DYNAMIC AMBULANCE DEPLOYMENT TO REDUCE AMBULANCE RESPONSE TIMES USING GEOGRAPHIC INFORMATION SYSTEMS: A CASE STUDY OF ODUNPAZARI DISTRICT OF ESKİŞEHİR PROVINCE, REPUBLIC OF TURKEY

Masoud SWALEHE

MASTERS DEGREE THESIS

Department of Remote Sensing and Geographic Information Systems

Thesis Supervisor: Prof. Dr. SEMRA GÜNAY AKTAŞ

Anadolu University

Graduate School of Sciences

June, 2016

This study was funded by the Scientific Projects' Research Commission of Anadolu University under Project No. 1603F127.

JURY AND INSTITUTE APPROVAL

Masoud SWALEHE's thesis titled ''Dynamic Ambulance Deployment To Reduce Ambulance Response Times Using Geographic Information Systems: A Case Study Of Odunpazarı District Of Eskişehir Province, Republic of Turkey'' for a masters degree in Remote Sensing and Geographic Information Systems was evaluated and accepted on the ....../....../2016 by the jury named below in accordance with relevant provisions of the Education and Examination Regulations of Anadolu University Graduate School of Sciences.

	Title-Name Surname	Signature
Member (Thesis Supervisor)	: Prof. Dr. SEMRA GÜNAY AKTAŞ	....
Member	: Prof. Dr. ERDAL KARKAŞ	....
Member	: Assoc. Prof. Dr. UĞUR AVDAN	....

....

Director Graduate School of Sciences.

ÖZET

AMBULANS MÜDAHALE SÜRESİNİ AZALTMAK İÇİN COĞRAFİ BİLGİ SİSTEMLERİNİ KULLANARAK DİNAMİK AMBULANS KONUŞLANDIRMA: TÜRKİYE CUMHURİYETİ, ESKİŞEHİR İL, ODUNPAZARI İLÇESİNİN BİR ÖRNEK OLAYI

Masoud SWALEHE

Uzaktan Algılama ve Coğrafi Bilgi Sistemleri Anabilim Dalı, Yüksek Lisans Tezi

Anadolu Üniversitesi, Fen Bilimleri Enstitüsü, Haziran, 2016

Tez Danışman: Prof. Dr. Semra GÜNAY AKTAŞ

Ambulanslar çağrı aldıktan sonra, hemen hastaya ulaşıp müdahale etmelilerdir özellikle kalp krizlerinde bu süre ne kadar azalırsa hastanın yaşama şansı o kadar artar. Ambulans yerleri hastaya ulaşma süresi açısından doğrudan etkilidir. Bu çalışmanın temel amacı Eskişehir'in Odunpazarı ilçesi acil hizmetlerindeki ambulans yanıt sürelerini azaltmaktadır.

Bu çalışmada talep ve zamana göre dinamik olarak ambulans yerlerini belirlemek için coğrafı bilgi sistemleri teknolojisinden yararlanılmıştır. Ambulans çağrılarının (talep), konum zamana göre dağılımı kullanılarak ve sistem durum yönetimi ile en uygun ambulans yerleri talebin fazla olduğu bölgelerde yoğunlaştırılmış ve böylelikle yanıt süreleri azaltılmıştır. ArcGIS ağ analizi konum belirleme aracı kullanılarak olabilecek en fazla alanı kapsayacak şekilde sınırlı sayıdaki ambulans her vakaya 5 dakika içerisinde ulaşabilecek şekilde istasyonlar konumlandırılmıştır ve bunun için konum optimizasyon modeli baz alınmıştı.

Sonuç olarak ambulans talep alanının %77,6'sına 5 dakikada vakaya yanıt verecek istasyon yerleri belirlenmiştir. Türkiye Cumhuriyeti Eskişehir il sağlık müdürlüğünden elde edilen 1 Ocak 2014 - 31 Aralık 2014 tarihleri arasında gerçekleşen toplam 20.260 acil ambulans çağrısı verisi bu çalışmada kullanılmıştır.

Anahtar Sözcükler: Acil sağlık hizmetleri, Ambulans yanıt süreleri, Coğrafi bilgi sistemleri, Hastane dışı kalp durması, Dinamik ambulans konumlandırma.

