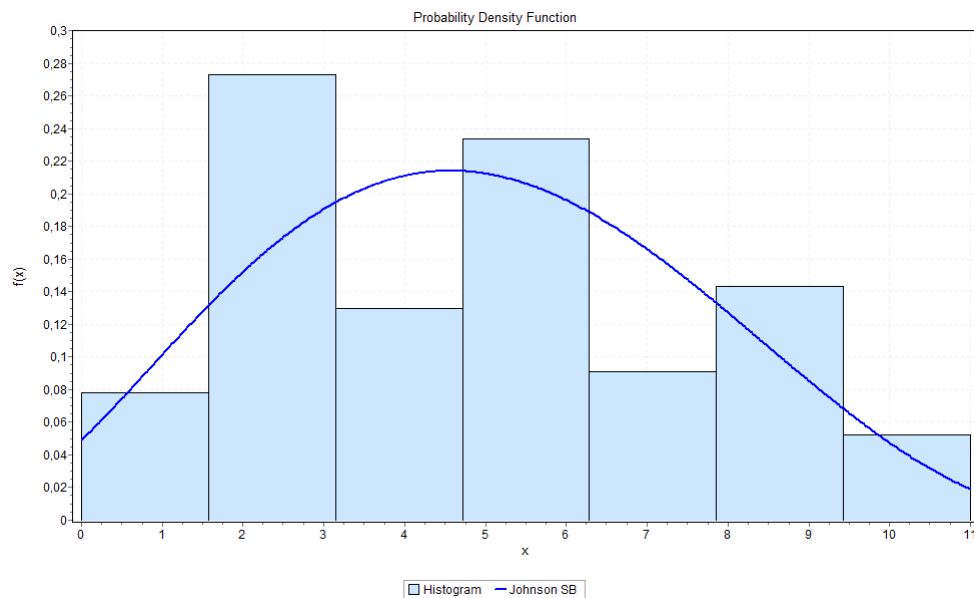


Figure J.16: Distribution of deployments made by CS-HID helicopter

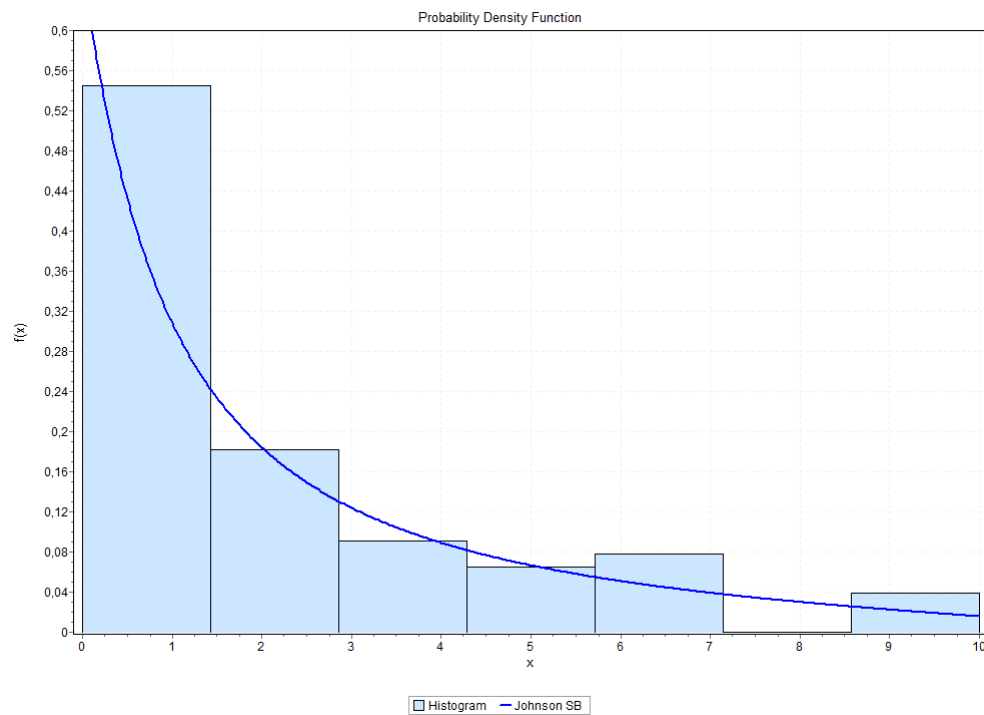


Figure J.17: Distribution of deployments made by I-LIGU helicopter

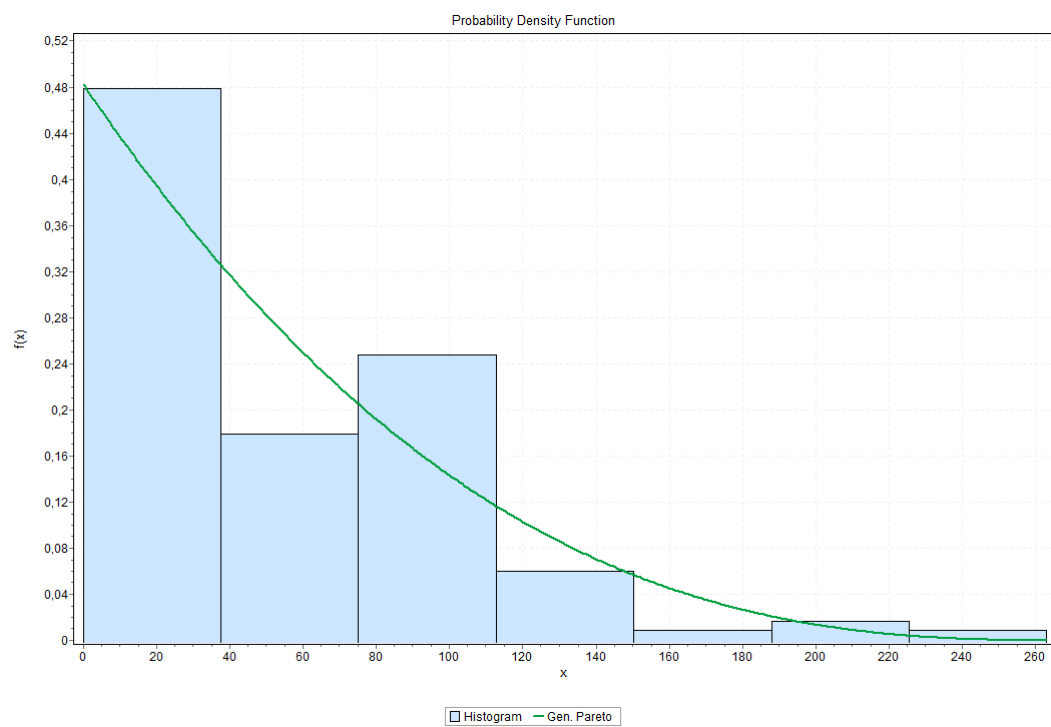


Figure J.18: Distribution of time of flight for *Seia* helipad

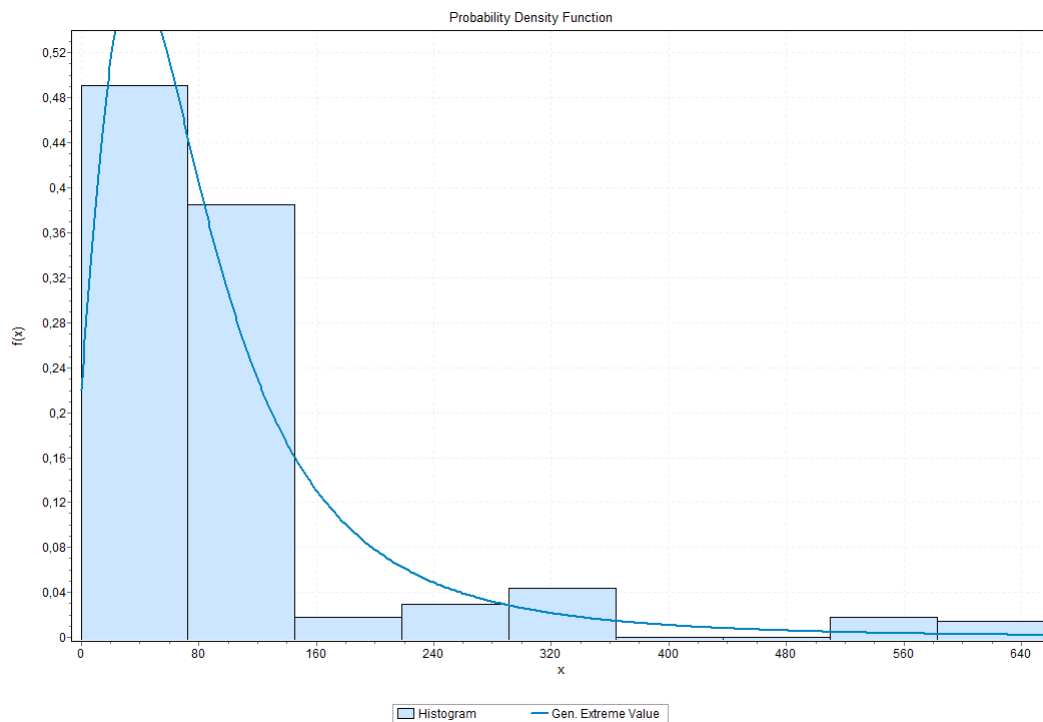


Figure J.19: Distribution of time of flight for *Vila Real* helipad

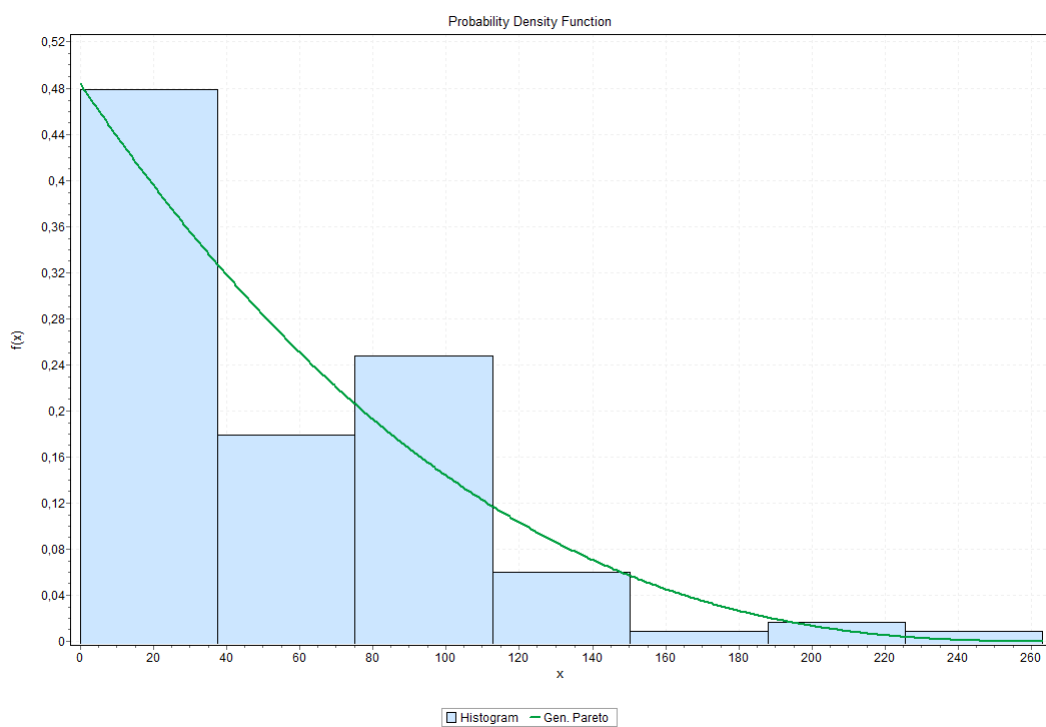


Figure J.20: Distribution of time of flight for I-AVM

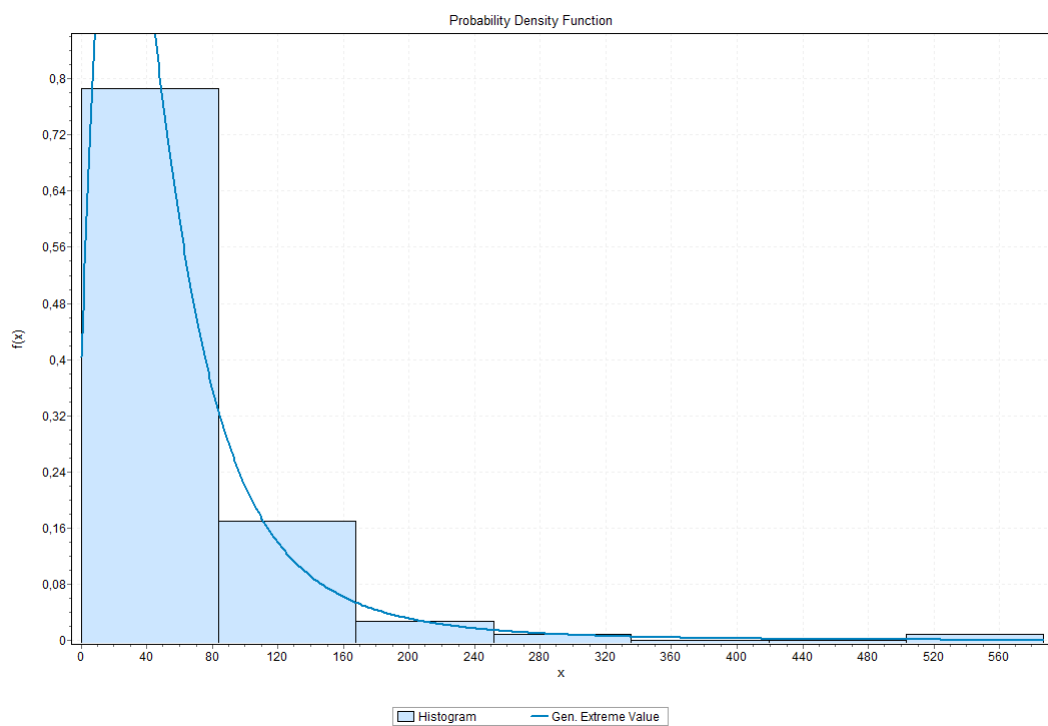


Figure J.21: Distribution of time of flight for O-EXBC

Appendix K

Logit Analysis

