DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

APPLICATIONS OF MANAGEMENT ENGINEERING FOR DISASTER MANAGEMENT IN TURKEY

by
Yunus Emre ERGENÇ

June, 2015
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APPLICATIONS OF MANAGEMENT ENGINEERING FOR DISASTER MANAGEMENT IN TURKEY

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of Science
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by

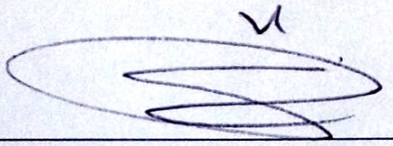
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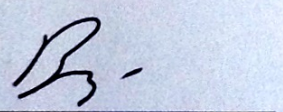
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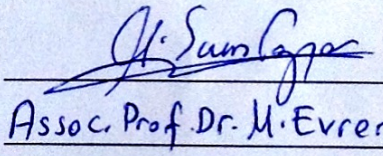
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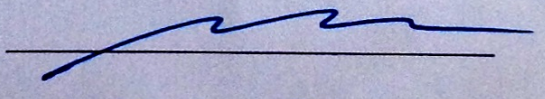
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APPLICATIONS OF MANAGEMENT ENGINEERING FOR DISASTER MANAGEMENT IN TURKEY

ABSTRACT

Disasters have continuously affected our community since our existence. As a result, disaster management started to play an important role in the livelihood of our community. Disaster management process contains four phrases; i.e. mitigation, preparedness, response and recovery. These stages are not clearly separable from each other but they are useful to analyze in order to plan our activities.

Among disasters, the primary focus of this study is forest fire initial response coordination (FFIRC). Initiating firefighting activities on time, especially arrival of fire water tender and ground team onto fire areas in critical response time is crucial for effective fighting against forest fires. Turkey suffers from forest fires which cause the loss of forest fauna, products and living organisms. Every forest fire causes losses in terms of scientific and environmental value as well as financial losses. In 2003, 2,177 fire cases occurred in Turkey, and 6,644 hectare forests were burnt. As a result, total loss was 21,883,721 TL. Therefore, the effective FFIRC plays a vital part in the formation of forest fires response plan.

In this study, a heuristic model is proposed in order to coordinate responses needed to suppress the forest fires in Turkey. The system is applied to potential forest fire zones by considering 9 Regional Forest Directorates and 14 airports in Turkey. Additionally, Network Analyst toolbox under ArcGIS program is used to determine optimum route that minimize arrival time to forest fires. This study investigates the large-scale forest fires occurred in Turkey. It can be clearly stated that the future losses can be minimized by using the effective FFIRC heuristic proposed in this study.

Keywords: Disaster management, forest fire, management engineering, response coordination

TÜRKİYEDE AFET YÖNETİMİ İÇİN MÜHENDİSLİK YÖNETİMİ UYGULAMALARI

ÖZ

Afetler sürekli olarak toplumumuzu tehdit etmektedir. Bunun sonucunda, toplumun geçimini sağlamasının üzerinde önemli bir rol oynamaya başlamıştır. Afet yönetimi dört aşamalı bir süreçtir. Bunlar sırasıyla hafifletme, hazırlık, müdahale ve iyileştirme çalışmalarıdır. Bu aşamaları birbirlerinden kesin çizgilerle ayırmak mümkün olmasada, literature çalışmasında ve faaliyetlerimizi planlamak için yararlıdır.

Bu çalışmada afetler arasından öncelikli olarak orman yangınına ilk müdahale koordinasyonuna (OYİMK) odaklanılmıştır. Orman yangınları ile etkin müdahalede yangın söndürme aktivitelerinin zamanında başlatılması ve özellikle arazöz ve yer ekibinin yangın sahasına en kısa sürede ulaşması büyük önem taşımaktadır. Türkiye, orman faunasının ve orman ürünlerinin kaybına sebep olan yangınlarından zarar görmektedir. Her orman yangını finansal değer kaybının yanında bilimsel ve çevresel zarara sebep olmaktadır. 2003'de meydana gelen 2.177 orman yangınında 6.644 hektar alan yanmış ve toplam finansal kayıp 21.883.721 TL olmuştur. Bu yüzden etkili bir OYİMK orman yangını ile mücadelede etkili bir rol oynayacaktır.

Bu çalışmada, Türkiye'de orman yangınlarını söndürmek için gerekli müdahaleyi koordine etmek amacıyla sezgisel bir model önerilmiştir. Sistem, Türkiye'de 9 Orman Bölge Müdürlüğü ve 14 Havalimanı dikkate alınarak potansiyel orman yangını bölgeleri için uygulanmıştır. Ayrıca, ArcGIS programı kapsamında Ağ Analizi modülü, araçların orman yangınlarına varış süresini en aza indiren optimum rotayı belirlemek için kullanılmıştır. Bu çalışma Türkiye'de meydana gelen büyük ölçekli orman yangınlarını incelemektedir. Bu çalışmada önerilen etkili OYİMK ile gelecekte orman yangınları sebebiyle meydana gelecebilecek kayıpların minimize edilebilir.

Anahtar kelimeler: Afet yönetimi, orman yangını, mühendislik yönetimi, müdahale koordinasyonu

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CHAPTER ONE
INTRODUCTION

Disasters tend to exist in a continuum and no nations, regardless of its wealth or improvements of their technology, fully affected from disasters' negative effects. Governments and societies have made many attempts to decrease their damage to the consequences of these disasters, developing measures to address impact, as well as post-disaster response and recovery needs. Regardless of the approach adopted, all of these efforts have the same goal: disaster management.

Disaster management is a repetitive process. It called disaster management cycle. For all of these reasons, government and societies should organize and plan their activities in disaster management cycle. Disaster management cycle divides into four phases: mitigation, preparedness, response and recovery. Response phase has gained importance in academic interest. According to Altay & Green (2006) who reviewed operations research and the management science research in disaster operation management, there is a need of research in this area and the 27% of the last published articles is related to response phase of the disaster management cycle.

Based on data from The International Emergency Disaster Database (EM-DAT) Turkey Profile (n.d.), estimated damaged caused by disasters between the years 2000 – 2015 are about $2,907,000 in Turkey. Disasters not only cause economic damages, but also affect human life. On average, 54,646 people are affected per year by disasters and the average death per disaster was 92 in Turkey.

Turkey is under threat of natural and human made forest fire. Indeed, socio-economic and natural conditions of Turkey cause this disaster. Especially, these disasters happen in coniferous forest in Turkey's Mediterranean and Aegean region along 5-6 months. In this context, forest fire happened 1978 times in Turkey between the years 1970 – 2012. At that time these records were confirmed as the highest number of natural disasters. Accordingly, 269 disaster as maximum number occurred in Antalya. In these forest fires, 283 people died, 90 people were injured and 964 people were influenced (Özşahin, 2013).

Successful forest fire management is partly about enabling authorities to react quickly and with certainty that resources consumed in a rescue will be recouped. Computer assisted methods such as network analysis have been widely used in solving the disaster management problems and requiring the determination of the shortest path.

This thesis focuses on one of the most important aspect of the wildfire response phase: initial response (e.g. fire water – tender, manpower, firefighting airplane and helicopter) in fixed regional forest directorates and airports.

The motivation for this thesis dates back from 1994 – 2006 when the government of Turkey faced its major 39 wildfire (Akkaş et al., 2008). The main cause of the human – made forest fires is arson and its rate is 2.9% in recognized cause in 2009 (Orman Genel Müdürlüğü, n.d.). This type of forest fires often occurs simultaneously in different regions. This thesis investigates the initial response one forest fire and at most three simultaneous forest fires. Land team (vehicles and manpower) have to reach the disasters in minimum time. For this purpose, a network model is produced in ArcGIS based on the real road map of Turkey. The network model is aimed at generating optimal routes for minimizing the initial response time from regional forest directorates to the forest fires under ArcGIS by taking into account the road speeds which is determined by the general directorate of highways of Turkey. Heuristic model generate a forest fire initial response plan by taken into account meteorological conditions (humidity, wind speed and temperature) of 39 forest fires, minimum time to reach the fires from the 9 regional forest directorates and prior areas where are in Eagan Coast especially in a peninsula and also the Taurus Mountains especially in a valley.

The remainder of this thesis is organized as follows. Chapter Two defines what disaster management is and presents a literature review related to the disaster management. In Chapter Three, overview of the forest fires is given: how the forest fires occur and what are the elements and types of forest fires are. Literature review related to the forest fires are expressed based on forest fire response. In Chapter Four, classifications of the forest fires, which are determined by the Ministry of Forestry of Turkey, are presented. Detailed information of major 39 historical forest

fires is given. Case studies are presented in Chapter Five. Finally, concluding remarks are presented in Chapter Six.

CHAPTER TWO
DISASTER MANAGEMENT

Disaster management defined as the organization and management of resources and responsibilities for dealing with all humanitarian aspects of emergencies, in particular, mitigation, preparedness, response and recovery in order to lessen the impact of disasters (International Federation of Red Cross and Red Crescent Societies, n.d.). We need to define what "a disaster is an unusual event that causes large-scale damage, loss, disruption, injury, and loss of life" (Sawalha, Jraisat, & Al-Qudah, 2013).

Agustrihardaning (2014) pointed out that disasters have two fundamental types: natural disasters and human – made disasters. The phases of all disasters, be it natural or human – made, are the same, but often differ in quantity of damage or quality of the type of medical consequences. Natural disasters, which are earthquake, tsunami, floods, landslides and so forth, affect human activities. Human – made disasters are directly caused by human activities that are nuclear power plant and nuclear blast, chemical threat and biological weapon, terrorist attack.

According to the Red Cross Societies, disaster arises from a "combination of hazards, vulnerability and inability to reduce the potential negative consequences of risk" (Chen, 2011). They have expressed the disaster in a formulation.

$$Disaster = \frac{Hazard + Vulnerability}{Capacity} \tag{2.1}$$

The fraction on the right side of the Equation (2.1) describes disaster as an inverse relationship between hazard plus social vulnerability and the responsive capacity of human institutions (Chen, 2011). Hazards can be defined as natural and human – made. Capacity is a combination of community, society strength, which can cope with the effects of the disasters (Thywissen, 2006). However, vulnerability is defined in terms of three physical and socio-economic variables: exposure, sensitivity, and adaptive capacity. Exposure is the frequency of an event, which is considered as a physical factor. It is a risk measure directly related to the proximity and the environmental characteristics of a particular place. Sensitivity is the magnitude of an

event in relation to human response, which can be considered a combination of physical and socio-economic factors. It reflects the degree to which people and place can be harmed. Adaptive capacity is the ability of the people or a system to easily and quickly cope with the impact of a disaster. Adaptive capacity is considered to be primarily a socio-economic factor. All these factors are vital variables that determine the level of vulnerability of a given population or a place (Paul, 2011).

The evaluation of the risk is the combination of the probability of an event occurrence (hazard) and its consequences (vulnerability). It widely agrees that these two concepts are used to assess natural risks (Blanchi, Jappiot, & Alexandrian, 2002). Equation (2.2) describes risk as:

$$Risk = Likehood\ of\ Hazard\ Occurence * Consequence \tag{2.2}$$

The likelihood is expressed either as a probability (e.g., 20%) or a frequency (e.g., in 5 years) of occurrence of a disaster, whichever is appropriate for the analysis being considered. The consequence is a measure of the effect of the hazard on humans and built and natural environments. It is expressed as a combination of three factors: expected loss of lives, expected number of people injured and expected damage. For instance event likelihood could be expressed as follows:

- Absolute: >99% chance of occurring in a given year (1 or more occurrences per year)
- Likely: 50–99% chance of occurring in a given year (1 occurrence every 1–2 years)
- Possible: 5–49% chance of occurring in a given year (1 occurrence every 2–20 years)
- Unlikely: 2–5% chance of occurring in a given year (1 occurrence every 20–50 years)
- Rare: 1–2% chance of occurring in a given year (1 occurrence every 50–100 years)
- Extremely rare:<1% chance of occurring in a given year (1 occurrence every 100 or more years) (Coppola, 2006).

Equation (2.2) can be regenerated replacing the vulnerability instead of the consequence. Thus, Equation (2.3) describe risk is as:

$$Risk = Hazard\ Probability * Vulnerability \quad (2.3)$$

Pelling, Maskrey, Ruiz, & Hall (2004) examine the risk as a function of hazard occurrence, population, and vulnerability in equation (2.4).

$$Risk = f\{(Hazard\ Occurence\ Probability)(Population)(Vulnerability\ )\} \quad (2.4)$$

If affected population was zero, the risk was null. Same result acquired if the vulnerability of population is zero.

However, Thywissen (2006) determined the risk as a function of hazard, vulnerability, exposure and resilience in Equation (2.5). Resilience defined recovery time of the system. If the value of any component is zero, the risk is zero (See Figure 2.1).

$$Risk = f\{(Hazard)(Vulnerability)(Exposure)(Resilince)\} \quad (2.5)$$



Figure 2.1 Components of risk

2.1 Disaster Management Cycle

Disasters as repetitive events, disaster management from a cycle that can be divided into four phases: mitigation, preparedness, response, and recovery. In the disaster management cycle, the end of one phase is the beginning of another phase. Disaster management tends to exist in a continuous process (Hidayat & Egbu, 2010).

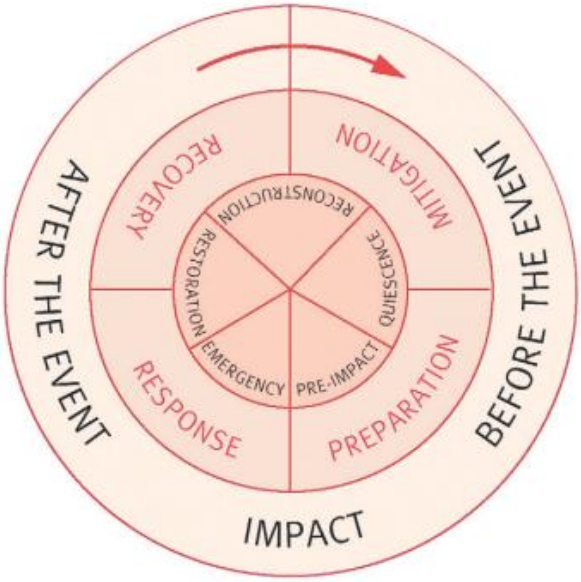


Figure 2.2 Disaster management cycle

Figure 2.2 shows that first two phases (mitigation and preparedness) transpire before an extreme natural event occurs, while the last two (response and recovery) take place after an event. Although there are several versions of the diagram illustrating the cyclic nature of activities undertaken in each phase, all activities seek to reduce potential fatalities and injuries, property losses, assure prompt assistant to victims, or achieve rapid and effective disaster recovery (Paul, 2011).

Mitigation and preparation phases occur before disaster strikes. Mitigation is all activities planned to reduce the impact of future disasters; these activities usually divided into two categories: structural mitigation and non-structural mitigation. Structural mitigations are engineering solutions, and non-structural mitigations include land-use planning, insurance, legislation and evacuation planning

Preparedness is activities designed to reduce the impact of disasters when they are forecasted (Hidayat & Egbu, 2010). Among many activities, preparedness includes such activities as formulating, testing and exercising disaster plans, providing hazard warnings, communicating with the public and others regarding disaster vulnerability and what to do to reduce it, evacuating people from harm ways, conducting emergency response drills, and providing disaster training for emergency responders and the general public (Paul, 2011).

Response and recovery phases occur after disaster strikes. Response refers to all actions taken immediately before, during, and after a disaster to save lives, minimize damage to property, and enhance the effectiveness of recovery at the shortest possible time. It is generally more narrowly defined to mean only the immediate actions (e.g., search and rescue operations for survivors, emergency medical care for the injured including mental health counseling, the proper identification and disposition of dead bodies, provision of temporary shelter, water, sanitation and food, repair utilities and key infrastructure, security for victims, protection of property, closure of roads and bridges, and attending to secondary hazards such as fire in the case of earthquake) taken immediately after a disaster at various levels, such as individual, household, community, national, and international. Similar to inadequate and poor response, delayed response to an extreme event is also undesirable. Disaster experts maintain that the first 72 hours after a natural disaster are the most important, during which prompt mobilization of emergency resources can save many lives. A plethora of private, public, humanitarian and nonprofit organizations, and individuals from both affected and non-affected areas are involved in most major disaster responses. The number of organizations and individuals involved in response operations largely depends on the scale of the disaster. Irrespective of the scale, the neighbors and neighboring communities are generally first to respond (Paul, 2011).

Disaster recovery is the emergency management function by which countries, communities, families, and individual repair, reconstruct, or regain what has been lost as a result of a disaster and, ideally, reduce the risk of similar catastrophes in the future. In a comprehensive emergency management system, which includes pre-disaster planning, mitigation, and preparedness actions, recovery actions may begin

as early as during the planning processes and activities, long before a disaster occurs. Once the disaster strikes, planned and unplanned recovery actions are implemented and may extend for weeks, months, or even years (Coppola, 2006).

2.2 Literature Review Related to Disaster Management

In this chapter, articles are sorted out and examined according to the phases of disaster management cycle. These four phases are not expressly separable from each other, but useful to analyze the literature review and to plan disaster management activities (Paul, 2011).