ABSTRACT

DYNAMIC AMBULANCE DEPLOYMENT TO REDUCE AMBULANCE RESPONSE TIMES USING GEOGRAPHIC INFORMATION SYSTEMS: A CASE STUDY OF ODUNPAZARI DISTRICT OF ESKİŞEHİR PROVINCE, REPUBLIC OF TURKEY

Masoud SWALEHE

Department of Remote Sensing and Geographic Information Systems, Masters Degree Thesis

Anadolu University, Graduate School of Sciences, June, 2016

Thesis Supervisor: Prof. Dr. Semra GÜNAY AKTAŞ

Ambulances should always reach patients in the shortest time possible whenever they are called upon so as to increase patient survival chances especially in cardiac related medical cases. The placement of ambulances directly affects the time ambulances reach patients. The primary objective of the study was to reduce ambulance response times for Odunpazarı District emergency medical services system and increase patient survival chances as a result.

The study used geographic information systems' technology to dynamically reallocate ambulance resources according to demand and time so as to reduce ambulance response time. Geospatial-time distribution of ambulance calls (demand) was used as a basis for optimal ambulance deployment using system status management strategy to deploy ambulances where higher demands are expected to cause ambulance response time reduction. The ArcGIS Network Analyst location allocation tool basing on maximal coverage location problem optimization model was used to come up with optimal ambulance stations to service most call demand areas within 5 minutes of drive time with a limited ambulance fleet size.

As a result 77.6% of ambulance demand areas were located within 5 minutes of drive time from the nearest ambulance station. A total of 20,260 ambulance demand calls' data collected from January 1st to December 31st 2014 was used for the study which was obtained from the Eskişehir Province Health Directorate.

Keywords: Emergency medical services; Ambulance response times; Geographic information systems; Out of hospital cardiac arrest; Dynamic ambulance deployment.

ACKNOWLEDGEMENT

I firstly thank the Almighty ALLAH for the gift of life to enable me pursue my education and for all the time I have spent on the universe. I also acknowledge the consistent teaching, support and mentoring offered to me by my teachers namely; Prof Dr. Semra GÜNAY AKTAŞ, Prof Dr. Alper ÇABUK, Associate Prof Dr. Hakan UYGUÇGİL, Associate Prof Dr. Uğur AVDAN, Associate Prof Dr. Saye NİHAN ÇABUK, Associate Prof Dr. Emrah PEKKAN, Associate Prof Dr. Muammer TÜN, Associate Prof Dr. Metin ALTAN, Associate Prof Dr. Alper Tolga KÜMTEPE, Prof Dr. Mustafa TOMBUL and Prof Dr. Can AYDAY.

I extend my gratitude to the Eskişehir Province Directorate of Geographic Information Systems and the Eskişehir Province Directorate of Health especially Mr. Serdar ERGEN, Ms. Duygu KARACA and Ms. Leyla HÜN for providing data which was used in this study. The support and encouragement from my loving family has been wonderful during my many years in school and I pray that the Almighty God continues to bless them with good health and enable them prosper. And to all my friends of different nationalities and backgrounds who have made my stay and study at Anadolu University very pleasant may the Almighty God continue to bless you.

Masoud SWALEHE

June/28th/2016

STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES AND RULES

I hereby truthfully declare that this thesis is an original work prepared by me; that I have behaved in accordance with the scientific ethical principles and rules throughout the stages of preparation, data collection, analysis and the presentation of my work; that I have cited the sources of all data and information that could be obtained within the scope of this study, and included these sources in the references section; and that this document has been scanned for plagiarism with "a scientific plagiarism detection program" used by Anadolu University , and that "it did not plagiarize" whatsoever. I also declare that, if a case contrary to my declaration is detected in my work at any time, I hereby express my consent to all the ethical and legal consequences that might arise.

Masoud SWALEHE

CONTENTS

Page

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

Page

Page

LIST OF ABBREVIATIONS

AVL : Automatic Vehicle Location

BACOP: Backup Coverage Optimization Problem

CAD : Computer-Aided Dispatch

CPR : Cardiopulmonary Resuscitation

DCM : Double Coverage Model

EMS : Emergency Medical Services

ESRI : Environmental Systems Research Institute

GIS **:** Geographic Information Systems

GPS : Global Positioning Systems

LSCM: Location Set Covering Model

MCLP: Maximal Covering Location Problem

OHCA**:** Out of Hospital Cardiac Arrest

RT : Response Time

SSM **:** System Status Management

SSP : System Status Plan

1. INTRODUCTION

This chapter explains the background of the study, problem statement, objectives of the study, significance of the study and gives a clear justification why there was need for the study to be carried out.