Table K.1: Families of candidate variables for *logit* analysis, with descriptive values in table E.2 and meaning in table E.1

Variable Family	Name	Type	Variable Family	Name	Type	#f
burnt area	baPltF	c	fuel proxy	Distrito	f	18
burnt area	baSrub	c	fuel proxy	Concelho	f	278
burnt area	baAgri	c	occ. type	Duracao	c	
burnt area	baFSpace	c	occ. type 4L	Tipo	f	4
burnt area	baTotal	c	occ. type Y/N	RKD	b	2
deployment	d	c	occ. type Y/N	Queimada	b	2
deployment	da	c	occ. type Y/N	FA	b	2
deployment	dh	c	occ. type Y/N	Fogacho	b	2
deployment	dhn	c	occ. type Y/N	Incendio	b	2
deployment	dg	c	occ. type Y/N	Agricola	b	2
deployment	dgf	c	resources #	ra	c	
fire weather	fwTEMP	c	resources #	rah	c	
fire weather	fwHR	c	resources #	rahn	c	
fire weather	fwWIND	c	resources #	rg	c	
fire weather	fwFWI	c	resources #	rgf	c	
fire weather	fwDSR	c	resources #	rp	c	
			resources Y/N	vlci	b	2
			resources Y/N	vfci	b	2
			resources Y/N	vttf	b	2
			resources Y/N	vcoc	b	2
			resources Y/N	vci	b	2
			resources Y/N	vgf	b	2

Table K.2: Correlation between helicopter presence and deployment variables

d*
(obs=23136)

	h	d	da	dh	dhn	dg	dgf
h	1						
d	0.3016	1					
da	0.5695	0.8429	1				
dh	0.6868	0.7524	0.9545	1			
dhn	0.6868	0.7524	0.9545	1	1		
dg	0.2973	0.995	0.8151	0.7315	0.7315	1	
dgf	0.2886	0.9411	0.7589	0.6774	0.6774	0.9555	1