2.2.1 Mitigation Phase

In the mitigation phase, risk assessment and statistical analysis play an important role in literature. Coles & Pericchi (2003) implemented Bayesian model for estimating the probability of the extreme level of rainfall in Venezuela. Additionally, Hsieh (2004) forecasted the next catastrophe loss. They carried out four steps: data normalization, Pareto assumption, selection of parameters and computation of predictive moment respectively. If the issue associated with computationally intensive, they suggested using other prior distribution beside the Bayesian analysis. Leung, Santos & Haimes (2003) discussed risk analysis framework to guide the management of risks in future volcanic activities. They integrated meteorological, hydrological, and sediment logical perspectives into a decision-making process. The process employed hierarchical holographic modeling and statistical analysis. Results solved with surrogate worth trade-off method and multi-objective risk impact. Data fusion can be used to efficiently organize and interpret massive amounts of data flowing from the disaster-affected area to emergency response centers when data is varied and alignment is required (Lin, Batta, Rogerson, Blatt, & Flanigan, 2011). Jotshi, Gong & Batta (2009) used data fusion that potentially can be implemented in disaster mitigation. They studied the ambulance routing problem considering traffic dynamics and damaged roads aftermath of the disaster. Tingsanchali (2012) took into account flood risk map that combine flood hazard map and flood vulnerability map in GIS (Geographical Based System) application to prepare a disaster management plan.

2.2.2 Preparedness Phase

Literature related to preparedness mostly consists of interviews and statistical evaluation of these interviews. Miceli, Sotgiu & Settanni (2008) interviewed with 400 people live in an alpine valley about risk perception of the flood and landslide. The results were practiced with correlation and regression analyses. The regression analysis showed that there were not a significant relation between likelihood judgments and adoption of protective behaviors, while feelings of worry were associated with disaster preparedness. Businesses that located in hazard areas, for providing their continuity, have to assess their structural vulnerability, and evaluate their needs for emergency response after different types (hurricanes, earthquakes, floods) and intensities of environmental disasters (Zhang, Lindell & Prater, 2004). In Howe (2011)'s web-based research, 30 percent of the business has emergency plan and 50 percent of the business in Florida had business continuity plans and they found that risk communication explain business action thus they can decrease their vulnerability. After the September 11th terrorist attack, many companies (UPS, Boeing, Toyota, USPS, General Motors, Ford, and Oracle) have wanted to enhance their knowledge how to deal with a disaster. Hale & Moberg (2005) established a network of secure storage fatalities. Seven supply chain facilities for seven cities can get served at least 50 miles away that represented in a GIS-Based program with circles. They solve the problem, adding three emergency resource locations while minimizing the total cost. This plan used in September 2009 cyclones, officials utilized for finding solutions to the problems and identifying possible evacuation centers. . In addition, 3D Mapping that based on topographic and GIS applied to risk assessment and disaster risk reduction in Masantol, Philippines (Cadag & Gaillard, 2012).

2.2.3 Response Phase

The basic philosophy of an emergency response agency is to respond as quickly as possible to minimize the loss of life and property damage (Subramaniam, Ali, & Shamsudin, 2012a). Subramaniam, Ali & Shamsudin (2012b) analyze the influence of firefighter physical ability on fire response performance. Disaster response effectiveness and efficiency depend on cost, procurement and resource planning.

Kelly (1995) proposed a disaster management framework. He asserted that modifying and updating response plans are much crucial operation for disaster management.

In response phase, it is hard to make a decision in less time and information is not dependable. Several methods have been employed to response disasters, simulation modeling and scheduling have good performance in different disasters. Abounacer, Rekik & Renaud (2014) studied complex three-objective location-transportation problem in disaster response operations. They offered an epsilon-constraint method to generate an exact Pareto frontier of a complex three objective location-transportation problem. The first objective minimizes the total transportation duration. The second minimizes the number of agents. The third objective minimizes the unsatisfied demand. Singhtaun (2015) proposed a mathematical model and branch and bound algorithm to solve problem sized three candidate locations with five demand points and one candidate locations with up to twenty demand points. Fiedrich, Gehbauer & Rickers (2000) investigated an optimized resource schedule assigning limited resource and time to minimize the total fatalities. First three days after an earthquake, have an essential role in search and rescue area. High priority search and rescue area, stabilize work and rehabilitation of transportation. They solved the problem with heuristic solution method.

Monitoring and evaluation of implemented measures enable the identification of best practices under the specific circumstances (Tingsanchali, 2012). Zou, Yeh, Chang, Marquess & Zezeski (2005) developed a simulation-based system for evacuation planning in Maryland during a hurricane. They performed six evacuation plans from the flood area to the selected safety location. Liu, Lai & Chang (2006) proposed a bi-level optimization model. The high level model aims to maximize the total throughput. The low level minimizes the total trip time. They offered the genetic algorithm to solve the case study of the Maryland evacuation. Zhang & Chang (2014) was formulated as an integer linear programming and implement to picking up evacuees by a rescue bus that transports them from an evacuation area to the safety area predetermined.

Lin, Batta, Rogerson, Blatt & Flanigan (2011) implied multi-objective integer programming model and two heuristic approaches for routing problem. The first approach is genetic algorithm. The second approach is decomposition and assignment heuristic approach. The model implied multiple nodes geographically dispersed which served by single depot. Hamedi, Haghani & Yang (2012) modeled routing and scheduling of humanitarian supply. The transportation is formulated as a mathematical model and adopted genetic algorithm model to find the shortest path. Chung, Chou & Lee (2012) proposed a multi-objective dynamic length genetic algorithm to solve the disaster response problem. The model defines the optimal routes for the limited number of rescuing vehicles within limited time periods. Saadatseresht, Mansourian & Taleai (2009) used three stages to solve evacuation problem. The first stage is safe area designation. The second stage is optimum path finding. In the third stage, to select the optimal safe area, they used NSGA-II, multiobjective optimization, and Pareto front optimization methods.

There have been numerous papers discussing humanitarian aid. Demand of humanitarian aid is classified into two types: first type occurs once at the beginning of the disasters, for instance: tents, blankets, tarpaulins, jerry cans, second type is periodical demands such as water, food, medical goods (Balcik, Beamon, & Smilowitz, 2008). Berkoune, Renaud, Rekik & Ruiz (2012) developed a genetic algorithm and performed in three distribution centers and 60 delivery points which need humanitarian aid. The model has been useful, especially for the first hours after a disaster. Ruan, Wang & Shi (2014) modeled helicopters and vehicles intermodal transportation problem for temporary distribution centers and its covered medial aid points. In the first stage is proposed fuzzy-based method which selects temporary distribution centers and their medical aid points. In the second stage is developed an integer-programming model to arrange the delivery routes between temporary distribution centers and medical aid points. Huang, Jiang, Yuan & Zhao (2015) offered a multi-objective optimization model that combines life-saving utilities and delay cost -shortest travel time- and demand equality. They introduced a delay cost to reflect the time urgency and calculated human suffering due to the delaying. Barzinpour, Saffarian, Makoui & Teimoury (2014) offered a model follows two main objectives. The first one is minimizing the total good distribution cost. The second

one, which compares simulated annealing algorithm and genetic algorithm results, is justice rate of the satisfaction in good distribution process. Christie & Levary (1998) developed and discussed multi-server queuing simulation for transportation of highly injured patient to the hospital.

In humanitarian aid operations, vehicle routing decisions are critically important. A large neighborhood search metaheuristic was offered to solve the ambulance routing problem for a large number of injured people, which are slightly and seriously injured patients, require medical aid at the same time (Talarico, Meisel, & Sörensen, 2015). Huang, Smilowitz & Balcik (2012) reached same results using route-length restricted optimal solution for three types of objective function that are service time, total travel time for selected routes and sufficiency of deliveries. They found different route for a different solution. Musolino, Polimeni, Rindone & Vitetta (2013) designed routes of emergency vehicles. The object of the dynamic vehicle routing model minimizes the total travel cost using the shortest path based on maps of Melito di Porto Salvo, Italy. Rennemo, Rø, Hvattum & Tirado (2014) proposed three-stage mixed-integer stochastic programming model. The first stage determines vehicle capacity and total demand, the second stage generates initial route, and the third stage dispatches the vehicles.

Every disaster is unique -even the same type of disaster in the same region can present different challenges- and every relief organization has its own set of practices and policies (De la Torre, Dolinskaya, & Smilowitz, 2012). Yi & Kumar (2007) implied ant colony optimization to minimize the total amount of unsatisfied demand. Sheu (2007) described a model that responding to the urgent demand. Fuzzy clustering and multi-objective dynamic programming models were performed for initial three-day. Hentenryck, Bent & Coffrin (2010) implemented multi-stage stochastic hybrid optimization algorithm for the single commodity allocation problem. The paper shows 16% decrease in expected maximum delivery time. Sherali, Desai & Glickman (2004) developed a model that solves the disaster problem via the branch-and-bound algorithm. The model decides the number of responder teams, which consist of police, firefighters, rescue teams, medical teams, sent to commercial and residential area and its object is to distribute the teams

equally. Campbell, Vandenbussche & Hermann (2008) proved bounds on arrival times, minimizing the maximum arrival time of supplies and minimizing the maximum arrival time of supplies instead of the total cost of travels. They use two methods to compare arrival times. The first method is to measure the inequity in the arrival times and the second is to respect to the other objective functions.

2.2.4 Recovery Phase

The recovery phase starts after relief phase. It may last five years, depend on the magnitude of the disaster (Shaw, 2006). In Altay & Green (2006) literature survey, the 11% of the last published articles are related to disaster. Nikolopoulos & Tzanetis (2003) analyzed flow of the homeless population to a temporary state by solving a non-linear system. They put into practice a case study concerning the earthquake of September 1999 in Athens, Greece. They separated people after the quake into three different categories. Chang & Nojima (2001) evaluated total system performance in the urban rail and highway transportation system in the Kobe, Japan after 1995 earthquake. In a post-disaster situation, one of the system performance measures consisted of total travel time overall system links. This system performance also affected the reconstruction period. They compared these results between Loma Priate earthquake in the USA in 1989, Northridge earthquake in the USA in 1994 and Hyogonken - Nanbu earthquake in Japan in 1995.

Disasters often cost our societies a lot more than we expect. During the last decade, disasters caused an average damage bill of approximate $67 billion every year (Yi & Yang, 2014). The deterministic road rehabilitation implemented in many cases to minimize time restoration after a catastrophe. Özdamar, Tüzün Aksu, & Ergüneş, (2014) proposed a model to maximize network accessibility and reduce travel times by cleaning up the road between locations affected by the disaster. Günneç & Salman (2011) performed probabilistic network reliability in case of damaged urban highway network of Istanbul affected by the earthquake. Chen & Tzeng (2000) asserted a simulation model that constructs again the damaged road. The goal is to minimize the travel time and total working time with limitless number of working groups. Orabi, El-Rayes, Senouci, & Al-Derham (2009) developed a model optimizes the reconstruction efforts to minimize costs and performance loss.

Emergency rehabilitation begins right after the quake and ends 72 hours because after 72 hours people survival chance reduces dramatically. Feng & Wang (2003) used Taiwan Chi – Chi earthquake as a case study to develop a multiobjective programming model. The model has limited resource -dozers, vehicle, manpower- and three objects are to maximize total length of road, to maximize the number of rescued people and to minimize the risk of work teams.

CHAPTER THREE
FOREST FIRES

Forest fires in the disaster area include damage of the forest's products and loss of objects of scientific, economic, or environmental value (Agustrihardaning, 2014).The three elements are need to reveal the fire. They are shown in a triangle. The triangle has three sides that show oxygen, heat, and fuel. If any element can be taken away, fire goes out or does not start. A fire sustain to burn at least. It needs 16% oxygen. Fuel is any capable of burning material (Fire behavior basics, n.d.) (See Figure 3.1).

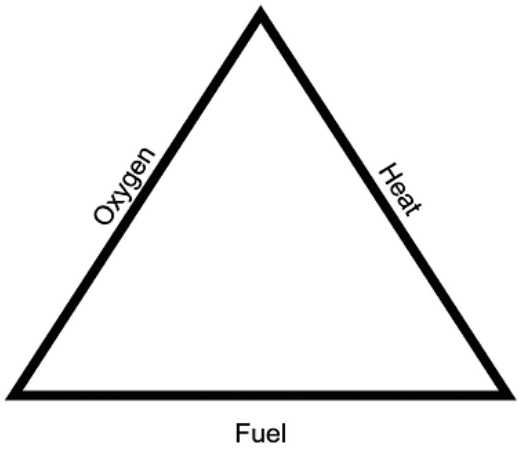


Figure 3.1 Fire triangle

3.1 Types of Forest Fire

Forest fire divide into three groups: ground fires, surface fires, and crown fires

- Ground fires: Fires that may not appear on the surface but it burns humus. There is no easy way to notice these fires because slash piles allow smoldering for weeks and months under the ground. In the fire season, spotter cannot define these fires. In order to prevent these types of fires, a tractor with brush blade clean slashes piles at regular intervals (See Figure 3.2).

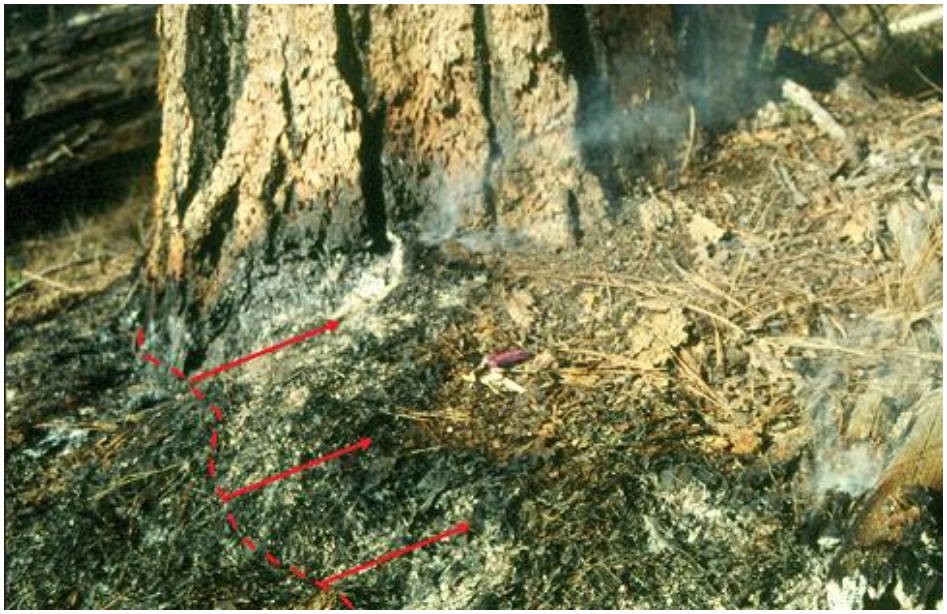


Figure 3.2 Ground fire (arrows point the smoldering duff layer)

- Surface fires: fires on the ground. Life litter, fallen branches, and felled trees cause to diffuse long distance. High-severity surface fires kill most trees (more than 70%) (Fire behavior basics, n.d.) (See Figure 3.3).



Figure 3.3 Surface fire

- Crown fires: fires occur on the top of the trees that has known crown. These fires are most intense but to continue, need strong winds. Crown fires become

active when enough heat is released to preheat and combust fuel above the surface, followed by active spreading of fires from one tree crown to the next through the canopy. Crown fires are usually intense and are strongly influenced by wind, topography, and tree (crown) density (Fire behavior basics, n.d.) (See Figure 3.4).



Figure 3.4 Active crown fire

Fire behavior triangle means its rate of spread (in m/s) and its intensity (that is, how hot it burns and how long its flame is) (Fire behavior basics, n.d.). Its behavior depends on three factors: topography, weather condition, and fuel quantity (See Figure 3.5).

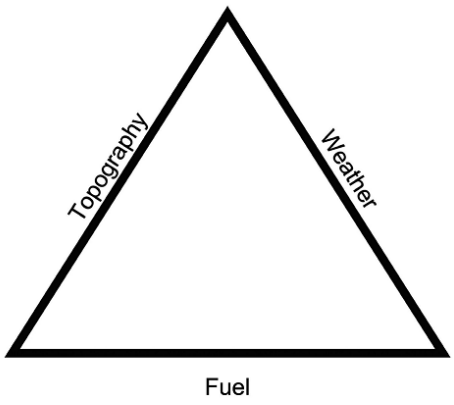


Figure 3.5 Fire behavior triangle

Few people realize that a fire seldom consumes all burnable material or scorches every square meter of the ground surface. Even the most extreme fires will create a patchy mosaic of burned and unburned areas, because of the variability of fire spread and flaming, fuel discontinuities, weather changes, and natural barriers. Fuel, weather determines combustion availability, and topographic factors included in Table 3.1. Thus, fire scientists and managers distinguish between fuel amount or quantity and fuel available for combustion when discussing the fire potential for an area. Fire managers focus particular attention on fuels because weather and topography are less easily manipulated (Omi, 2005).