1.1. Background of the Study

The utilisation of ambulance services in response to emergency medical cases has been an integral part of healthcare service delivery for a long time in most parts of the world. Ambulance RT is often used as a basis for evaluating the performance of an Emergency Medical Services (EMS) system. One of the important issues in healthcare is pre-hospital care provided by EMS. The mission of EMS is to coordinate the delivery of timely and appropriate first aid services under emergency conditions from incident reporting, i.e. call to an emergency number, to definitive care, involving facilities, equipment and personnel trained to provide phone support, stabilization of patient's condition and transportation to an appropriate care facility. Such services aim at reducing patient mortality, prevent disability and improve chances of recovery (Aringhieri, Carello, & Morale, 2007a; R. L. Church & Gerrard, 2003).

Ambulance resources are often constrained and EMS providers cannot continuously expand their ambulance fleet size, a more optimal deployment of ambulances to meet the demands for ambulance services is an attractive option to achieve faster response. Dynamically reassigning ambulance deployment locations to balance ambulance availability and demands can be a more effective strategy to reduce ambulance RT (Lam et al., 2014). In this study, the performance of a dynamic ambulance reallocation strategy based on the idea of SSM was evaluated. The study also made use of Location Allocation tool in ArcGIS network analysis to come up with ambulance candidate sites where ambulances can be deployed to achieve a lower ambulance RT. The study was carried out with an aim of developing a more efficient dynamic ambulance resource allocation plan for Odunpazarı District using geographic and time aspects of ambulance demand calls recorded between January 1st 2014 to December 31st 2014 using Geographic Information systems (GIS) technology.

1.2. Statement of the Problem

The survival of individuals with serious medical cases of stroke, myocardial infarction, pulmonary embolism and cardiac arrest is largely dependent on the RTs of ambulances which provide out of hospital acute medical care. The shorter the ambulance RT, the greater the possibilities of survival. It has been found out that, the immediate delivery of medical services to a patient in a cardiac arrest can have a survival rate of approximately 67%, while the decline in survival rate without treatment is 5.5% per minute and after 12 minutes, there is no possibility of the patient to survive (Peters & Hall, 1999).

According to ambulance demand calls' data (registered between January 1st and December 31st 2014) the average RT of Odunpazarı District EMS was 10 minutes and one specific case, an ambulance demand call in Karapinar parish received an ambulance after 24 minutes of waiting. When there are serious cases like cardiac arrest a patient might not survive due to unavailability of timely emergency medical care intervention especially defibrillation. The ambulance deployment plan used by the EMS management of Odunpazarı District is static; thus each permanent station has one ambulance all day long to serve demand calls. These ambulances only leave their stations when ambulance demand calls arrive and come back to the same stations after delivering patients to hospitals. The population of the Odunpazarı District is dynamic thus it changes between hours of the day and therefore ambulance deployment should be dynamic to provide adequate optimal coverage.

Cardiac arrest victims have higher chances of survival if they receive emergency medical attention within 4 minutes after an attack (Ong et al., 2010). Due to this, the study found reason to model a dynamic load responsive ambulance deployment strategy for the Odunpazarı District EMS to reduce ambulance RTs and in turn reduce deaths which result from Out of hospital cardiac arrest (OHCA). Ambulance demand calls' data which were used in the study were obtained from the Eskişehir province Directorate of Health which manages Odunpazarı District EMS.

1.3. Objectives of the Study

The primary objective of the study was to develop a dynamic, optimal, demand and time based ambulance fleet deployment plan for Odunpazarı District with an aim of reducing ambulance RTs without enlarging the ambulance fleet size;

The secondary objectives of the study were;

- To demonstrate through a GIS based model how a higher demand coverage can be achieved with a limited ambulance fleet size.
- To design a valid GIS- based framework to assist healthcare planners in mapping and assessing EMS vehicle response.
- To demonstrate the usefulness of the approach using empirical data, of Odunpazarı District of Eskişehir Province in the study.