Table K.3: Correlation between helicopter presence and resource variables

r*
(obs=23136)

	h	ra	rah	rahn	rg	rgf	rp
h	1						
ra	0.7686	1					
rah	0.8787	0.9439	1				
rahn	0.1277	0.6333	0.3423	1			
rg	0.4207	0.7134	0.6348	0.5424	1		
rgf	0.3657	0.6087	0.5377	0.4719	0.8942	1	
rp	0.2837	0.6771	0.5366	0.6691	0.849	0.7316	1

Table K.4: Correlation between helicopter presence and fire weather variables

f*
(obs=23133)

	h	fwTEMP	fwHR	fwWIND	fwFWI	fwDSR
h	1					
fwTEMP	0.152	1				
fwHR	-0.1109	-0.5926	1			
fwWIND	-0.0618	-0.3922	0.2606	1		
fwFWI	0.1598	0.6114	-0.685	0.1308	1	
fwDSR	0.1465	0.5534	-0.6598	0.178	0.9602	1

Table K.5: Correlation between helicopter presence and burned area variables

b*
(obs=23136)

	h	baPltF	baSrubb	baAgri	baFSpace	baTotal
h	1					
baPltF	0.0678	1				
baSrubb	0.066	0.4181	1			
baAgri	0.0446	0.2342	0.3756	1		
baFSpace	0.078	0.7383	0.9214	0.3791	1	
baTotal	0.0788	0.734	0.9214	0.434	0.9982	1

Table K.6: Correlation between helicopter presence and resource presence variables

v*							
(obs=23136)							
	h	vlci	vfcf	vtff	vcoc	vci	vgf
h	1						
vlci	0.2029	1					
vfcf	0.1339	-0.2399	1				
vtff	0.0076	-0.032	0.0664	1			
vcoc	0.1277	0.0879	0.0618	0.1172	1		
vci	0.1051	0.3324	0.5298	0.0202	0.0327	1	
vgf	0.1038	0.3303	0.5264	0.0497	0.0325	0.9936	1

Table K.7: Correlation between helicopter presence and success variables

ia*			
(obs=22937)			
	h	ia90	ia110
h	1		
ia90	-0.0619	1	
ia110	-0.0987	0.5188	1

Table K.8: Correlation between helicopter presence and helipad variables

h	hpN	hpD	hia	hea		
(obs=22611)						
	h	hpN	hpD	hia	hea	
h	1					
hpN	0.1085	1				
hpD	-0.1646	0.18	1			
hia	0.9748	0.1082	-0.1607	1		
hea	0.2634	0.0236	-0.0386	0.1121	1	

Table K.9: Correlation between helicopter presence and occurrence variables

Distrito	Concelho	Charlie	Critical	IgnDay			
(obs=23136)							
	h	Distrito	Concelho	Charlie	Critical	IgnDay	
h	1						
Distrito	0.0038	1					
Concelho	-0.0052	0.1457	1				
Charlie	0.1885	0.0279	0.0274	1			
Critical	0.1583	0.0436	0.0179	0.7728	1		
IgnDay	0.1401	0.0277	0.0117	0.6826	0.5248	1	

Table K.10: Correlation between helicopter presence and type variables

	h	Duracao	Tipo	RKD	Queimada	FA	Fogacho	Incendio	Agricola
h	1								
Duracao	0.0288	1							
Tipo	0.0692	0.0052	1						
RKD	0.075	0.0044	0.1433	1					
Queimada	-0.0245	-0.0013	0.2367	-0.0468	1				
FA	0.0062	0.0419	-0.1535	-0.0671	-0.0267	1			
Fogacho	-0.0918	-0.026	0.5027	0.1263	-0.1808	-0.2595	1		
Incendio	0.2004	0.0283	0.1865	0.0216	-0.0577	-0.0829	-0.5608	1	
Agricola	-0.0708	-0.0148	-0.8588	-0.1367	-0.0586	-0.0841	-0.5692	-0.1817	1