Table 3.1 Indicators of a fire environment

Fuels	**Air mass**	**Topography**
Fuel moisture	Wind speed and direction	Slope Steepness
Vertical arrangement	Relative humidity	Slope position
Fuel loading	Precipitation	Aspect
Compactness	Temperature	Elevation
Size (i.e., the time lag) and shape	Atmospheric stability	Shape of Country
Horizontal continuity		Canyon shape
Chemistry		Canyon width
		Ridges
		Flat terrain

If a forest has less fuel, the future fires will be less intense. When a fire occurs, the ground of the fire returns their fuel of capacity in five – eight years period. For this reason, regularly planned burning problem implement forests. This rehabilitation project has refresh the forest and prevents high-intensity damage after a big fire (Wildland fire spread, n.d.).

Controlling the forest fires depend on early detection and interfere with scale number of firefighters (Barham, 1996). Effective planning to wildfire involves how to response the event with necessary resource, perceive changing of meteorological statement, and develop new response plans.

3.2 Literature Review Related to Response Planning in Forest Fires

Forest fires are an inseparable component of the ecosystems of the forests. Therefore, forest fires will continue to play a role in the future as in the past. It is supposed to accept the role of the fire and build the fire programs on this base.

Fiorucci, Gaetani, Minciardi, & Trasforini (2005) implied optimal relocation problem in Italian territory. The resources were water-bombers, heli-tanker, and a mix of single and light medium twins helicopter. Forest fire hazard assessment presented topography, meteorological forecast, vegetation data and real time information (Fiorucci, Gaetani, & Minciardi, 2004). The dynamic forest hazard model provided reliable information in order to relocate the resource. Figure 3.6 represents the dynamic forest hazard model.

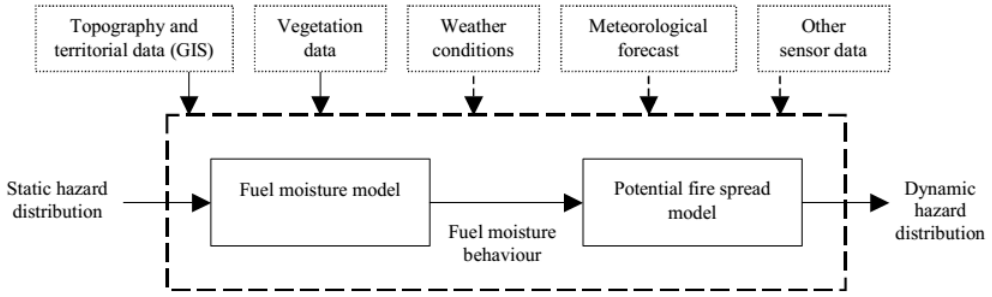


Figure 3.6 A schematic representation of the structure of the dynamic forest fire hazard assessment module

For many years, to achieve a quick and strong initial response to forest fire, the closest forces were used to select the suppression resources. Wiitala (1999) offered a deterministic dynamic programming model to find the economical initial attack to suppress the forest fire. Wiitala & Wilson (2004) developed a stochastic simulation model for forest fire preparedness planning. The model is designed to closely represent the dynamics of fire occurrence and suppression.

Initial attack is generally defined as the first 1−8 hours of fire suppression effort, during which the primary objective is containment of the fire at a small size in the shortest possible time. Examples of fire suppression resources used for initial attack

include fire engines, bulldozers, hand crews, and water-dropping helicopters (Lee, Fried, Albers, & Haight, 2013). Ntaimo, Arrubla, Stripling, Young, & Spencer (2014) modeled a two-stage stochastic integer programming standard response model for initial attack. They relocated the resource units based on the 30 minutes and 60 minutes maximum travel time restriction. Lee et al. (2013) developed a resource deployment decision model with three planning units in order to minimize the expected number of fires that do not receive a standard response, subject to budget and capacity constraints and uncertainty about the daily number and location of fires. Kirsch & Rideout (2005) offered an integer programming model for initial attack preparedness planning. Their model deploys initial attack resources. The objective is to maximize the weighted area protected for a given level of budget funding, using the performance measure of weights assigned based on protection priorities (Minas, Hearne, & Handmer, 2012). Donovan & Rideout (2003) proposed an integer programming model to determine the optimal mix of fire-fighting resources to dispatch to a given fire.

There have been numerous papers discussing air resource management. Greulich & O'Regan (1975) offered two models which select allocation area for initial air tanker attack: the first identifies initial attacks, the second selects attack within the constraint of budget level. Mees (1978) described a computer model for computing arrival times of firefighting resources for an initial attack on a fire. Finney (2002) described an approach as a search for the minimum time from fire to travel among nodes in a two-dimensional network. Haight & Fried (2007) formulated a scenario-based standard response model with two objective functions: the number of suppression resources deployed and the expected daily number of fires that do not receive a standard response, defined as the desired number of resources that can reach the fire within a specified response time. The authors used the budget as the main constraint as well as the uncertainty about the number, location and intensity of the fires (Mitsakis, Stamos, Grau, & Aifadopoulou, 2014). Greulich (2003) proposed spatial distribution that specified the expected flight distance from airtanker location to random fire ignition point. The model optimizes airbase location according to flight distance moments. Greulich (2005) designed a model which is determined variability of flight distance between random fire locations that is useful for

reallocating the air tanker resource between fires. These two articles address the determination of these flight distance parameters for randomly located points within polygonal regions (Greulich, 2008).

Other models have been designed to incorporate various aspects of wildfires into land management planning (Bettinger, 2009). Linear programming, binary search, simulation models, and heuristics have all been used to assess the impacts of wildfire on forest planning (Bettinger, 2010). Botti, Rideout, & Kirsch (2004) explained how program management and planning efforts can integrate fire use into the initial attack planning and budgeting. Minas, Hearne, & Martell (2013) offered an integer programming model for fuel management and the location of a resource (suppression preparedness decisions). Dimopoulou & Giannikos (2001) proposed a mathematical model (a generalized demand-covering model) for the location of fire-fighting resources. Models have been developed to represent graphically the optimal deployment of resources. Dimopoulou & Giannikos (2004) developed an integrated approach: static and dynamic model for forest fire control. The system consists of the following three components. GIS module is used to represent geographic information regarding the forest area. Mathematical module deploys the available firefighting resources in proper positions. The simulation module is used to experiment with alternative scenarios and to decide how the firefighting services should be reallocated according to the development of a particular fire.

Aktaş, Özaydın, Ülengin, Önsel, & Ağaran (2011) designed a model that organization of firefighters to access up to five minutes each zone and designed to be 100% of the coverage area in Istanbul. Location of New Fire stations determined by setting covering location model. Speed limit of highways, main arteries, streets was determined 80km/h, 50km/h and 20km/h, respectively by the Istanbul Fire Disaster Planning and Coordination Unit. An integer programming model was established for this purpose, the data obtained geographical information system was resolved. Akay & Şakar (2009) used same examination for from 6 fire operations center of regional forest directorate to 6 fire areas using ArcGIS in Kahramanmaraş. In order to perform effective response to forest fires, especially fires occurred in the first degree sensitive areas; first responders must reach in critical time (20 min.) the area due to

the higher possibility to control the fire. The area which can be reached by the first responders in 20 minutes and 40 minutes was determined. In addition, Network 2001 program was used in order to determine the optimum route that provided access to the fire area in the minimum time. In the study, potential forest fire areas were chosen from the place where forest fires occurred between the years 1999 – 2009 in Kahramanmaraş. They determined transport time from the first responders to the fire areas in the existing road network (Akay, Gesoğlu, & Gülci, 2014). Duff, Chong, & Tolhurs (2015) developed a network to determine the fastest travel routes and optimal travel times to reach the forest fire location. ArcGIS Network Analyst was used for vector network analysis. If the overland travel time were over 90 minutes, the aircraft would be used.

Based on the observations in the Akkaş et al. (2008)'s field study, the main progress of large-scale forest fires occurs in the first two hours. After this phase, while the helicopters, which are transferred to the zone, are cooling the sidelines more than the direction of the fire spread; lack of air force can occur in the other forest areas where aircrafts come and big areas can be lost because all available forces are sent to big fire zones when new fires occur. After the great fire grows economic cost increase because of the fact that the helicopters cannot reach the zone in time. Fiorucci, Gaetani, Minciardi, & Trasforini (2005) controlled the meteorological conditions then resource units relocated. In a similar manner, initial response forest fire is examined. First, a forest fire occurs. Its meteorological conditions (wind, humidity and temperature results) are evaluated. Its road haulage and access time are evaluated. Then its response plan is prepared.

As stated by Altay & Green (2006), there is a little research in response planning for disaster management. Hence, there is less research focusing on response planning for forest fires. Moreover, the related literature deals with experimental case and small size real world problems. This thesis focuses on filling the research gap in this area where we considered forest fire initial response planning using real geographical data, road network and weather conditions.

In literature, achieving a quick and strong response to forest fire is usually found in the forest fire response problems, because it concerns the shortest path and

suppression under the specific/determined time. For this purpose air and land resource management, allocation and transportation model was used frequently to suppress the forest fire. This thesis focuses on initial attack in the wildfire forest area. The contents in this study are arranged as follows: problem will be analyzed, then the initial attack heuristic model will be formulated, and finally a case study 39 large – scale forest fires will be conducted.

CHAPTER FOUR
FOREST FIRES IN TURKEY

Turkey with a surface area of approximately 80 million hectares has a rich diversity of mountain and eco-geography. Correspondingly ecological richness, its forest is rich in species and composition. Based on the between the years of 2005 – 2012 updated forest management plans, Turkey has 21,678,134 hectares of forested area. According to this determination, the forest covers 27.6% of the country's surface area in Table 4.1 (Orman Genel Müdürlüğü, 2014).

Table 4.1 Distribution of country of land use class between the years of 2005 – 2012 in Turkey

Land use	**Hectare**	**Percent**
Forest	21,678,134	27.6
Range	14,617,000	18.6
Water Areas	1,050,854	1.4
Agriculture	24,437,000	31.1
Others (treeless forest land, steppe, rocky-stony soils, sand .etc)	16,751,482	21.3
Total Area	**78,534,470**	**100**

Forest inventory studies had begun in 1963, between the years 1963 – 1972 forest inventory data were collected, and the forest management plans were published first in 1980. By the end of 2004, the reevaluated results have been shown to reach 21.2 million hectares of public forest areas. In this period composed forests covered 27.2% of the country field. A country must be covered with 30% of the productive forest to be self-sufficient in terms of forest land. As can be seen from Table 4.2, Turkey's forest areas in the last 30 years, despite of an increase of approximately 1.5 million ha, 49% of forests were found to be inefficient (Koç, 2010).

Special terms related to the forestry are defined below (Orman Genel Müdürlüğü, 2012).

- The forest land where tree canopy cover is between 11 – 100%.

- Degraded forest (Very low coverage): The forest land where tree canopy cover is less than 10%.
- High forest: Forest established through seeding (usually species which are expected to have a long maturity age and relatively high are chosen).
- Coppice forest: forest originating mainly from sprouts or root suckers rather than seed.

In Figure 4.1, productive forest and degraded forests represents respectively, as dark green and light green (Orman Genel Müdürlüğü, 2012).

Classified by the species type and Turkey forests covered, oaks (Quercus spp.) takes the lead with 13 species and 6,476,277 hectares, Calabrian pine (Pinus brutia) seconds oaks with 5,420,524 hectares followed by Anatolian black pine (Pinus nigra) with 4,202,298 hectares. Beeches (Fagus orientalis and F. sylvatica), Scotch pine (Pinus sylvestris) and firs (Abies nordmanniana and A. cilicica), also take up a considerable share in the country's overall forest resources (Terzioğlu, Bilgili, & Karaköse, 2012).

Table 4.2 Distribution of forest land 1973, 1999, 2005, 2009, 2010, 2012 in Turkey

Year	Forest Form	Total		Productive		Degraded	
		Hectare	%	Hectare	%	Hectare	%
	High Forest	10,934,607	54	6,176,899	31	4,757,708	23
	Coppice Forest	9,264,689	46	2,679,558	13	6,585,131	33
1973	**Total**	**20,199,296**	**100**	**8,856,457**	**44**	**11,342,839**	**56**
	High Forest	14,418,340	69	8,237,753	40	6,180,587	29
	Coppice Forest	6,344,908	31	1,789,815	9	4,555,093	22
1999	**Total**	**20,763,248**	**100**	**10,027,568**	**49**	**10,735,680**	**51**
	High Forest	15,439,595	73	8,940,215	42	6,499,380	31
	Coppice Forest	5,749,152	27	1,681,006	8	4,068,146	19
2005	**Total**	**21,188,747**	**100**	**10,621,221**	**50**	**10,657,526**	**50**
	High Forest	16,305,210	76	9,494,322	44	6,810,888	32
	Coppice Forest	5,084,573	24	1,478,187	7	3,606,386	17
2009	**Total**	**21,389,783**	**100**	**10,972,509**	**51**	**10,417,274**	**49**
	High Forest	16,662,379	77	9,782,513	45	6,879,866	32
	Coppice Forest	4,874,712	23	1,420,324	7	3,454,388	16
2010	**Total**	**21,537,091**	**100**	**11,202,837**	**52**	**10,334,254**	**48**
	High Forest	17,260,592	79	10,281,728	47	6,978,864	32
	Coppice Forest	4,417,542	21	1,276,940	6	3,140,602	15
2012	**Total**	**21,678,134**	**100**	**11,558,668**	**53**	**10,119,466**	**47**

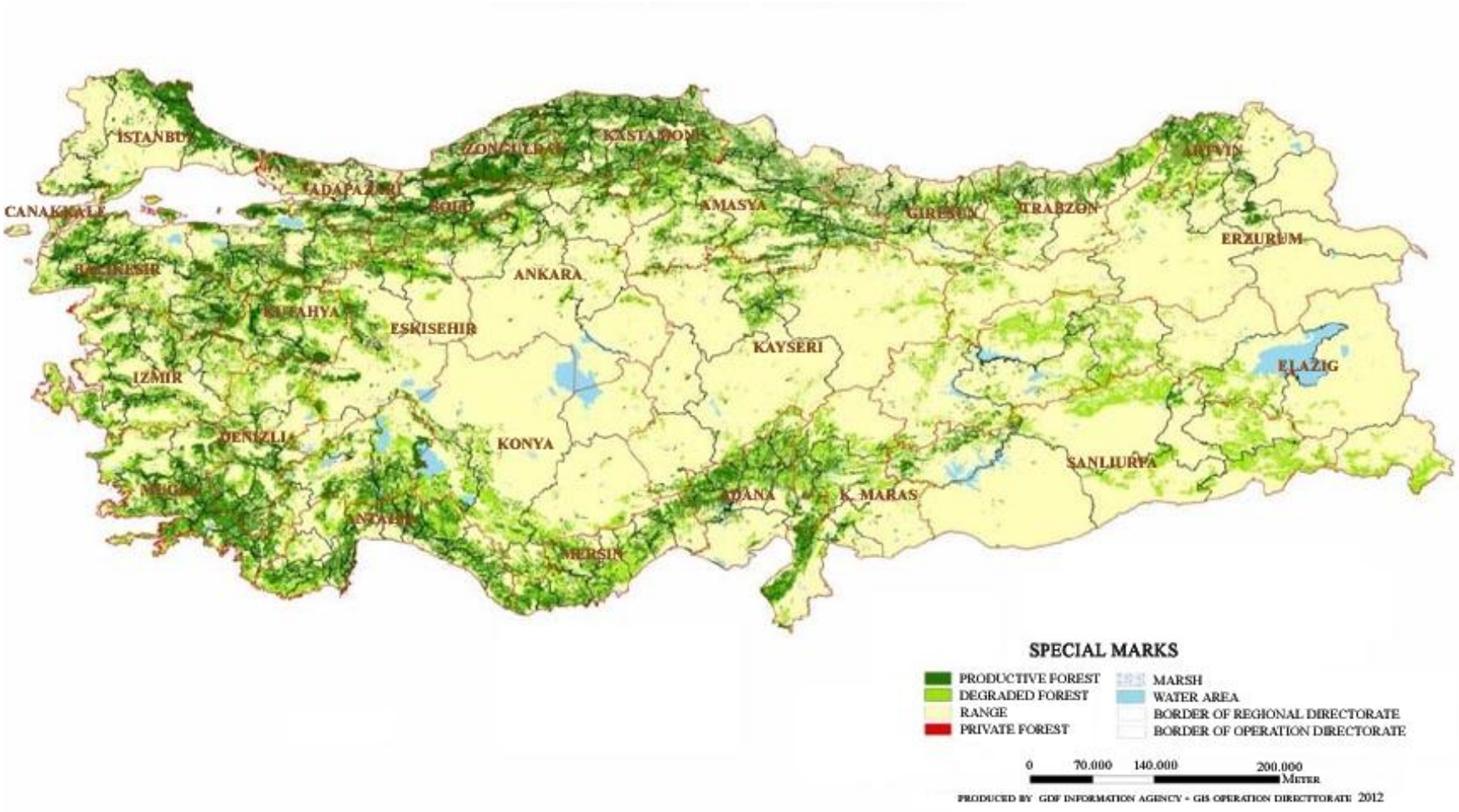


Figure 4.1 Turkey forest map in 2012

Turkey is under threat of natural and human made forest fire. Indeed, not only socio-economic but also natural condition of Turkey causes this disaster. Especially, this disaster happens in coniferous forest in Turkey's Mediterranean and Aegean region along 5-6 months. In this context, forest fire happened 1978 times in Turkey between the years 1970 – 2012. At that time these records were confirmed as the highest number of natural disasters. Accordingly, 269 disaster as maximum number occurred in Antalya. In these forest fires, 283 people died, 90 people were injured and 964 people were influenced (Özşahin, 2013).