1.4. Justification of the Study

The placement or deployment plan of ambulances, which has been a subject of thorough investigations has been found to have an effect on the time ambulance services reach patients (Aringhieri, Carello, & Morale, 2007b; Berlin & Liebman, 1974; Iskander, 1989). Various research studies undertaken have all registered steady reduction in ambulance RTs making use of dynamic ambulance deployment basing on system status management (SSM) plan implemented by GIS technology (Lam et al., 2014; M. E. Ong et al., 2009; Ong et al., 2010). Ambulances should not have fixed stations, they should be continuously moved around cities or provinces, presumably to decrease ambulance RTs and by so doing SSM has drastically changed EMS system for the better. The fleet of 17 ambulances maintained by Odunpazarı District EMS can provide proper coverage and service within 5 minutes of drive time if a dynamic, load-responsive ambulance deployment plan is implemented.

Victims of non-traumatic cardiac arrest have a better outcome if basic life support (BLS) Cardiopulmonary resuscitation (CPR) is initiated within 4 minutes of the onset of cardiac arrest and advanced life support (primarily defibrillation) is provided within 8 minutes (Pons & Markovchick, 2002). In a Scottish study, it was calculated that a reduction in target ambulance RTs of 90% of calls from 14 minutes to 8 minutes would increase cardiac arrest survival from 6% to 8% and an ambulance RT of 5 minutes would increase survival by up to 11%. Faster ambulance RT mean earlier initiation of CPR and earlier defibrillation (Pell, Sirel, Marsden, Ford, & Cobbe, 2001).

The ‘‘chain of- survival’’ concept also states that survival can be improved with early access, early CPR, early defibrillation, and early advanced care. There is currently good evidence that indicates the importance of delivering early defibrillation (<4 minutes) see Figure 1.1 (Eisenberg et al., 1980; White, Asplin, Bugliosi, & Hankins, 1996).

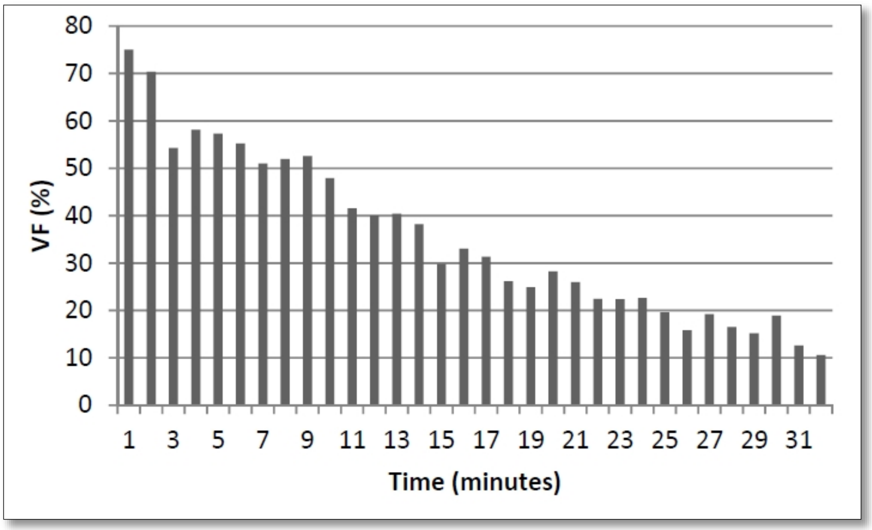


Figure 1.1. *The Patient Survival Rate In Terms Of Percentages In Comparison With the Time of Defibrillation after Cardiac Arrest*

Source: *Sund, 2010*

A study carried out in Texas to come up with an efficient ambulance deployment strategy ensured reduction in average ambulance RT, improved prehospital medical care, equity improvements and capital and operation costs savings with the introduction of dynamic ambulance deployment strategy (Eaton, Daskin, Simmons, Bulloch, & Jansma, 1985). Early bystander CPR is less helpful in resuscitation if EMS personnel equipped with the defibrillator arrive late, or about 8-12 minutes after collapse (Cummins, Ornato, Thies, & Pepe, 1991). The use of additional (flexible) ambulance locations with an equal number of ambulances is a straightforward and cost-effective alternative to increasing the flexibility and adaptability of an EMS system (Degel, 2015).

1.5. Thesis Outline

This thesis report is subdivided into five chapters which are; Introduction, Review of Literature, Research Methodology, Results and Discussions and Conclusions and Recommendations.