Appendix L

Three dimensional matrixes

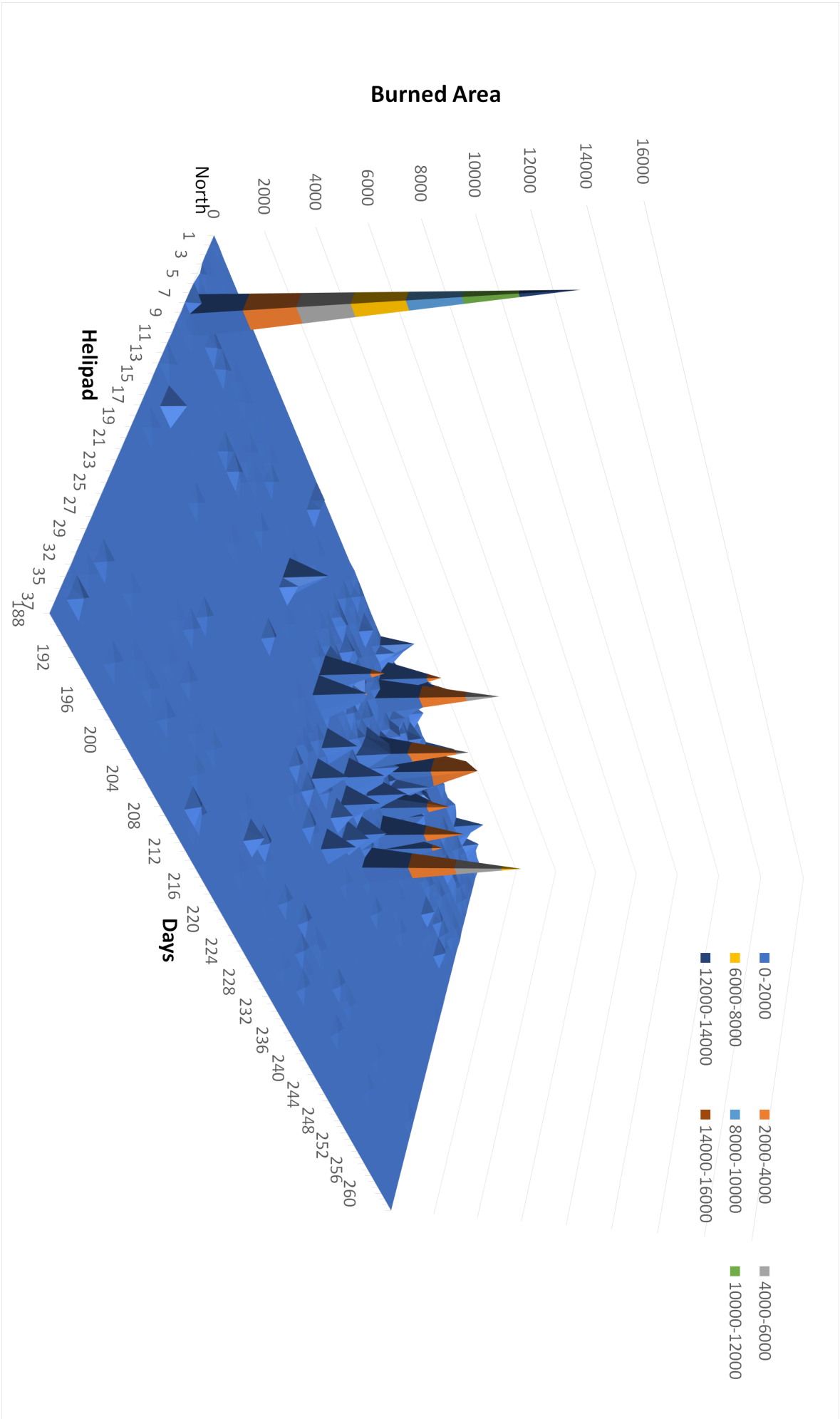


Figure L.1: 3D map of burned area

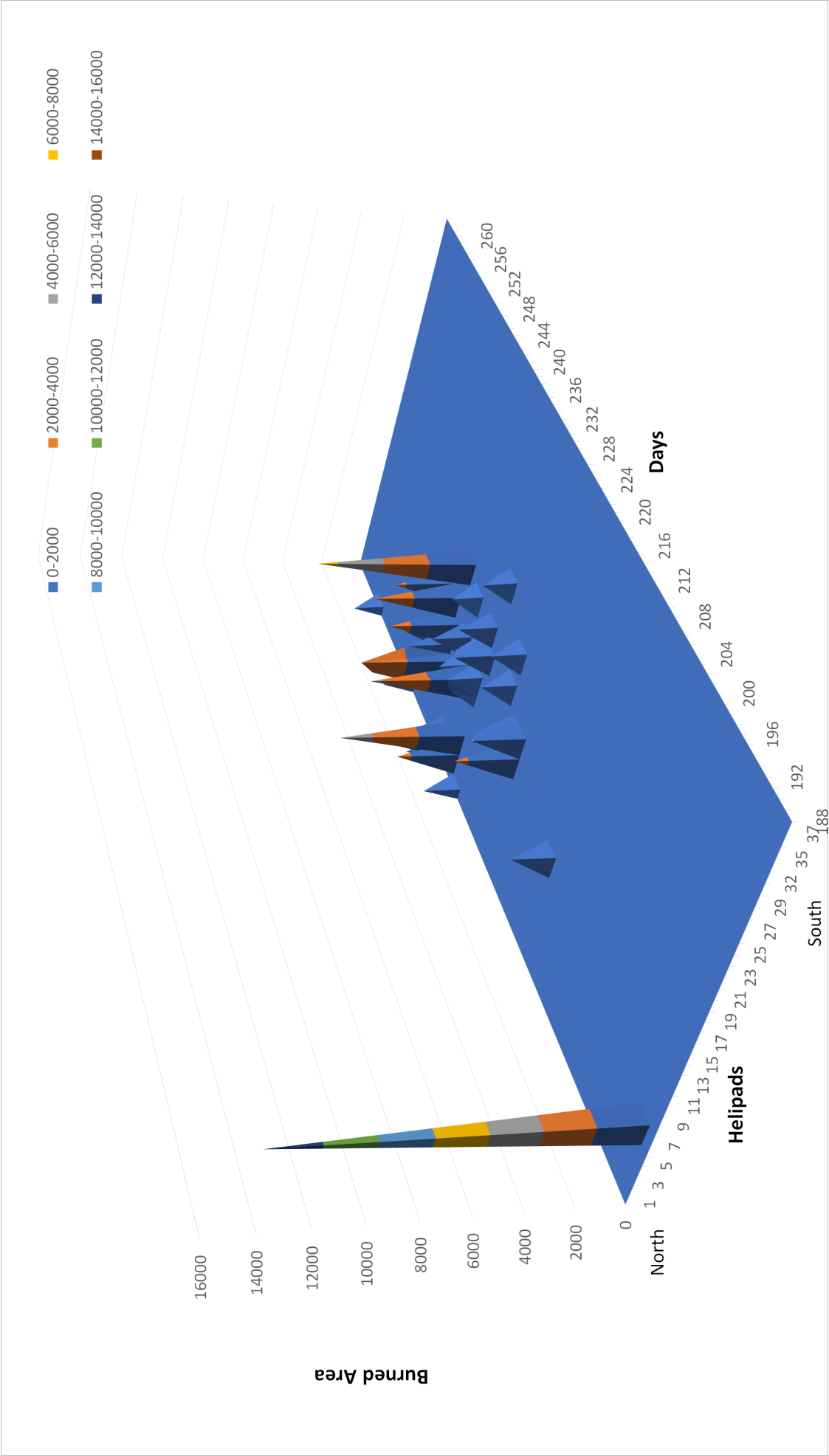


Figure L.2: 3D map of burned area over 1000 ha

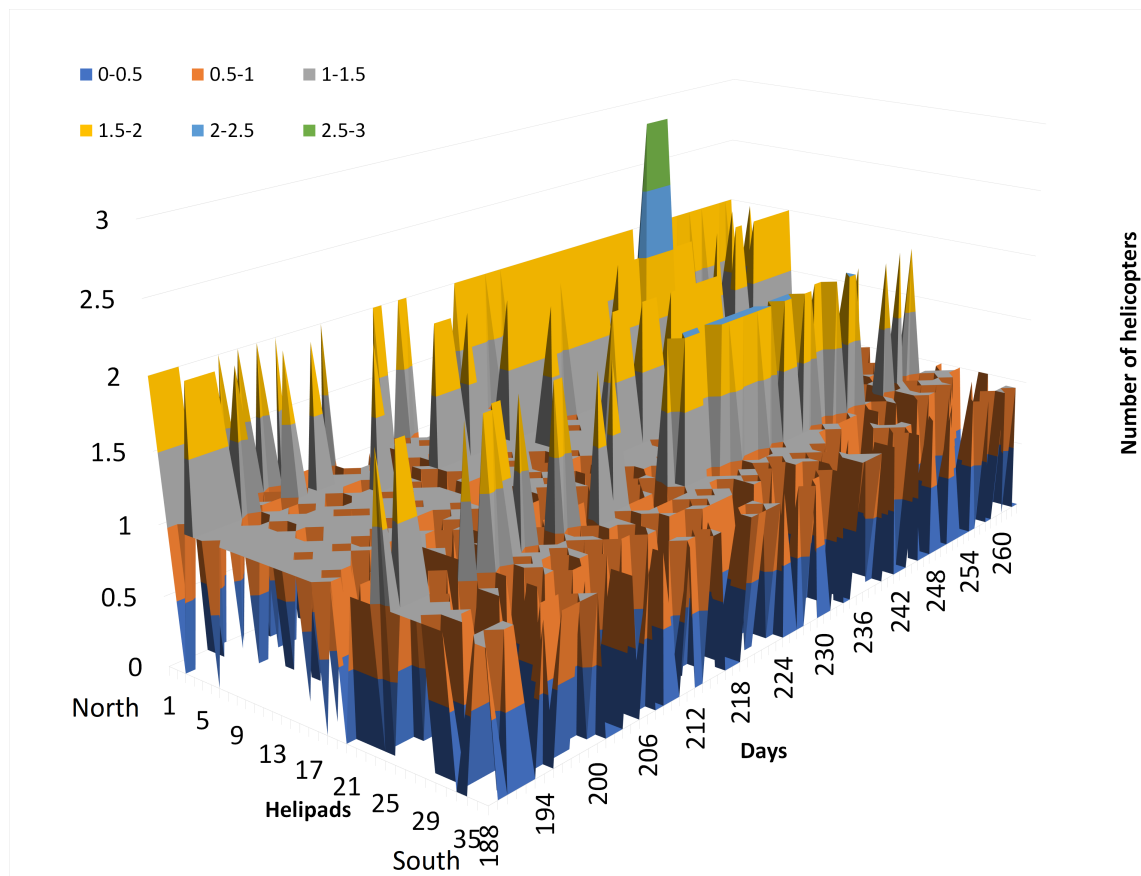


Figure L.3: 3D map of distinct helicopters parked in the helipads

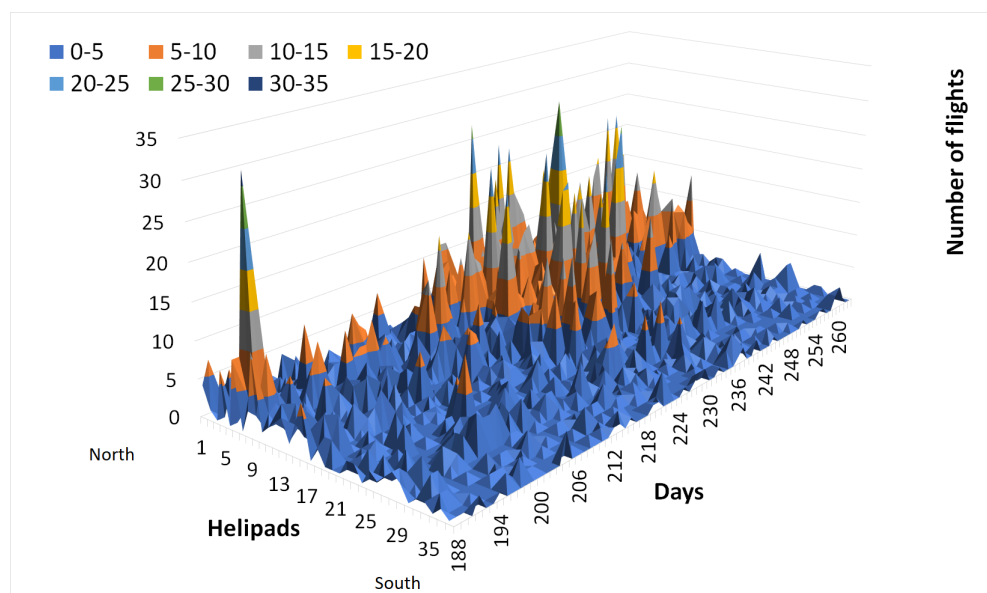


Figure L.4: 3D map of flights of helicopters

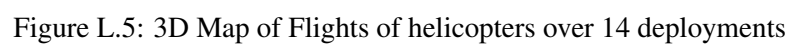


Figure L.5: 3D Map of Flights of helicopters over 14 deployments

Appendix M

Three-dimensional matrix Standard Deviations

Table M.1: Standard deviation of 3D matrix for helipads, reference by their order in table B.1

HP	Occ.	Occ. with Helicopters	Burned Area	Deployments	Helicopter flights	Distinct Helicopters	Helicopters in Base
1	14.813	4.278	334.394	82.142	5.185	0.808	0.808
2	1.615	0.907	162.468	17.087	1.286	0.492	0.492
3	4.870	2.312	526.392	40.756	1.902	0.428	0.428
4	8.285	2.501	79.671	39.052	2.089	0.516	0.516
5	2.800	1.612	628.564	22.032	2.064	0.367	0.367
6	11.813	3.390	124.076	44.292	2.353	0.309	0.309
7	1.519	0.920	1660.719	34.613	1.856	0.486	0.486
8	2.875	1.623	471.610	36.158	3.023	0.757	0.757
9	29.119	4.315	316.713	104.706	2.602	0.225	0.225