In Turkey, the main cause of fires is human activities, and nature causes only a small part. The 97% forest fires accidently or intentionally occurred by human (CL-215, n.d.). Table 4.3 shows a total of 27 cities that forest fires occurred and the total burned area (hectares) in Turkey (Orman Genel Müdürlüğü, n.d). The cause of forest fires are categorized into 5, i.e. neglect/inattention, intention, accident, unbeknown, lighting/naturally. As represented in the distribution of the cause of the forest fire occurrence, 2% percent of the fires were occurred naturally specifically caused by lightening in 2009. Additionally, most of the forest fires happened in Aegean region followed by Mediterranean region.

Table 4.3 The total burned forest areas according to the cause of fire in 2009 in Turkey

REGION	**Neglect / Inattention** (Area in ha)							**Arson** (Area in ha)			**Accident** (Area in ha)			**Unbeknown** (Area in ha)	**Lightning** (Area in ha)	**Total** (Area in ha)
	Stubble	**Dump**	**Hunting**	**Camp Fire**	**Cigarette**	**Picnic**	**Others**	**Terrorism**	**Incension**	**Expend**	**Energy**	**Traffic**	**Others**			
ADANA	77.40	1.50		4.20	2.40	0.70	64.99		0.70		7.20	3.70	0.38	14.90	5.11	183.18
ADAPAZARI	0.22	2.50			44.55		260.20				0.12		7.10	40.68	2.70	358.10
AMASYA	32.06			0.20		2.50	17.63		0.05		1.35		0.02	29.91	1.60	85.33
ANKARA	1.30	0.40			5.70	0.40	11.49				0.20		0.10	41.26	4.22	65.07
ANTALYA	4.20	1.00	15.50			0.20	72.32				2.12		361.20	1.44	10.70	468.80
ARTVİN																0.00
BALIKESİR	0.50			6.00	1.00	1.41	104.81		65.21		9.50	49.20	0.08	14.60	0.19	252.50
BOLU							0.62				0.08			6.33	5.24	12.27
BURSA	1.50	15.92			1.35	0.02	47.23				6.71	15.00	0.80	339.86	23.58	451.97
ÇANAKKALE	6.00			1.15	0.81	48.00	11.72				4.90			1.02	2.08	75.68
DENİZLİ	5.5	2.0		10.6	9.6	0.3	34.4		16.6		1.0		0.1	4.5	3.2	87.60
ELAZIĞ							52.5				50.0			107.6		210.10
ERZURUM				0.2												0.15
ESKİŞEHİR				8.4	30.4		20.7						0.0	0.1	11.0	70.49
GİRESUN							4.0							6.9		10.85
ISPARTA	2.9	0.25		0.0			13.3				7.5	0.8	0.6	6.7	6.1	38.20
İSTANBUL	4.6					1.6	60.5		0.0		2.9		9.5	10.8	0.1	89.95
İZMİR	10.6	7.0	0.7	6.4	1242.6	0.7	294.0		26.1	0.1	7.3	1.2	2.4		4.0	1603.10
K.MARAŞ	7.3	1.6		0.4	12.1		44.3	3.1				3.7	1.0	3.0	1.1	77.60
KASTAMONU				0.01	0.05		1.5			0.0	1.2		0.0	1.7	0.2	4.66
KONYA	30.9	0.9		0.5	4.0		12.1				0.50		0.2	34.5	4.0	87.55
KÜTAHYA	3.6			0.8			18.2							1.6	1.3	25.48
MERSİN	1.8	37.3	1	0.5	3.7	0.6	19.1		2.4		12.2				1.3	79.93
MUĞLA	41.1			15.7	44.1	0.1	29.3		22.9	0.1	67.40	0.1	14.3	10.7	13.9	259.70
SİNOP							0.01						2.0	19.2	0.0	21.24
TRABZON							38.0						4.0	3.7		45.72
ZONGULDAK	1.55				2.50		0.01							6.88	2.57	13.51
Total (Area in ha)	**232.9**	**70.4**	**17.2**	**55.1**	**1404.8**	**56.6**	**1232.8**	**3.1**	**133.9**	**0.2**	**182.2**	**73.7**	**403.8**	**707.8**	**104.2**	**4.679**
%	5.0	1.5	0.4	1.2	30.0	1.2	26.3	0.1	2.9	0.0	3.9	1.6	8.6	15.1	2.2	100.00
	65.6							**2.9**			**14.1**			**15.1**	**2.2**	100.00

4.1 Assessment of Fire Warnings

Meteorological conditions and parameters play a very important role on the occurrence, severity and duration of forest fires. Human – made and natural forest fires only occur when meteorological conditions are suitable. The effect of the meteorological factors may differ depending on the land structure, size of forests, topography, type of flora, and season. Initial factors, which affect the spread of fire, are air temperature, relative humidity, the air stability, wind speed and direction. Moisture reduction effect of increased temperature are also added these factors in time. As a result, it accelerates the combustion process, the fire point occurs and tendency of fire spread increase. In our country, when the air temperature exceeds 25°C and relative humidity decrease below 40%, the risk of forest fires is very high. Under these conditions, fires spread very quickly by the effect of the wind and that cause difficult to control. Additionally, fire spread is directly related to the continuity of inflammable material in direction of spread (Akkaş et al., 2008).

Fire warning is issued after the watchtower has seen. Basis of fire warning assessment divides into four categories by the Ministry of Forestry of Turkey (Orman yangınlarını söndürme ve müdahale çalışmaları, n.d.).

- *First category*: When the fire warning is issued, if the humidity is over 60(%), wind is between 1 – 5 km/h, temperature is 15 – 25 °C and fuel have all conditions, it is labeled as first category fire warning.
- *Second category*: When the fire warning is issued, if the humidity is 50 – 60(%), wind is 2 – 5 km/h; temperature is 20 – 30 °C. The forest is not continuous, and the fire does not threaten the residential areas, it is labeled as second category fire warning.
- *Third category*: When the fire warning is issued, if the humidity is 30 – 40(%), wind is 5 – 10 km/h, temperature is 30 – 35 °C and the forest does not continuous. If the area is in Eagan Coast especially in a peninsula and also the Taurus Mountains especially in a valley, it is labeled as third category fire warning.

- *Fourth category*: When the fire warning is issued in a critical area, if the humidity is less 25(%), wind is 10 km/h or over 10 km/h. Temperature is over 35 °C. Forest is young, and fire threatens the residential areas.

Fire coordinators consider these fire warning categories to interfere with the fire. The following are the results published in online database of Forest Directorate as early warning system.

- In the first category, there is no danger for forest fires.
- In the second category, in the way of the forest fire there is no immediate danger.
- In the third category, underestimating the criteria of the peninsulas with peculiar climate, forelands, canyons, forelands, canyons and forest blocks mentioned. The overrated confidence about being able to act in time, are most crucial reasons which trigger the forest fires and give maximum damage afterwards. This poses danger. Immediate intervention plays the most important part. There must be a planning for the alliance forces besides early interventions considering the circumstances in which the fire may start
- Fourth category is red warning. Not only first responder team should reach the fire area, but also helicopter and land team immediately must interfere with the forest fire.

4.2 Historical Data

Statistics shows that forest fires in 1945 burnt more than 165,307 hectares. Biggest ten fire cases occurred in 1945, 1946, 1942, 1950, 1952, 1947, 1943, 1977, 1944 and 1956 and total burnt area 723,067 hectares (1937 yılından günümüze orman yangınları, n.d.). Figure 4.2 illustrates the number of fires (shown as line) and burnt area in hectares (shown as bar) between 1937 and 2009. Atmospheric movement and climatic changes may have an effect on an annual forest fire variation. After Gökçen Flying had been established; burnt area decreased despite that the number of fire cases increased (Gökçen havacılık, n.d.).

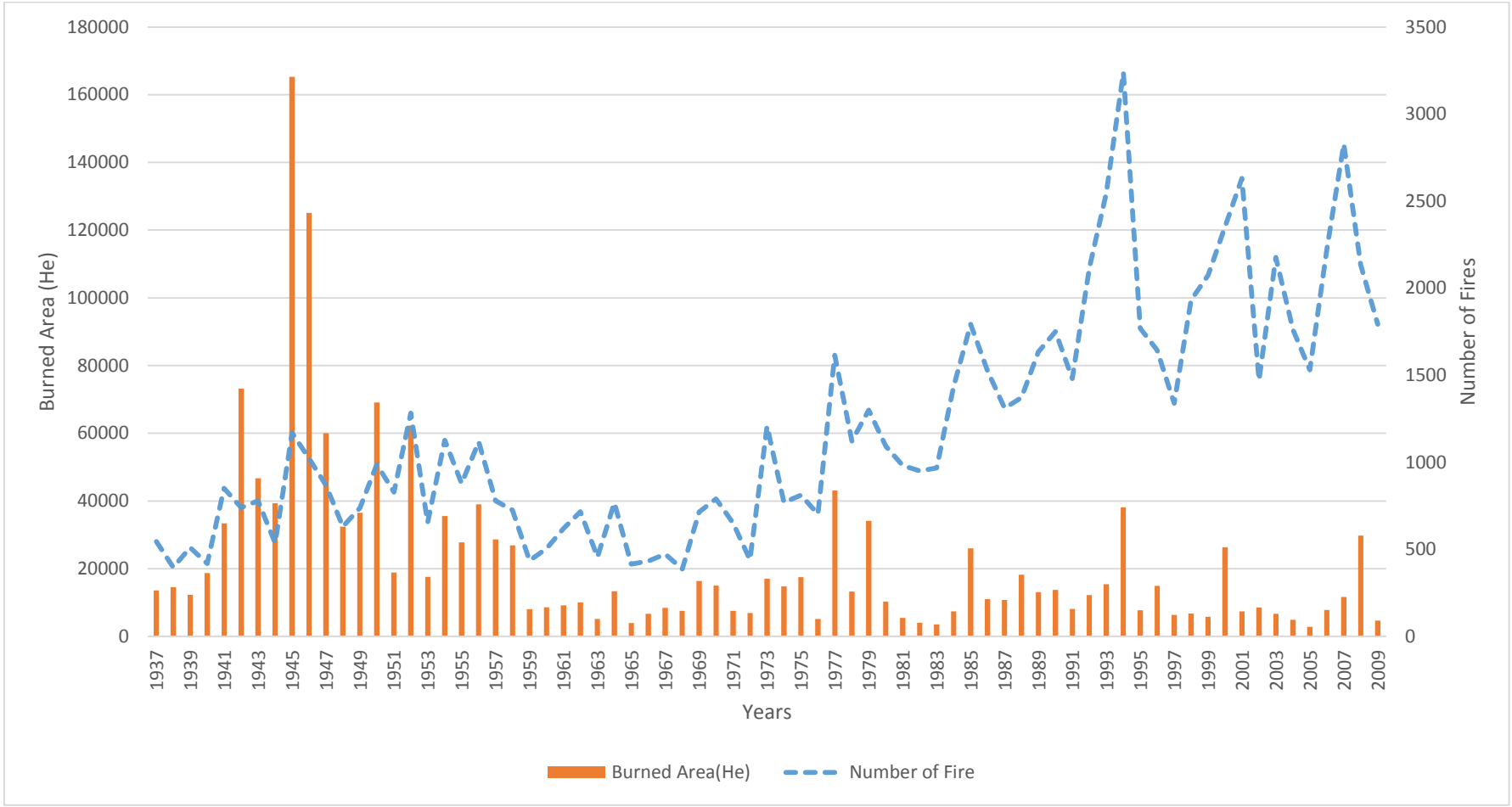


Figure 4.2 Forest fire distributions between the years 1937 - 2009 in Turkey

In Table 4.4 thirty – nine large scale forest fire sorted based on the findings of Akkaş et al. (2008) that distance of fire spread horizontally increases depending on the average fire speed, hence total burning area increase naturally. Taşağıl (1994) forest fire is even the fastest fire. Topography of the land is much fractured in order that horizontal distance was great. Therefore average fire speed is high. Located on the second and third row is remarkable in high wind speeds Bandırma (2000) and Çetibeli (1996) forest fire. It can be found effect of the high temperatures and existing canyons in the topography in Buldan (2000) forest fire (Akkaş et al., 2008). In Şile (2000), Çetibeli (2002) and Orhaneli (2000) forest fires were affected by the high speed wind. Kepsut (2002), Buldan (1994) and Akhisar (2000) forest fire was observed the effects of high temperatures.

The average wind speed of all fire is 5.7 m/h. However, it should be noted that these are normal meteorological conditions. As an example 05.04.2000 Erdek forest fire, out of fire season, wind speeds above this average are also effective in the fire. The average high temperature for all the fires is 32.7ºC. The average relative humidity value is 28.07% for all fires. According to the index forest fire, large scale forest fire occurs between 16% - 32% relative humidity. In Table 4.4, between 41% - 57% relative humidity scale large forest fire can be observed (Akkaş et al., 2008).

Table 4.4 Detailed information regarding to 39 forest fires in Turkey

Location (Year)	X Coord.	Y Coord.	Fire Speed (m/h)	Temp. (C)	Humidity (%)	Wind (m/sn)	Horizontal Distance (m)	Slope (%)	Area (he)
Tasagil (1994)	31.073931	37.038023	2.0	36	15	2	31741	19.93	2353
Bandirma (2000)	27.849449	40.12381	9.7	24.4	31	9.7	17280	16.6	1579
Cetibeli (1996)	28.312567	37.002682	6.9	32.4	32	6.9	42783	16.35	6452
Buldan (2000)	28.719365	38.066597	3.5	41.6	8	3.5	14713	15.51	1428
Gebze (1994)	29.445274	40.879647	0.6	36.7	39	0.6	8775	15.64	691
Sile (2000)	29.811664	41.098117	11.0	29.6	31	11	10733	20.07	1118
Orhaneli (2000)	29.003331	39.898904	8.2	27.7	25	8.2	13082	12.26	2397
Kepsut (2002)	28.234484	39.74082	3.7	39.7	18	3.7	25383	18.35	3477
Cetibeli (2002)	28.322511	37.008117	8.9	28.5	55	8.9	24296	33.37	1958
Akhisar (2000)	27.938781	38.990755	4.4	37.7	17	4.4	18258	11.52	986
Buldan (1994)	28.719365	38.066597	1.2	41.3	20	1.2	14960	26.04	1522
Karaisali (2000)	35.10849	37.269025	3.4	31.5	23	3.4	13884	11.47	2952
Karabiga (2000)	27.181188	40.379946	6.6	35.7	27	6.6	20320	9.92	1943
Sogucak (2000)	27.329551	37.772223	9.2	24.2	32	9.2	9236	16.3	1009
Hisaronu (1997)	28.133092	36.814042	8.6	26.7	61	8.6	32106	20.75	2525
Gelibolu (2003)	26.519659	40.295012	8.7	26.6	49	8.7	11866	15.55	491
Selcuk (2006)	27.450942	37.892156	5.3	42.5	15.4	5.3	17644	17.46	1271
Eceabat (1994)	26.359169	40.18391	6.4	28.3	40	6.4	40601	8.32	4167
Mentes (1994)	26.764919	38.333885	8.8	29.2	31	8.8	16541	12.82	1592
Duzlercami (1997)	31.045404	36.992149	3.4	35	31.5	3.4	15032	24.51	1644
Manavgat (2000)	31.321509	36.832636	4.7	29.5	27	4.7	14840	44.23	1906
Turgutlu (2000)	27.751699	38.433852	8.9	23.6	36	8.9	4860	39.29	502
Bodrum (2006)	27.446849	37.049664	8.7	41.8	16.6	8.7	40251	16.87	3052
Kusadasi (1996)	27.323714	37.776126	7.6	29.5	33	7.6	29284	7.09	4155
Gelibolu (2004)	26.609446	40.37147	3.3	36.7	9.1	3.3	8198	7.36	608

Table 4.4 Detailed information regarding to 39 forest in Turkey (continue)

Kesan (2000)	26.73877	40.862022	4.9	28.5	32	4.9	30605	8.37	1795
Dalaman (1990)	28.84963	36.770159	5.9	23.7	34	5.9	10160	33.05	1868
Gumuldur (1994)	27.020153	38.086793	7.0	32.3	27	7	10516	22.21	988
Soma (1994)	27.569352	39.188575	2.5	36.3	16	2.5	33654	19.32	3574
Serik (1994)	31.094762	37.010054	2.0	36.8	24	2	9322	24.79	1034
Hisaronu (2003)	28.133974	36.814558	11.5	28.2	52	11.5	6999	4.31	319
Seferihisar (2004)	26.834845	38.186599	4.9	42.2	8.4	4.9	3770	17.62	330
Erdek(2000)	27.789392	40.404555	10.7	24.9	31	10.7	5046	15.41	390
Karabel (1994)	27.417086	38.426807	5.5	34.8	10	5.5	31053	27.73	2374
Eceabat (1994-2)	26.366901	40.16946	2.5	30.2	30.6	2.5	8064	12.26	334
Osmaniye (1999)	36.275314	37.051967	1	36.2	17	1	14441	14.03	2189
Bayramic (2000)	26.626226	39.771015	4.0	29.1	54	4	6171	14.8	372
Kestel (2000)	29.226473	40.164715	4.2	41.5	9	4.2	2793	17.03	564
Geyve (1994)	30.31501	40.51328	1.4	37.6	35.0	1.4	9377	24.12	612

Every forest fire case causes financial losses. Table 4.5 represents loss related to the important 39 large-scale forest fires occurred in Turkey. Consequential loss of 39 fire cases was $108,193,498. Additionally, in 2003, 2,177 fire cases occurred, and 6,644 hectare forests were burnt. As a result, total loss was 21,883,721 TL. For this reason, to minimize the loss of the forest fires, an effective way should be organized to fight the fire (Akkaş et al., 2008).

Table 4.5 List of records and damage reports of 39 large scale forest fires in Turkey

Burnt area	52,948.60
Administration loss than burning seedlings	29,983,115
Administration loss than burning trees	14,041,716
Reforestation fee	57,064,686
Subsistence expenses	228,085
Work premium expenses	483,531
Fuel oil expense	379,463
Rental vehicle expense	16,588
Street sprinkler expense	698,887
Dozer and digger expense	290,657
Trailer expense	32,113
Power saw expense	6,377
Plane expense	862,264
Helicopter expense	3,906,533
Total flying expense	4,766,412
Suppress expense	6,901,798
Compensations	202,183
Total General Loss	108,193,498

CHAPTER FIVE
FOREST FIRES DISASTERS MANAGEMENT: AN APPLICATION OF INITIAL RESPONSE COORDINATION

5.1 Case Study

Response coordination in forest fires is selected from the field of disaster management. Initiating firefighting activities on time, especially the arrival of fire-water tender and the ground team onto fire areas in critical response time is crucial for effective fighting against the forest fires.

In this study a heuristic model is proposed for coordinating the responses needed to suppress the forest fires in Turkey. The schematic representation of the structure of the forest fire initial response coordination model is illustrated in Figure 5.1.

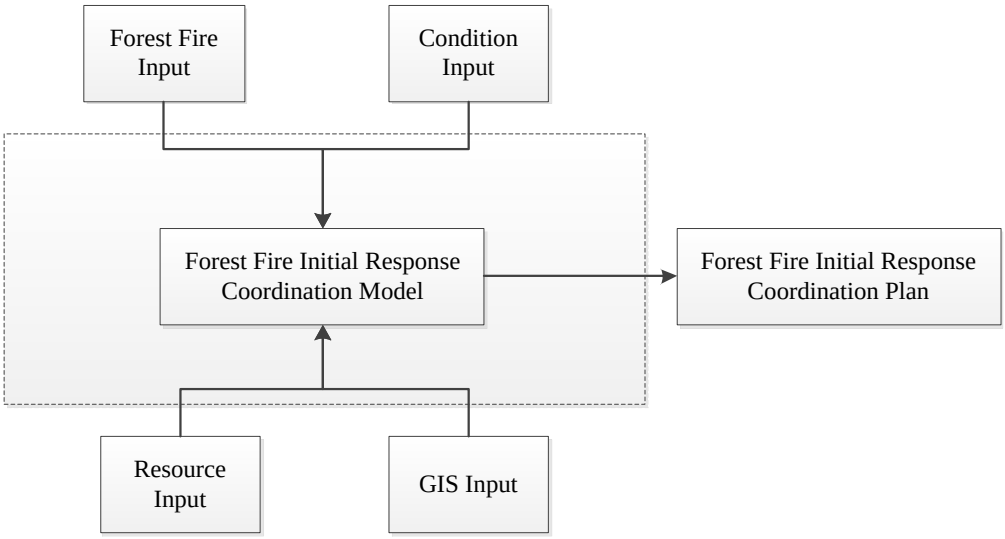


Figure 5.1 Schematic structural representation of the proposed model

The proposed model uses four types of input data related to resource, GIS, forest fire and condition. These data are processed by the proposed heuristic model and a forest fire initial response coordination plan (FFIRCP) is generated. FFIRCP contains who will be going to interfere, which resources will be needed, how many resources will interfere, which road they will be using, and how long will it take to travel there.

In the following subsections, first the input data needed in the model are described in detail. Later, the proposed heuristic model is presented in detail. Following experimentations are conducted and finally the results and discussions are given.

5.2 Inputs for the Model

5.2.1 Resource Input

Resource units consist of the land and air teams. They are located in different place. Fire water tender and the ground team are located in regional forest directorates. The aircraft teams are located in the airports and their coordinates can be seen in Table 5.1. The aircraft teams charter by the forestry ministry to suppress the fire in summer season. Helicopters and CL-415 Bombardier aircrafts are founded in the airports as the fire-fighting planes. The coordinates of the nine regional forest directorates connected to the forest ministry are shown in Table 5.2.

Air tankers have a normal cruising speed of 180 kt (333 km/hr) and a stall speed of 68 kt (126 km/hr). The air tanker fuel capacity is 10,250 lb and burns fuel at an average rate of 1,660 lb/hr, which implies that a typical trip should not last much longer than 6 hours. At the normal cruising speed, the air tanker can cover approximately 2,000 km in 6 hours. However, air tankers do not often travel far from their home base, since they must have enough fuel on reserve to fulfill their firefighting duties and return back to base (Clark, 2012).

Water scooping is an effective firefighting technique, if a body of water is 1,340 meters long, 90 meters wide and 2 meters deep, then it is safe for a CL-415 to scoop from it. The aircraft only needs about 410 meters on the water to make a pick up, but the remainder is needed for its approach and climb-out. The CL-415 typically travels at 70 kt (130 km/hr) along the body of water to scoop up a 6,137-litre water load (Clark, 2012). Once the air tanker arrives at the fire with a full load, it is typically travelling at 110 kt (204 km/hr) (Hava araclari, n.d.). And it will drop its load 30 to 35 meters above the treetop level (Clark, 2012).

Helicopters have a normal cruising speed of 150 km/hr). Bambi – bucket capacity is 2500 lt (Hava araclari, n.d.). All air resources need 15 minutes preparation time to departure from the airport.

Fire water tenders: 5-7 passengers including the driver always have the ability to pass from 4x4 to 4x2 and vice versa. It can climb up 60% slope and move more than 30% side slope. Due to the difficult terrain it has the ability to move and climb. Fire water tenders is one of the most effective vehicles used in the intervention and control forest fire. Fire water tenders have movable component attached to the 3000 – 6000 liters of water tank and have up to 200 liters of chemical foam tank. Fire water tenders are fire vehicles and the average consume per liter of fuel in 3 kilometers (Orman ve kırsal alan yangınlarına müdahale, n.d.).

Table 5.1 Coordinates of airports in Turkey

Location	X Coord	Y Coord
Canakkale-Center(1)	26.374683520018	40.0824891045626
Canakkale-Center(2)	26.4265998022075	40.1377854991125
Edirne-Kesanli	26.7585975596521	40.712777653973
Bursa-Yenisehir	29.5575897794233	40.2541437281706
Yalova-Ciflikkoy	29.3763706151424	40.6847972241194
Kocaeli-Kartepe	30.1012065351767	40.7325858258841
Izmir-Selcuk	27.3337801347368	37.9512668039393
Izmir-Menderes	27.1756301758746	38.0917829394402
Izmir-Kemalpasa	27.4407751394325	38.4676936838724
Izmir-Bergama	27.1182664809254	39.0833285794828
Manisa-Akhisar	27.9180209798067	39.0272013208007
Denizli-Center	29.0919916005854	37.7383988596548
Adana-Saricam	35.5240388511836	37.1284633200175
Adana-Kozan	35.8386639071199	37.5298352079546

Table 5.2 Coordinates of nine regional forest directorates in Turkey

Location	X Coord	Y Coord
Sakarya	30.3847578806415	40.7568151641223
Balıkesir	27.8844947494496	39.64503727434
İzmir	27.1140784896837	38.4677838933132
Şanlıurfa	38.8179481669202	37.1948734416778
Artvin	41.8290705942257	41.178966740614
Ankara	32.8108784010676	39.8989656549874
Kahramanmaraş	36.9186396672568	37.5686995382304
Afyonkarahisar	30.6618592750753	38.8157606331881
Isparta	30.5543678514179	37.7848713913677

The Table 5.1 and Table 5.2 show coordinate of resource units respectively, airports and regional forest directorates. Table 5.3 represents flights distance from airports to forest fires. Distance was generated under ArcMap 10.2.2.

Table 5.3 Flight distance (km) between 39 large - scale forest fires and 14 airports in Turkey

Airports / Fires	Adana Kozan	Adana Saricam	Bursa Yenisehir	Canakkale Center(1)	Canakkale Center(2)	Denizli Center	Edirne Kesan	Izmir Bergama	Izmir Kemalpasa	Izmir Menderes	Izmir Selcuk	Kocaeli Kartepe	Manisa Akhisar	Yalova Çiftlikkoy
Tasagil (1994)	426.199	396.018	380.160	531.045	531.384	191.512	553.697	414.633	357.130	363.607	345.785	418.253	353.953	430.362
Bandirma (2000)	750.756	746.032	146.324	126.236	121.686	285.996	113.873	131.559	187.338	233.267	245.556	202.935	121.821	144.069
Cetibeli (1996)	673.505	644.606	382.661	385.371	388.981	112.559	438.070	257.396	183.368	159.463	138.568	448.055	232.080	424.822
Buldan (2000)	626.360	606.234	255.107	306.712	308.258	45.114	343.267	183.839	124.553	139.063	125.602	320.346	131.473	298.223
Gebze(1994)	659.934	665.887	71.081	283.112	276.897	352.658	235.448	288.484	324.174	371.943	378.184	51.120	249.317	26.746
Sile (2000)	653.090	661.542	95.729	312.246	305.833	377.934	260.913	320.638	355.716	403.424	409.287	47.105	280.860	58.321
Orhaneli (2000)	651.043	647.483	62.344	224.687	220.815	240.574	210.341	185.172	208.316	255.537	260.256	132.156	134.092	93.053
Kepsut (2002)	706.812	699.831	129.803	162.809	160.148	232.525	166.589	117.612	153.874	201.672	210.410	196.799	80.437	146.665
Cetibeli (2002)	666.634	638.153	374.410	381.815	385.279	103.447	433.375	253.602	179.713	157.975	137.035	439.572	226.231	416.854
Akhisar (2000)	710.298	696.881	201.214	183.478	184.534	169.416	219.807	71.672	68.893	116.434	123.222	271.460	8.012	228.883
Buldan (1994)	620.342	600.281	253.299	310.557	311.990	41.610	346.051	188.380	130.055	145.086	131.645	318.000	134.693	296.955
Karaisali (2000)	70.921	40.127	584.981	821.659	819.562	534.343	818.042	728.451	687.609	705.709	690.616	579.295	659.651	624.555
Karabiga (2000)	812.459	808.170	200.782	78.387	71.815	336.566	52.763	144.907	214.180	255.096	270.931	248.669	162.874	187.293
Sogucak (2000)	749.905	727.098	336.443	271.253	275.751	154.129	331.799	147.778	78.320	39.074	20.442	406.552	148.780	368.799
Hisaronu (1997)	689.281	659.347	403.290	396.037	399.969	134.545	451.201	268.915	194.964	166.520	146.005	469.104	248.066	444.891
Gelibolu (2003)	873.680	867.716	266.612	30.182	23.651	371.129	49.131	152.998	227.059	259.655	278.372	314.412	195.110	252.939
Selcuk (2006)	738.793	716.793	320.196	263.475	267.639	143.711	321.705	137.816	65.817	35.430	14.757	390.265	133.802	352.923
Eceabat (1994)	881.044	874.255	277.700	20.086	16.831	370.190	64.375	148.143	221.963	252.427	271.608	327.187	195.028	265.808
Mentes (1994)	802.765	783.734	322.253	197.702	203.068	215.157	264.949	88.959	61.052	45.036	65.695	391.975	126.782	344.950
Duzlercami (1997)	429.163	398.457	384.445	532.931	533.346	191.828	556.300	415.891	357.710	363.433	345.436	423.049	355.710	434.668
Manavgat (2000)	408.221	375.282	410.183	563.608	563.982	222.219	586.340	446.691	388.247	393.211	374.978	446.095	386.440	460.283
Turgutlu (2000)	716.142	698.472	254.764	219.675	222.443	139.702	268.260	91.854	28.781	64.241	65.671	325.060	67.452	286.166
Bodrum (2006)	746.287	718.449	401.223	350.568	355.325	165.088	412.315	228.330	157.971	118.569	100.985	470.084	224.092	437.833
Kusadasi (1996)	744.156	721.280	334.230	274.184	278.566	148.357	333.866	149.819	79.101	42.659	22.663	404.242	148.082	367.191
Gelibolu (2004)	864.901	859.799	254.324	43.977	36.594	371.542	33.515	158.506	232.319	267.031	285.205	300.288	195.249	238.775
Kesan (2000)	868.887	866.738	248.721	92.793	85.533	403.151	17.349	201.359	273.961	311.398	328.766	284.606	228.443	224.024
Dalaman (1990)	627.326	596.729	390.366	425.230	428.241	108.137	472.709	296.850	223.958	206.729	185.853	451.944	261.864	435.690
Gumuldur (1994)	778.910	758.220	326.682	230.167	235.102	186.298	294.233	112.193	56.831	13.628	30.916	397.005	131.462	353.996
Soma (1994)	744.417	732.329	206.494	143.960	145.134	208.373	183.650	42.239	81.454	127.445	139.688	275.088	34.084	226.025
Serik (1994)	423.987	393.460	383.937	535.088	535.434	195.248	557.771	418.591	360.944	367.201	349.318	421.764	357.981	434.130
Hisaronu (2003)	681.333	651.331	400.961	399.186	402.996	129.646	453.366	271.681	197.638	170.754	150.075	466.327	248.827	443.075
Seferihisar (2004)	794.935	774.973	328.025	214.376	219.630	204.230	280.715	101.958	60.547	31.202	50.761	398.103	131.913	352.796
Erdek (2000)	760.944	758.522	144.027	134.342	128.339	317.606	100.176	164.049	222.142	267.774	280.375	191.048	156.617	129.819
Karabel (1994)	746.223	728.233	274.605	205.604	209.242	165.535	261.039	77.893	5.092	42.846	53.245	344.934	79.823	302.474
Eceabat (1994-2)	882.250	875.308	279.634	18.889	16.700	369.922	67.164	147.260	220.984	251.051	270.309	329.427	194.977	268.072
Osmaniye (1999)	65.184	68.037	684.000	926.236	923.945	641.102	920.179	834.883	794.614	812.686	797.502	673.189	765.912	721.439
Bayramic (2000)	839.650	830.290	256.174	40.454	43.835	312.150	104.943	88.008	161.836	193.502	212.263	314.510	139.159	255.240
Kestel (2000)	645.062	644.372	30.519	242.891	238.183	270.527	217.406	217.226	243.695	291.032	295.899	97.656	169.226	58.702
Geyve (1994)	579.421	585.776	72.699	341.363	336.026	326.623	304.644	318.980	337.874	383.746	385.665	31.946	265.567	84.147

5.2.2 Forest Fire Input

39 large scale forest fires which detailed information is given about in Table 4.4 are used as the forest fire input. They are represented in Figure 5.3.