10	6.289	2.168	581.425	39.027	2.443	0.250	0.250
11	2.148	1.366	471.808	30.543	1.571	0.428	0.428
12	8.245	2.599	183.558	50.441	2.394	0.200	0.200
13	5.252	2.484	586.465	58.313	2.200	0.225	0.225
14	2.956	1.617	234.370	39.304	2.014	0.309	0.309
15	1.664	1.101	170.520	20.053	1.361	0.436	0.436
16	2.567	1.513	215.400	39.891	1.894	0.443	0.443
17	1.731	1.283	785.943	39.080	2.075	0.588	0.588
18	2.375	1.083	197.281	43.577	1.273	0.495	0.495
19	2.003	0.915	8.940	14.663	1.172	0.499	0.499
20	2.132	1.277	35.655	30.737	1.183	0.499	0.499
21	0.792	0.520	142.188	26.138	1.015	0.499	0.499

Table M.1: Standard deviation of 3D matrix for helipads, reference by their order in table B.1

HP	Occ.	Occ. with Helicopters	Burned Area	Deployments	Helicopter flights	Distinct Helicopters	Helicopters in Base
22	1.216	0.808	30.453	32.680	1.136	0.503	0.503
23	2.098	1.027	1.285	17.324	0.943	0.499	0.499
24	0.774	0.493	8.008	18.649	0.819	0.499	0.499
25	1.110	0.720	2.035	11.899	2.003	0.955	0.955
26	1.037	0.763	1.433	11.614	1.259	0.704	0.704
27	1.154	0.823	7.005	12.073	0.839	0.503	0.503
28	7.265	1.630	36.614	56.487	1.485	0.410	0.410
29	1.265	0.717	63.739	13.286	0.786	0.501	0.501
30	0.736	0.444	11.591	11.378	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	2.025	0.844	11.032	14.475	0.857	0.502	0.502