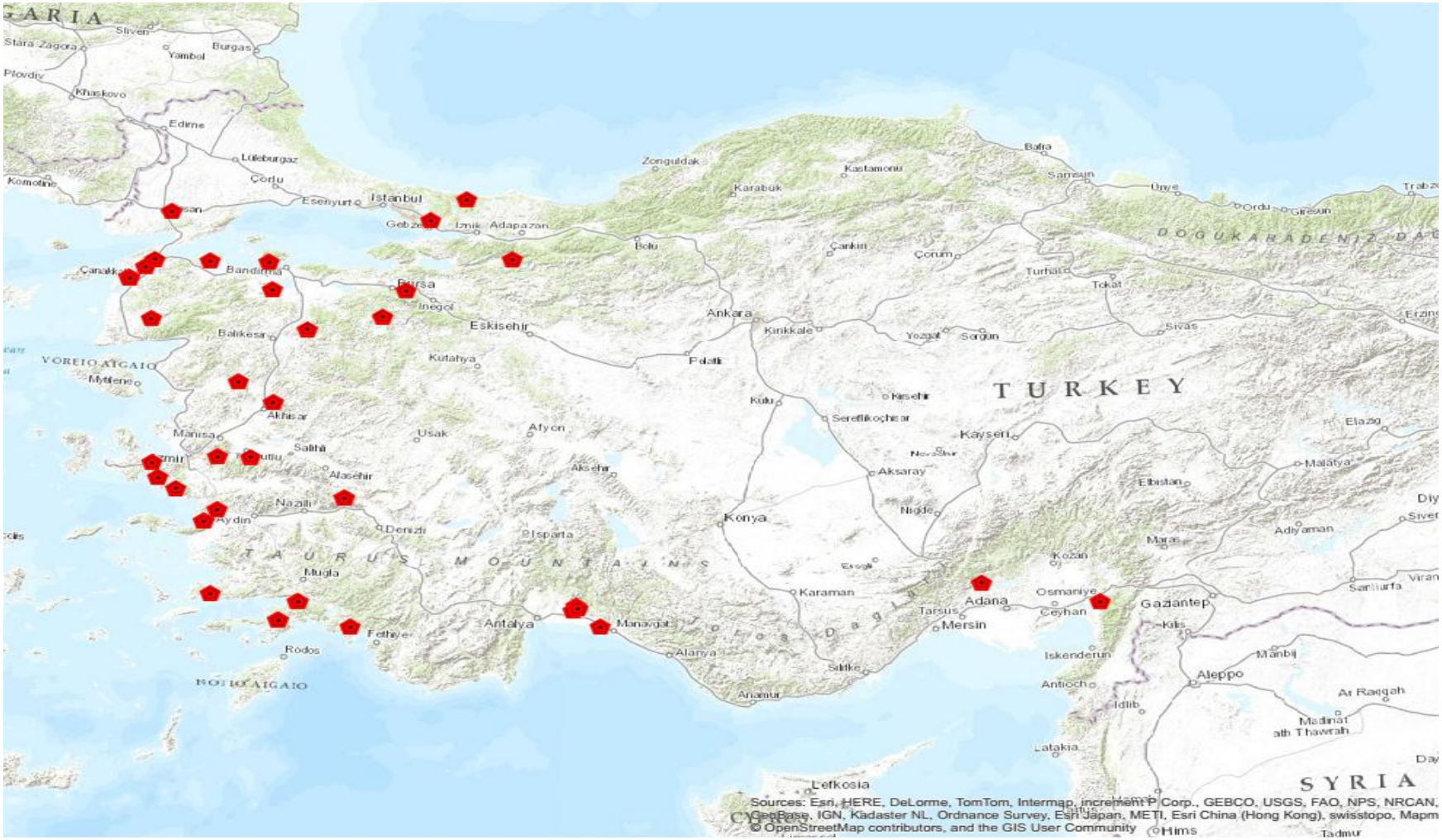


Figure 5.2 Locations of 39 historical forest fires in Turkey

5.2.3 GIS Input

Emergency management is not isolated, and there are numerous GIS applications related theoretical, management, application, and technical innovations that affect this application arena (Cova, 1999) (See Figure 5.3).

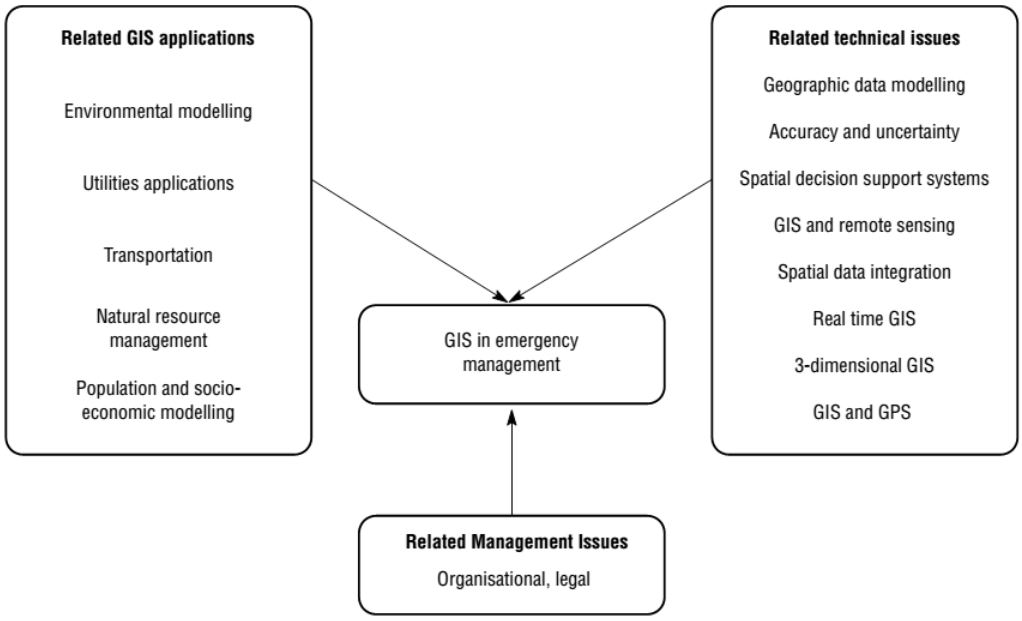


Figure 5.3 GIS in emergency management and related areas

In this case study, GIS was used to minimize the time interval to reach the fire area. Network Analyst Toolbox was used under ArcGIS 10.2.2.

Closet facility analysis calculates 9 regional forest directorates – 39 fire areas network paths as facilities to incidents. It generates a closest road between each facilities and incidents.

Network cost was determined as the travel time. The problem was implemented for 9 regional forest directorates and 39 fire areas. Turkey road map was achieved from Geofabrik (n.d) that generated based on openstreet.com map database. All data projected to WGS 1984 UTM_Zone 36N. Speed limits were defined for different road type based on speed limitation. Table 5.4 represents the travel speeds of land teams.

Table 5.4 Travel speeds by road class

Type of road	**Kilometers / hours**
Bus guideway	20
Byway	20
Footway	20
Hollow Way	20
Living Street	20
Path	20
Pedestrian	20
Steps	20
Residential	50
Road	50
Service	50
Unclassified	50
Tertiary	50
Motorway link	40
Primary link	40
Secondary link	40
Trunk link	40
Secondary	80
Track	80
Trunk	85
Primary	85
Motorway	90

Table 5.5 represents minutes of optimum routes between forest fires – 9 regional forest directorates. The table was generated from closest facility module network analyze toolbox under Arc Map 10.2.2. In Figure 5.4, closest facility roads from 9 regional forest directorates to Eceabat (1994), Mentes (1994), Düzlerçamı (1997), Manavgat (2000), Turgutlu (2000), Bodrum (2006), Kusadası (1996), Gelibolu (2004), Kestel (2000) forest fires are represented. It is generated under ArcGIS 10.2.2.

Table 5.5 Total duration (minute) between forest fires and 9 regional forest directorates

	Afyon	Ankara	Artvin	Balikesir	Isparta	Izmir	K.Maras	Sakarya	S.Urfa
Tasagil (1994)	221.37576	355.66698	963.33087	384.38084	106.23335	353.20872	504.86363	422.90404	618.96606
Bandirma (2000)	288.27468	364.81280	1016.78953	69.15386	347.05176	191.70318	771.77053	211.05246	903.70713
Cetibeli (1996)	283.18753	450.10669	1135.49673	291.36613	216.73759	173.82868	732.41975	453.87661	846.52218
Buldan (2000)	176.28703	347.32691	1032.71695	178.04016	158.89146	136.45740	685.18704	336.31183	799.80117
Gebze (1994)	275.32249	269.24530	875.82960	236.17602	373.86183	358.72534	680.16822	67.86829	826.28947
Sile (2000)	289.27568	271.27112	875.77478	250.99366	387.81502	373.54298	682.19404	72.07643	828.31529
Orhaneli (2000)	162.62947	302.19707	961.33118	123.72711	259.04440	246.42792	676.56490	155.59411	791.17903
Kepsut (2002)	220.18480	359.75240	1032.67329	24.45888	302.42573	147.15969	734.12023	226.93621	848.73436
Cetibeli (2002)	273.26390	440.18306	1125.57310	281.44250	206.81396	163.90505	722.49612	443.95298	836.59855
Akhisar (2000)	226.99930	398.03918	1083.42922	75.28260	262.32690	73.48250	740.93473	293.58021	855.54886
Buldan (1994)	167.00850	338.04838	1023.43842	176.21689	149.61293	134.63413	675.90851	327.03330	790.52264
Karaisali (2000)	379.70323	310.84455	761.17642	601.68006	402.61790	603.58787	167.91388	515.70656	282.25222
Karabiga (2000)	340.30509	415.41400	1067.39073	137.08419	416.38955	244.02454	822.37174	261.65366	954.30833
Sogucak (2000)	280.36913	451.14988	1136.53993	195.35593	240.42680	74.93027	766.72238	413.65354	881.33651
Hisaronu (1997)	303.22235	470.14151	1155.53155	311.40095	236.77241	193.86350	752.45458	473.91143	866.55700
Gelibolu (2003)	525.24246	517.46798	1123.90376	486.09599	623.78180	608.64531	928.39090	317.41679	1074.51215
Selcuk (2006)	267.44024	438.22099	1123.61104	185.55252	227.49791	68.01507	753.79349	403.85013	868.40762
Eceabat (1994)	530.47078	522.69629	1129.13207	491.32430	629.01012	613.87362	933.61921	322.64511	1079.74046
Mentes (1994)	263.27128	434.31116	1119.70120	151.96433	298.59778	30.80009	777.20671	370.26194	891.82084
Duzlercami (1997)	215.35681	349.64804	971.99294	378.36190	100.21441	344.60802	499.92337	416.88510	614.02579
Manavgat (2000)	230.23495	351.99399	957.94600	393.24003	115.09254	359.48615	471.89204	431.76323	585.99447
Turgutlu (2000)	212.27865	383.31853	1068.70857	130.87594	247.60515	47.51071	726.21409	349.17355	840.82821

Table 5.5 Total duration (minute) between forest fires and 9 regional forest directorates (continue)

Bodrum (2006)	334.13473	503.90156	1189.29160	282.50042	270.53246	164.96297	811.46630	494.15953	925.56873
Kusadasi (1996)	276.19224	446.97299	1132.36304	191.23462	236.24991	73.69716	762.54549	409.53223	877.15962
Gelibolu (2004)	502.93532	495.16084	1101.59662	463.78885	601.47467	586.33817	906.08376	295.10965	1052.20501
Kesan (2000)	454.59123	446.81675	1053.25252	415.44475	553.13057	537.99407	857.73966	246.76556	1003.86092
Dalaman (1990)	293.59894	453.93775	1138.40213	317.90459	194.48473	200.36714	678.26225	464.28802	792.36467
Gumuldur (1994)	274.70030	445.74018	1131.13022	163.42854	271.33601	42.26430	788.63573	381.72615	903.24986
Soma (1994)	244.26060	415.30048	1080.32223	54.88570	279.58821	90.26086	758.19604	274.58516	872.81017
Serik (1994)	220.78416	355.07538	967.19123	383.78924	105.64175	350.03536	499.08259	422.31244	613.18502
Hisaronu (2003)	299.17042	466.08958	1151.47963	307.34903	232.72049	189.81157	748.40265	469.85950	862.50507
Seferihisar (2004)	272.61910	443.65898	1129.04903	161.31215	292.11161	40.14791	786.55454	379.60976	901.16867
Erdek(2000)	285.83908	360.94799	1012.92472	86.68417	364.57554	209.23349	767.90572	207.18765	899.84232
Karabel (1994)	223.95138	394.99126	1080.38130	132.40849	259.27788	18.96220	737.88681	350.70610	852.50094
Eceabat (1994-2)	527.06817	519.29368	1125.72946	487.92169	625.60751	610.47101	930.21660	319.24250	1076.33786
Osmaniye (1999)	460.32713	391.46845	667.13143	682.30396	483.24180	684.21177	72.82576	596.33046	186.62440
Bayramic (2000)	368.09823	460.42858	1112.40531	134.21185	413.51721	212.02891	867.38631	306.66824	996.64780
Kestel (2000)	192.86596	260.12022	915.00153	117.80937	289.28089	240.35869	667.07795	109.26446	799.01454
Geyve (1994)	206.50057	203.22914	832.37380	206.93295	305.06205	329.48228	614.15206	26.65648	760.27331

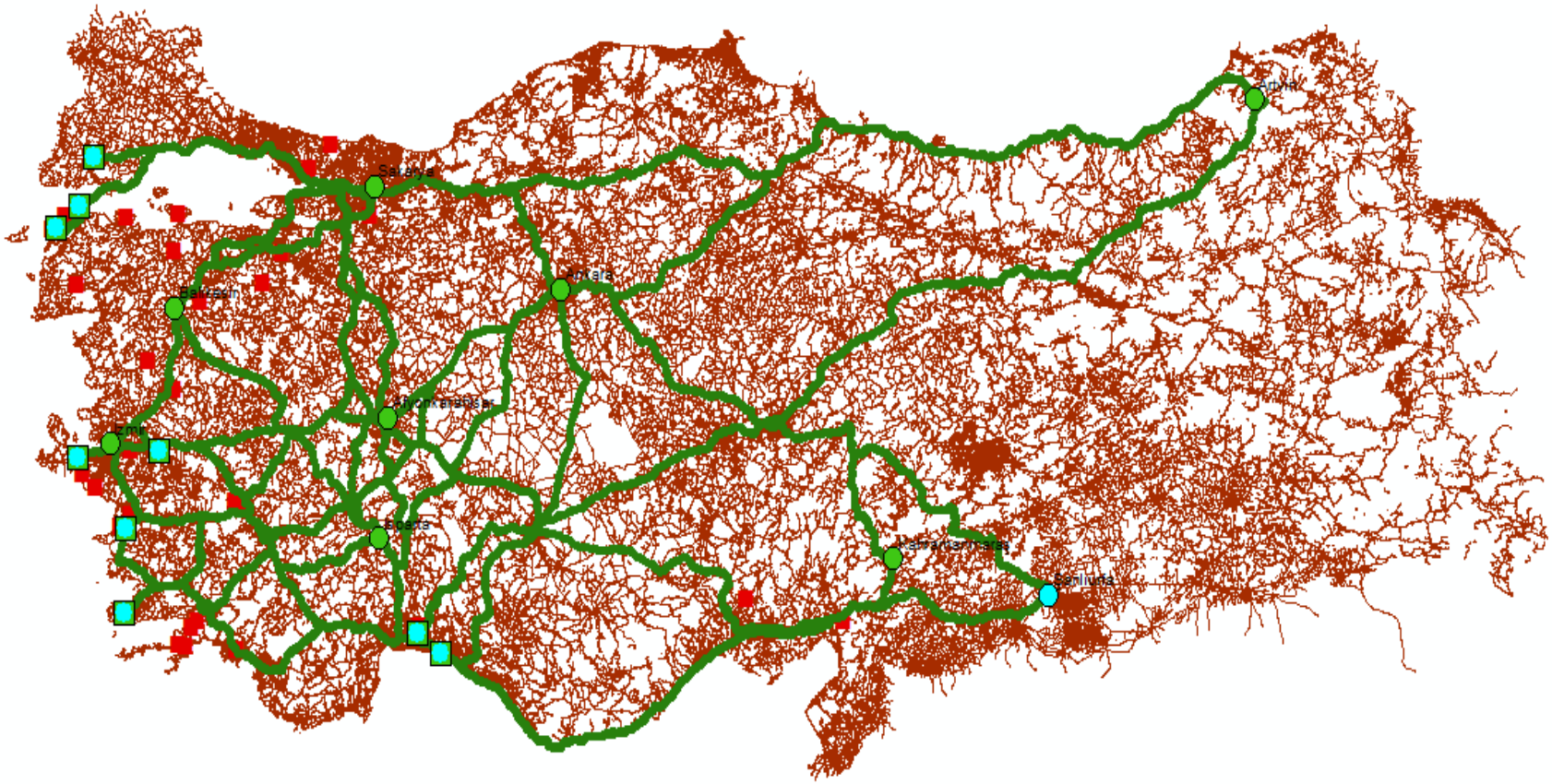


Figure 5.4 Closest facility roads for Eceabat (1994), Mentes (1994), Düzlerçamı (1997), Manavgat (2000), Turgutlu (2000), Bodrum (2006), Kusadası (1996), Gelibolu (2004), Kestel (2000) forest fires

5.2.4 Condition Input

If a wildfire occurs under the following meteorological conditions, the fire is in danger of spreading and growth. Categorize of the meteorological conditions is essential to right suppress to the wildfire.

As the condition input which detailed information given about in Section 4.1.

First category: First condition and the second condition are very close reference points so that they are combined within one category.

- The humidity is over 40(%)
- Wind is between 0 – 5 km/h (except 5)
- Temperature is 20 – 30 °C (except 30 °C)

Second category:

- The humidity is 30 – 40(%)
- Wind is 5 – 10 km/h
- Temperature is 30 – 35 °C

Third category:

- The humidity is less 30(%)
- Wind is over 10 km/h
- Temperature is over 35 °C

Turkey wind map were evaluated based on wind statistics in homogeneous distributed 45 meteorological stations by General Directorate of Meteorology. The results based on the observation between the years 1989 – 1998. (Turkey wind map, n.d.) (See Figure 5.5).

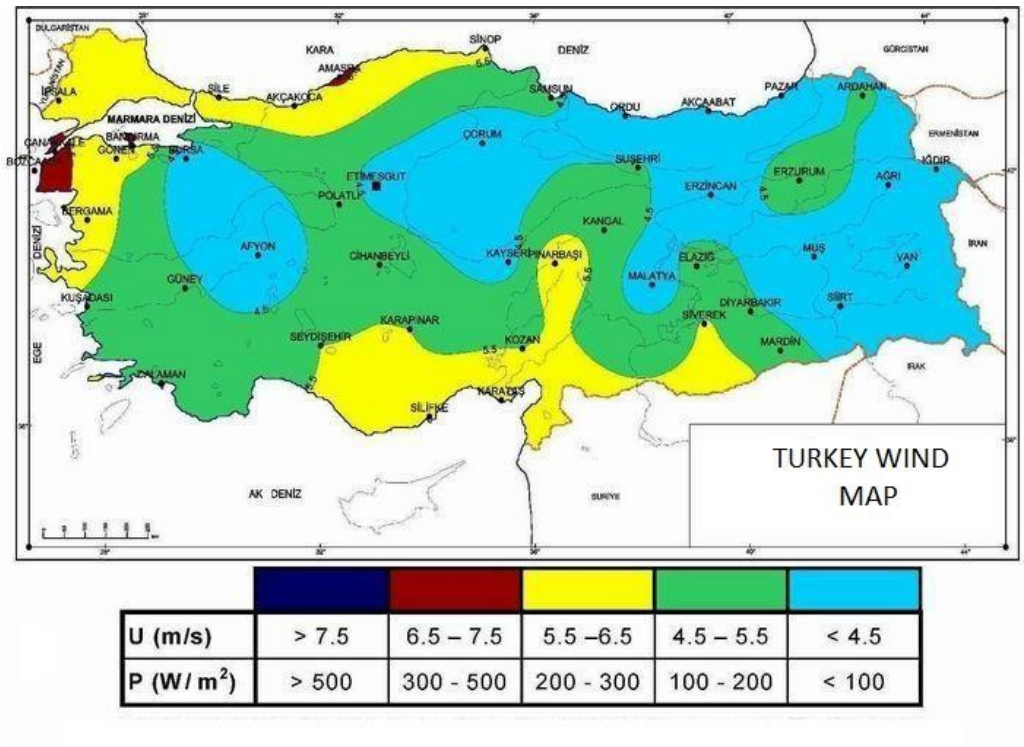


Figure 5.5 Turkey wind map based on the observation between the years of 1989 – 1998

Maximum temperature records in April which is generated general directorate of meteorology (Turkey temperature map, n.d.) (See Figure 5.6).

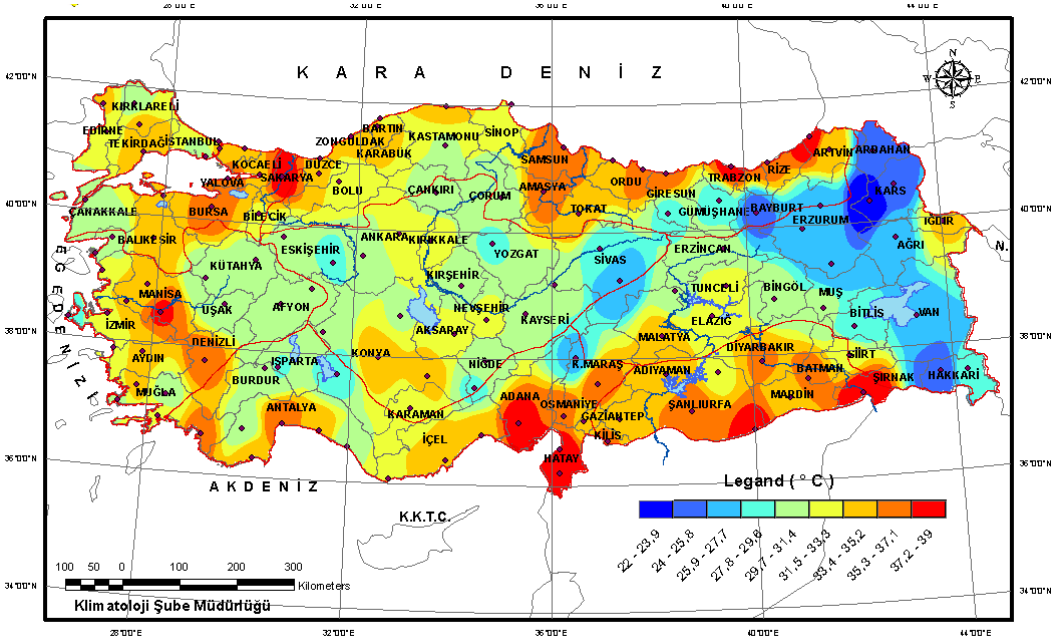


Figure 5.6 Turkey temperature map in 2014

Turkey humidity map was generated by general directorate of meteorology (Turkey humidity forecast, n.d.) (See Figure 5.7).

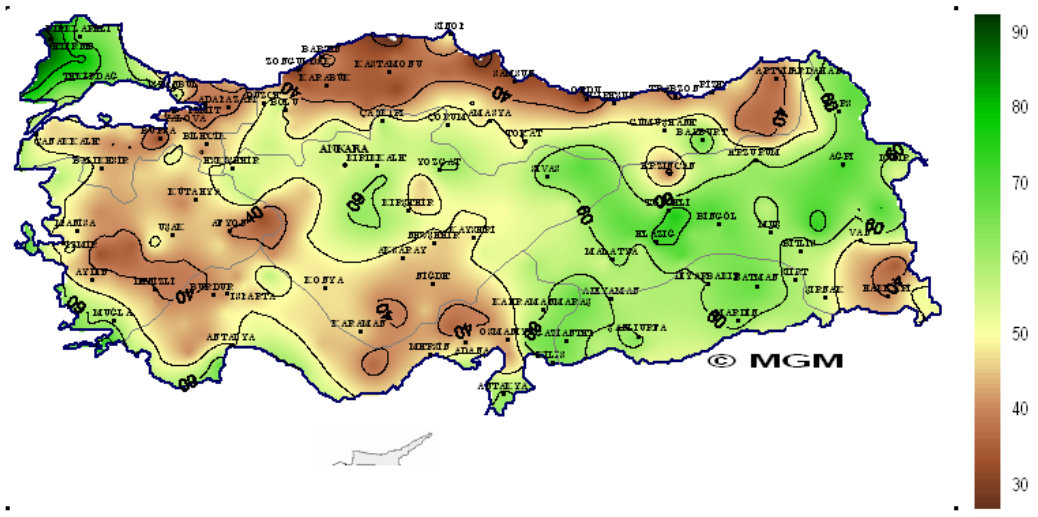


Figure 5.7 Turkey humidity forecast map in 2014

5.3 Proposed Initial Response Coordination Model

This initial response coordination model focuses on one of the most important aspect of the wildfire response phase: initial response (e.g. helicopter, aircraft, fire water - tender, manpower) in fixed regional forest directorates and airports. Model investigates the initial response one forest fire and at most three simultaneous forest fires. Land team (vehicles and manpower) have to reach the disaster in minimum time. For this purpose, a network model is produced in ArcGIS based on the real road map of Turkey. The network model aims at generating optimal routes for the minimizing the initial response time from 9 regional forest directorates to the forest fires under ArcGIS by taking into account the road speeds which is determined by the general directorate of highways of Turkey. Heuristic model which is programmed by MATLAB R2013a is taken into account meteorological conditions (humidity, wind speed and temperature) of 39 forest fires, minimum time to reach the fires from the 9 regional forestry directorates and 14 airports where the air teams are located. When a forest fires occurs in Eagan Coast especially in a peninsula and also the Taurus Mountains especially in a valley. These forest fires have suppression priority. Figure 5.8 represents flowchart of the FFIRCP, and may be decomposed into two sub-charts, namely ArcGIS and MATLAB.

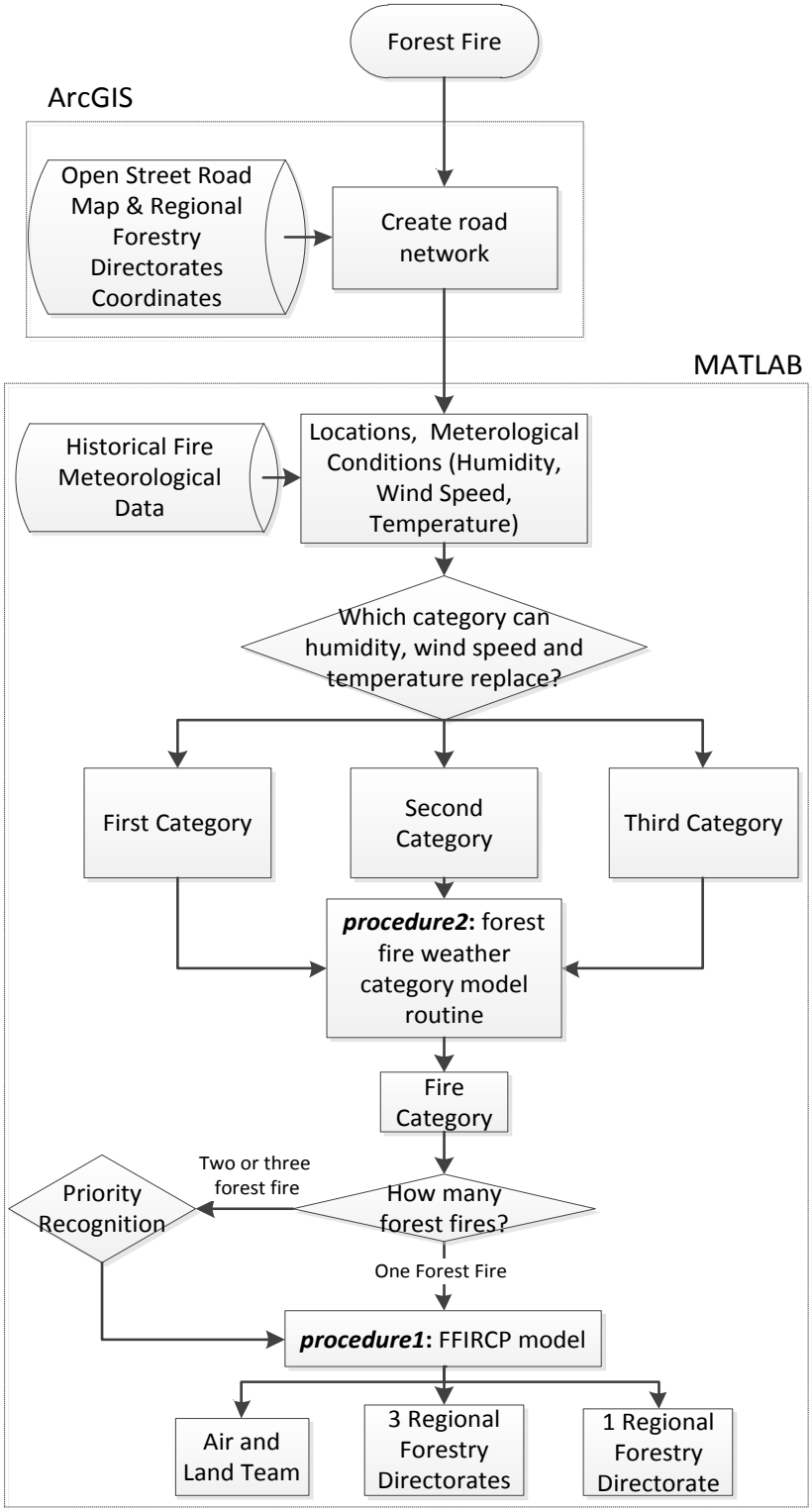


Figure 5.8 Flowchart of the FFIRCP

For one forest fire, initial response coordination model can be defined by the following assumptions;

A1. A forest fire has known humidity, wind speed and temperature data.
A2. Forest fires are divided into three categories which are defined by the Ministry of Forestry of Turkey for fire warning assessment.
A3. A forest fire has known where its coordinate information (WGS 1984).
A4. Resources available in limited quantities they are non-renewable during a forest fire.
A5. There is substation between resources.
A6. There are two types of resources, manpower and vehicle.
A7. The vehicle resources can be divided into two; ground and air.
A8. Air resources are only assigned to category 3 forest fires.
A9. The ground vehicle speed changes by the road class restrictions (see Table 5.4).
A10. The airplane speed is defined as 333 km/h which is normal cruising speed. From point of departure till (last 1 km) forest fire the airplane speed is constant with a value of 204 km/h.
A11. The helicopter speed is defined as 150 km/h which is normal cruising speed.
A12. Preparation time to departure from the airport is defined as 15 minutes for all air resources.
A13. All land vehicle resources and air resource is identical.
A14. The main objective is to minimize the time need for initial response to forest fires

5.3.1 Notation

The following notation is used to formulate the FFIRCP model:

Indices

i: index of land team (i=1,2,…, I)
j: index of air team (j=1,2,…, J)
c: index of meteorological condition (c=1,2,3)
d: index of regional forest directorates (d=1,2,…,9)
t: index of time period

Parameters

humid: humidity during forest fire
winds: wind speed during forest fire
temp: temperature during forest fire
cat_humid: humidity categorisation
cat_ winds: wind speed categorisation
cat_temp: temperature categorisation
M(cat_humid, cat_ winds, cat_temp): forest fire meteorological condition categorization
MC: forest fire meteorological condition ID
I: number of land team
J: number of air team
X_Coord: X coordinates
Y_Coord: Y coordinates
CF(*X_Coord*, *Y_Coord*): Coordination set for forest fire
CLT_d(*X_Coord*, *Y_Coord*): Coordination set for regional forest directorate *d*
CAT_j(*X_Coord*, *Y_Coord*): Coordination set for air team *j* (airport)
TDL_d: distance times from land team *d* to forest fire
TDA_j: distance times from air team *j* to forest fire
LRT: Land team initial response time
ART: Air team initial response time
FIR: Fire initial response time

5.3.2 Overall Procedure for FFIRCP Model

The overall procedure for the proposed FFIRCP model is outlined as follows;

---

procedure1: FFIRCP model
input: fire coordination data *CF*(*X_Coord*, *Y_Coord*), meteorological conditions (*humid*, *winds*, *temp*),
output: the best solution (the shortest initial response time)
begin
    $t \leftarrow 0$;
    categorize fire according to *humid*, *winds* and *temp*;
    evaluate *MC* by forest fire weather category model routine;
    //step 1: Land team planning
    determine CLT_d(*X_Coord*, *Y_Coord*) for all regional forest directorates
    calculate distance times TDL_d from each CLT_d*(X_Coord, Y_Coord)* to *CF(X_Coord, Y_Coord)*;
    sort the distance times TDL_d in increasing order;
    assign the land team with minimum TDL_d;
    $LRT \leftarrow min(TDL_d)$
    //step 2: Air team planning
    if *MC*=3
        assign air team;
        determine CAT_j(*X_Coord*, *Y_Coord*);
        calculate distance time TDA_j from CAT_j*(X_Coord, Y_Coord)* to *CF(X_Coord, Y_Coord)*;
        sort the distance times TDA_j in increasing order;
        assign the air team with minimum TDA_j;
        $ART \leftarrow \min(TDA_j)$
    evaluate fire initial response time *FIR* with minimum response time;
    $FIR \leftarrow \min(LRT, ART)$
    output the best solution *FIR*
end

5.3.3 Forest Fire Category

For one forest fire, forest fire category can be defined by the following assumptions;

B1. The humidity which is over 40 (%) is assigned as 1

B2. The humidity which is 30 – 40 (%) is assigned as 2

B3. The humidity is less 30 (%) is assigned as 3

B4. Wind is between 0 – 5 km/h (except 5) is assigned as 1

B5. Wind is 5 – 10 km/h is assigned as 2

B6. Wind is over 10 km/h is assigned as 3

B7. Temperature is 20 – 30 °C (except 30 °C) is assigned as 1

B8. Temperature is 30 – 35 °C is assigned as 2

B9. Temperature is over 35 °C is assigned as 3

The forest fire category is outlined as follows;

---

procedure2: forest fire weather category model routine
input: meteorological conditions (*humid*, *winds*, *temp*),
output: *meteorological category MC*
begin
define cat_humid, cat_winds and cat_temp according to forest fire category assumptions;
M ← M[cat_humid, cat_winds, cat_temp];
sort cat_humid, cat_winds, cat_temp by ascending;
if M[1,1,3] or M[1,2,3] or M[1,3,3]
M ←M[1,3,3];
else M[1,1,2]
M ←M[1,2,2];
MC ← mode(M);
output *meteorological category MC*
end

5.3.4 Additional Assumptions for Simultaneous Forest Fires

Sometimes, multiple forest fires can occur simultaneously. In addition to the above mentioned assumptions, the initial response coordination for multiple simultaneous forest fires can be defined by the following assumptions;

A15. The forest fire with high alert categorize has the priority during response coordination.