33	3.609	0.699	10.961	20.933	0.659	0.478	0.478
34	0.000	0.617	0.000	0.000	0.596	0.250	0.250
35	1.189	0.340	46.868	11.530	0.739	0.492	0.492
36	0.617	0.773	1.798	4.740	0.739	0.486	0.486
37	1.120	0.718	1.140	9.876	0.869	0.486	0.486
38	1.325	1.002	1.211	9.714	0.000	0.000	0.000

Table M.2: Standard deviation of 3D matrix for days, for critical period, where day 188 represents the 7th of July and 263 the 20th of September

Day	Occ.	Occ. with Helicopters	Burned Area	Deployments	Helicopter flights	Distinct Helicopters	Helicopters in Base
188	13.280	2.299	16.323	35.644	1.961	0.471	0.471
189	9.933	1.973	50.293	29.730	1.912	0.572	0.572
190	7.882	2.004	2354.646	34.552	1.332	0.530	0.530
191	6.675	1.748	112.945	34.168	1.772	0.550	0.550
192	5.490	0.941	1.883	29.069	1.136	0.547	0.547
193	5.022	1.105	25.585	17.767	1.105	0.505	0.505
194	3.335	0.645	1.477	10.413	0.778	0.530	0.530
195	5.184	1.394	21.316	20.925	1.332	0.553	0.553
196	5.058	1.219	8.517	14.293	1.245	0.530	0.530
197	5.181	1.579	2.616	15.688	1.120	0.561	0.561
198	5.283	1.918	8.526	19.364	1.285	0.490	0.490
199	3.960	1.276	15.947	16.051	1.294	0.631	0.631
200	4.769	1.125	3.222	19.377	1.187	0.558	0.558