A16. If simultaneous forest fires belong to same category, the forest fire in geographic region with the highest fire risk has the priority during response coordination.

A17. If simultaneous forest fires belong to same category and same geographic region, response coordination is planned randomly.

For this kind of problem, an overall procedure can be used similar to overall procedure presented in Section 5.3.2.

5.4 Experimentation

5.4.1 Experimentation A: One Forest Fire

Experiment A1: Randomly generate a forest fire at time zero and plan initial response coordination

This forest fire started near Balıkesir in (28.4416, 39.8767) coordinates. The forest fire occurs under the following meteorological conditions, the fire is in danger of spreading and growth. Categorize of the meterological conditons is essential to right suppress to the wildfire. During this forest fire, the meteorological conditions were recored as follows;

- The humidity is over 40(%)
- Wind is over 10 km/h
- Temperature is 30 – 35 °C

For this forest fire, Table 5.6 shows the solution found by FFIRCP model. Balıkesir land team and air teams (airplane & helicopter) which are located in Izmir Selçuk Airport were used to suppress the forest fire. In this solution, initial response time is approximately 34 minutes.

Table 5.6 Initial response to one forest fire near Balıkesir

			Initial response coordination plan			
			Departure point	Departure time(min)	Travel time(min)	Arrival time
Land team	1	Man power Ground vehicle	Balıkesir	0	56.35	56.35
Air team	1	Aircraft (airplane)	Izmir - Selçuk	0	33.72	33.72
	2	Man power Aircraft (helicopter)	Izmir - Selçuk	0	55.93	55.93

Figure 5.9 illustrates the mapped solution found by FFIRC model, where fire location is represented by red circle, initial response teams assigned to this forest fire are represented by squares, i.e. land (green) and air (yellow).

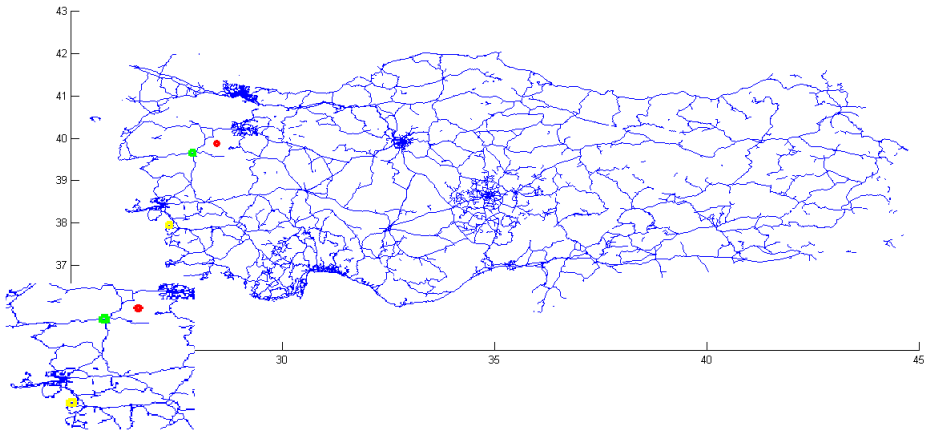


Figure 5.9 Response location for randomly generated one forest fire near Balıkesir

Experiment A2: Randomly select a historical forest fire and plan initial response coordination

This forest fire started near Osmaniye in (36.275314, 37.051967) coordinates. The forest fire occurs under the following meteorological conditions, the fire is in danger of spreading and growth. Categorise of the meterological conditons is essential to right suppress to the wildfire. During this forest fire, the meteorological conditions were recored as follows;

- the humidity was less 30(%).
- the wind was between 0 – 5 km/h (except 5).
- the temperature was over 35 °C.

For this forest fire, Table 5.7 shows the solution found by FFIRCP model. Kahramanmaraş land team and air teams (airplane & helicopter) which are located in Adana Kozan Airport were used to suppress Osmaniye (1999) forest fire. In this solution, initial response time is approximately 27 minutes.

Table 5.7 Initial response to one forest fire near Osmaniye

			Initial response coordination plan			
			Departure point	Departure time(min)	Travel time(min)	Arrival time
Land team	1	Man power Ground vehicle	Kahramanmaraş	0	72.85	72.85
Air team	1	Aircraft (airplane)	Adana - Kozan	0	26.93	26.93
	2	Man power Aircraft (helicopter)	Adana - Kozan	0	41.07	41.07

Figure 5.10 illustrates the mapped solution found by FFIRC model, where fire location is represented by red circle, initial response teams assigned to this forest fire are represented by squares, i.e. land (green) and air (yellow).

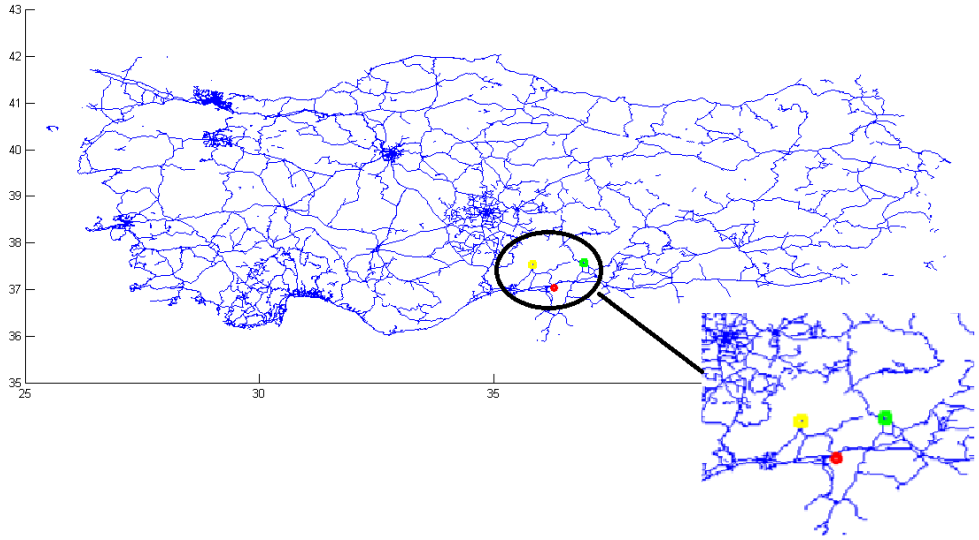


Figure 5.10 Response location for one forest fire near Osmaniye

5.4.2 Experimentation B: Simultaneous Forest Fires

Experiment B1: Randomly select two historical forest fire and plan initial response coordination

This forest fire started simultanenously near Hisarönü in (28.133974, 36.814558) coordinates and near Karabiga in (27.181188, 40.379946) coordinates. Two forest fires occur under the following meteorological conditions, the fire is in danger of spreading and growth. Categorise of the meterological conditons is essential to right suppress to the wildfire. During Hisarönü (2003) forest fire, the meteorological conditions were recored as follows;

- the humidity is over 40(%)
- the wind is over 10 km/h
- the temperature is 20 – 30 °C (except 30 °C)

In addition, Hisarönü is in prior areas where is in Eagan Coast especially in a peninsula.

During Karabiga (2000) forest fire, the meteorological conditions were recored as follows;

- the humidity is less 30(%)
- the wind is 5 – 10 km/h
- the temperature is over 35 °C

For these forest fires, Table 5.8 shows the solution found by FFIRCP model. Izmir land team and Denizli air teams (airplane & helicopter) were used to suppress the Hisarönü (2003) forest fire. In this solution, initial response time is approximately 39 minutes. Balıkesir land team and Edirne – Keşanlı air teams (airplane & helicopter) were used to suppress Karabiga (2000) forest fire. In this solution, initial response time is approximately 25 minutes.

Table 5.8 Initial response to two forest fires near Hisarönü and Karabiga

			Initial response coordination plan				
			Arrival point	Departure point	Departure time(min)	Travel time(min)	Arrival time
Land team	1	Man power Ground vehicle	Hisarönü (2003)	Izmir	0	189.81	189.81
Air team	1	Aircraft (airplane)		Denizli	0	38.68	38.68
	2	Man power Aircraft (helicopter)		Denizli	0	66.85	66.85
Land team	1	Man power Ground vehicle	Karabiga (2000)	Balıkesir	0	137.08	137.08
Air team	1	Aircraft (airplane)		Edirne - Keşanlı	0	24.70	24.70
	2	Man power Aircraft (helicopter)		Edirne - Keşanlı	0	36.10	36.10

Figure 5.11 illustrates the mapped solution found by FFIRC model, where fire location is represented by red circle, initial response teams assigned to this forest fire are represented by squares, i.e. land (green) and air (yellow).

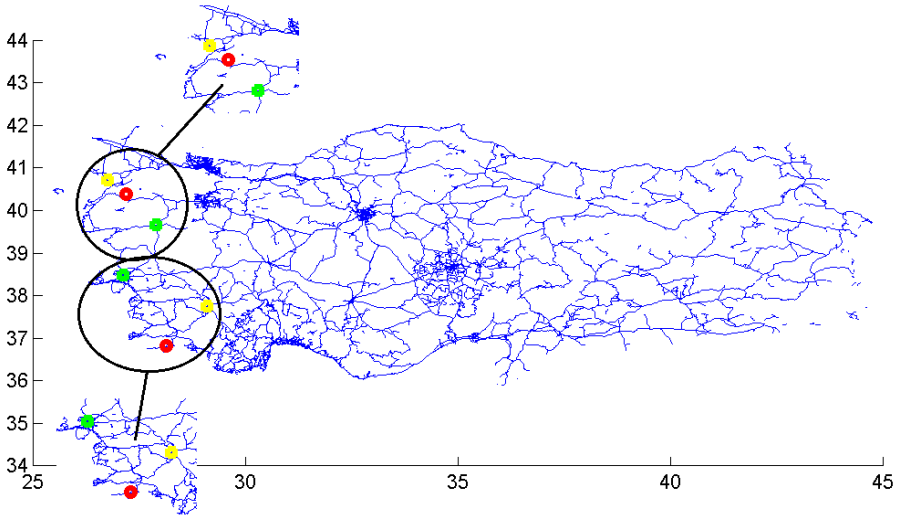


Figure 5.11 Response locations for two forest fires near Hisarönü and Karabiga

Experiment B2: Randomly select three historical forest fire and plan initial response coordination

This forest fires started simultanenously near Bodrum in (27.446849, 37.049664) coordinates, near Osmaniye in (36.275314, 37.051967) and near Turgutlu in (27.751699, 38.433852). Three forest fires occur under the following meteorological conditions, the fire is in danger of spreading and growth. Categorise of the meterological conditons is essential to right suppress to the wildfire. During Bodrum (2006) forest fire, the meteorological conditions were recored as follows;

- the humidity was less 30(%).
- wind is 5 – 10 km/h
- temperature is over 35 °C

In addition, Bodrum is in prior areas where is in Eagan Coast especially in a peninsula.

During Osmaniye (1999) forest fire, the meteorological conditions were recored as follows.

- the humidity was less 30(%).
- wind is 5 – 10 km/h
- temperature is over 35 °C

During Turgutlu (2000) forest fire, the meteorological conditions were recored as follows.

- the humidity is 30 – 40(%)
- the wind is 5 – 10 km/h
- the temperature is 20 – 30 °C (except 30 °C)

For these forest fires, Table 5.9 shows the solution found by FFIRCP model. Izmir land team and Izmir Selçuk air teams (airplane & helicopter) were used to suppress the Bodrum (2006) forest fire. In this solution, initial response time is approximately 33 minutes. Kahramanmaraş land team and Adana Kozan air teams (airplane & helicopter) were used to suppress the Osmaniye (1999) forest fire. In this solution, initial response time is approximately 27 minutes. Balıkesir, Afyonkarahisar and Isparta land teams were used to suppress the Turgutlu (2000) forest fire. In this solution, initial response time is approximately 130 minutes.

Table 5.9 Initial response to forest fires near Bodrum, Osmaniye and Turgutlu

			Initial response coordination plan				
			Arrival point	Departure point	Departure time(min)	Travel time(min)	Arrival time
Land team	1	Man power Ground vehicle	Bodrum (2006)	Izmir	0	164.96	164.96
Air team	1	Aircraft (airplane)		Izmir Selçuk	0	33.47	33.47
	2	Man power Aircraft (helicopter)		Izmir Selçuk	0	55.39	55.39
Land team	1	Man power Ground vehicle	Osmaniye (1999)	Kahramanmaraş	0	72.85	72.85
Air team	1	Aircraft (airplane)		Adana - Kozan	0	26.93	26.93
	2	Man power Aircraft (helicopter)		Adana - Kozan	0	41.07	41.07
Land team	1	Man power Ground vehicle	Turgutlu (2000)	Balıkesir	0	130.87	130.87
Air team	1	Aircraft (airplane)		Afyonkarahisar	0	212.27	212.27
	2	Man power Aircraft (helicopter)		Isparta	0	247.60	247.60

Figure 5.12 illustrates the mapped solution found by FFIRC model, where fire location is represented by red circle, initial response teams assigned to this forest fire are represented by squares, i.e. land (green) and air (yellow).

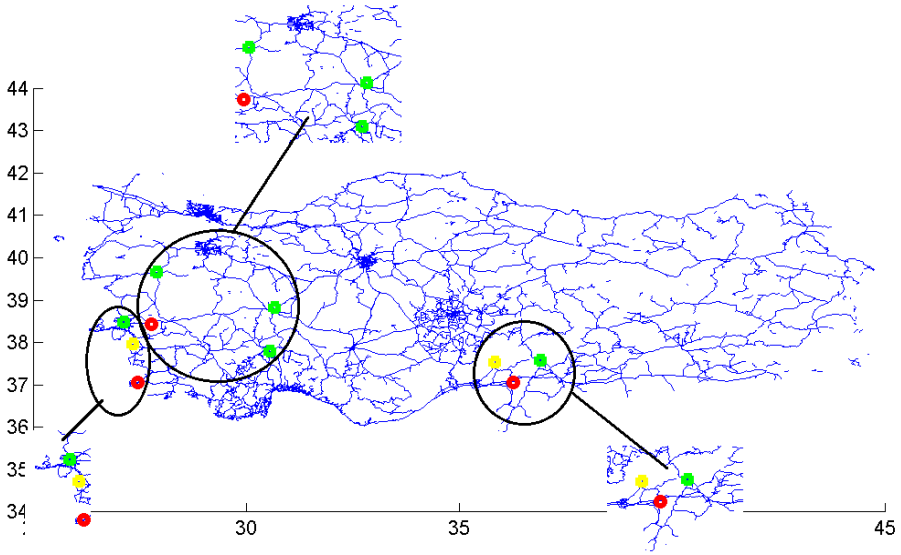


Figure 5.12 Response locations for three forest fires near Bodrum, Osmaniye and Turgutlu

CHAPTER SIX
CONCLUSION

Turkey suffers frequently from natural disasters of various kinds, from which the economic impacts are severe. Consequences from the disasters depend on two factors, namely natural and societal. This thesis defines and models an important response problem encountered in disaster response operation to decrease these consequences.

Turkey is under threat of natural and human made forest fire. Indeed, not only socio-economic but also natural condition of Turkey causes this disaster. Between the years 1970 – 2012, forest fire happened 1978 times in Turkey. At that time these records were confirmed as the highest number of natural disasters.

When a forest fire occurs, a range of facilities may be needed to cope with the disasters. Although these facilities may be efficient, we should coordinate the usages according to the requirements needed for a particular forest fire. Initiating firefighting activities on time, especially arrival of fire water tender and the ground team onto fire areas in critical response time is crucial for effective fighting against forest fires. Additionally, when multiple fires occur during a dry season, the response planning, and coordination become vital to fighting fires. Response coordination is for this reason of paramount importance.

During the dry season in summer, Turkish forests are vulnerable to forest fires. As stated in Section 4.2, most of these fires resulted in losing of our forest and its distinctive fauna. Also, the forest fires have severely affected the livelihoods of people relying on the forests.

Forest fires are not predictable events, but when it strikes will may damages the forest areas and endanger the settlements which is located the forests. It seems to be a need to cope with the forest fires. The main objective of forest fire management is to minimize the damage caused by forest. For this reason, in this thesis study, response coordination for forest fire management is proposed in order to shorten the time of response when a fire occurs. The proposed response coordination approach is

using Network Analyst Toolbox under ArcGIS software to determine the optimum route that minimizes the arrival time of the response team to forest fire location. Later, the approach is applied to coordinate the responses of potential forest fire zones in Turkey by considering 9 regional forest directorates of Turkey.

Forest fire initial response plan uses the historical 39 large - scale forest fires data which are humidity, wind speeds and temperature. The heuristic model propose initial attack from 9 regional forestry directorates and firefighting airplane and helicopter which are located in airports to the forest fires by considering priority areas and the meteorological conditions. Priority areas are Eagan Coast especially in a peninsula and also the Taurus Mountains especially in a valley.

There are still further works which can perform. Considerations can be given to reasonably consider evacuating the people which live endangered settlements where the forest fires occurs and reducing the uncertainty of the extinguish time with defining the real capacity of the resource units. The model can be regenerated for serving the all forest areas from the forest fire first responder stations and forestry operation directorates in Turkey.

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