Table M.2: Standard deviation of 3D matrix for days, for critical period, where day 188 represents the 7th of July and 263 the 20th of September

Day	Occ.	Occ. with Helicopters	Burned Area	Deployments	Helicopter flights	Distinct Helicopters	Helicopters in Base
201	8.226	1.804	30.861	24.291	1.382	0.591	0.591
202	6.437	1.362	9.674	21.423	1.287	0.558	0.558
203	5.399	1.282	11.634	26.833	1.421	0.539	0.539
204	6.731	1.214	18.846	25.880	1.150	0.482	0.482
205	8.220	1.964	10.268	28.449	1.576	0.553	0.553
206	4.931	1.442	13.715	15.033	1.150	0.547	0.547
207	5.206	1.450	8.183	19.992	1.272	0.558	0.558
208	4.397	0.809	2.606	11.156	1.003	0.553	0.553
209	2.523	0.378	0.557	6.769	0.382	0.382	0.382
210	3.212	0.632	7.592	15.653	0.651	0.471	0.471
211	4.111	1.076	53.036	27.488	1.052	0.562	0.562
212	4.123	1.228	24.119	16.977	0.891	0.514	0.514
213	4.900	1.638	288.611	31.375	1.323	0.583	0.583
214	5.244	1.214	1.782	19.805	1.413	0.561	0.561
215	5.430	1.554	2.746	17.561	1.442	0.505	0.505
216	7.031	2.462	6.676	25.181	2.028	0.561	0.561
217	4.602	1.546	1.620	18.657	1.294	0.490	0.490
218	5.246	1.339	3.591	18.026	1.200	0.497	0.497
219	5.209	0.770	2.949	17.187	0.702	0.497	0.497
220	6.180	1.410	89.617	22.227	1.208	0.482	0.482
221	12.053	2.708	12.548	43.777	1.999	0.547	0.547
222	12.296	2.730	54.048	58.212	2.628	0.514	0.514
223	15.295	2.994	547.219	64.397	2.526	0.601	0.601
224	10.837	2.177	294.697	52.628	2.774	0.591	0.591
225	14.148	4.604	90.171	53.122	3.322	0.514	0.514
226	15.787	2.649	70.571	62.971	2.683	0.632	0.632
227	14.298	2.620	303.354	57.942	2.242	0.539	0.539
228	6.133	1.339	76.430	30.541	1.859	0.690	0.690
229	9.073	2.352	75.836	38.684	1.907	0.542	0.542
230	8.874	2.768	20.563	29.203	2.576	0.591	0.591
231	11.693	2.994	256.888	45.952	3.338	0.583	0.583
232	17.433	4.077	353.585	75.583	3.518	0.482	0.482
233	13.772	2.713	1045.417	62.880	2.971	0.514	0.514
234	11.280	2.158	767.464	52.599	2.651	0.632	0.632

Table M.2: Standard deviation of 3D matrix for days, for critical period, where day 188 represents the 7th of July and 263 the 20th of September

Day	Occ.	Occ. with Helicopters	Burned Area	Deployments	Helicopter flights	Distinct Helicopters	Helicopters in Base
235	10.792	1.670	560.125	57.268	1.871	0.420	0.420
236	11.225	2.773	433.397	53.521	2.729	0.514	0.514
237	18.641	2.602	331.091	75.136	3.264	0.514	0.514
238	16.227	3.039	132.636	63.280	3.443	0.539	0.539
239	20.701	3.130	861.928	71.735	3.554	0.632	0.632
240	18.508	3.285	1251.610	73.798	3.169	0.612	0.612
241	23.741	2.693	626.888	87.119	2.945	0.583	0.583
242	16.367	2.412	278.952	71.037	2.571	0.664	0.664
243	15.408	2.254	406.823	52.981	2.875	0.612	0.612
244	22.283	3.581	221.291	94.391	3.098	0.507	0.507
245	17.973	3.045	266.757	76.029	3.052	0.531	0.531
246	15.996	2.259	151.565	64.930	2.548	0.568	0.568
247	14.893	2.285	158.534	56.070	2.442	0.632	0.632
248	3.112	0.841	7.758	13.030	0.658	0.497	0.497
249	3.631	0.910	3.536	13.489	0.817	0.553	0.553
250	4.684	1.422	20.899	20.205	1.853	0.558	0.558
251	5.775	1.687	3.181	18.150	1.862	0.598	0.598
252	4.723	1.900	9.447	22.361	1.900	0.604	0.604
253	5.699	2.054	46.828	18.851	1.883	0.547	0.547
254	10.335	2.856	67.568	45.738	2.644	0.572	0.572
255	12.191	2.678	8.312	45.123	2.582	0.572	0.572
256	12.049	2.933	217.810	49.809	2.564	0.572	0.572
257	10.599	2.449	94.553	46.838	2.624	0.583	0.583
258	8.545	2.042	25.987	28.525	1.754	0.611	0.611
259	8.323	2.046	113.019	37.374	2.336	0.622	0.622
260	9.546	2.009	53.515	45.683	2.471	0.591	0.591
261	10.651	2.118	41.687	46.843	2.479	0.598	0.598
262	9.845	3.102	38.632	40.818	3.234	0.651	0.651
263	12.663	3.156	12.561	49.473	2.763	0.583	0.583