Chapter 1. Introduction

In this chapter the research topic is introduced, key concepts are defined, the problem the study was meant to address is clearly stipulated and reasons are put forward to clearly explain (justify) why there was a need to carry out the study.

Chapter 2. Review of Literature

This chapter clearly reviews and indicates what other scholars and writers have written and studied about among others Ambulance Response Time, Geographic Information Systems, Emergency Medical Services, Facility Allocation Models and Out of Hospital Cardiac Arrest.

Chapter 3. Research Methodology

This chapter discusses the study area, the means of data collection, data analysis methods, the process of arriving at results and the various computer software used for this particular study.

Chapter 4. Results and Discussions

The output of the analysis carried out on the data that was used in the study is presented in this chapter in form of maps, graphs and tables. Maps, graphs and tables indicating optimal ambulance fleet deployment stations according to demand and time are all included in this chapter and discussed in detail. Graphs and tables indicating the origin of ambulance demand calls are also included in this chapter.

Chapter 5. Conclusion and Recommendations

In this chapter of the report, conclusions about the findings are formulated while recommendations are made not only to emphasize the significance of geographic information systems to emergency medical systems particularly in ambulance fleet deployment but also to future researchers who will find this subject area interesting.

2. REVIEW OF LITERATURE

This chapter reviews relevant literature concerning the main subject areas which formed part of the study and these are; Emergency Medical services, Ambulance Response Time, Geographic Information Systems, Ambulance Deployment Models and System Status Management.

2.1. Ambulance Response Time

Authors in the field of emergency medicine have abundantly written about ambulance RT see Figure 2.1. ''Ambulance RT is defined as the period between an emergency call is recorded and the time the first ambulance arrives at the scene in a life-threatening event to provide out of hospital medical care'' (Maleki, Majlesinasab, & Sepehri, 2014). ''Ambulance RT is a waiting period which is referred to as the time from when the call has reached the emergency operator until the ambulance personnel have reached the patient'' (Andersson, 2005).

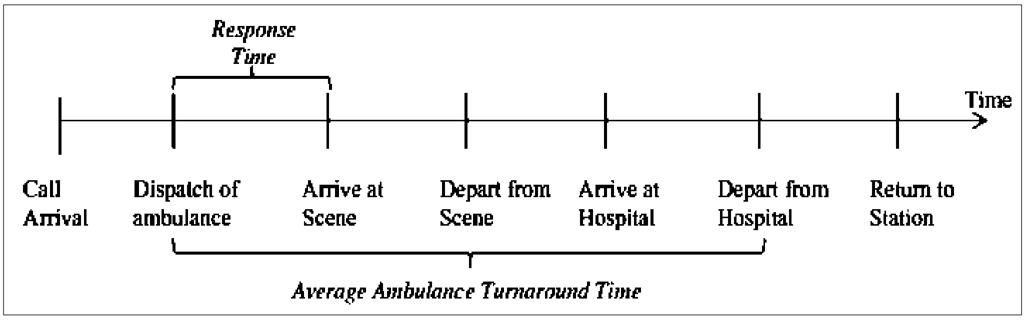


Figure 2.1. *Ambulance Response Time*

Source: *Lam, Nguyen, et al., 2015*

Ambulance RT is an integral part of out of hospital healthcare provision. A study was carried out about the effect of ambulance RT on the survival of OHCA patients where a reduction of 1 minute of ambulance RT resulted into increased patient survival rate from 3.9 % to 4.6% (Sund, 2010). The importance of ambulance RT as a key performance indicator of an EMS is driven by the need to treat time-sensitive medical conditions without delay to increase patient survival chances. Examples of such conditions include OHCA, acute myocardial infarction, stroke, and severe trauma cases (Valenzuela, Roe, Cretin, Spaite, & Larsen, 1997; Valenzuela et al., 2000). Time is a vital factor in emergency situations to save lives. Therefore, it is critical that ambulances be effectively pre-positioned at the correct locations in anticipation of ambulance demand calls, so that there can be adequate coverage within the target response time thresholds (Lam, Ng, Lakshmanan, Ng, & Ong, 2016).

The relationship between ambulance RT and survival in five mixed patient populations (trauma and non-trauma) was studied using retrospective research designs. The study included 5,424 patients serviced by an EMS agency in a crude analysis of death probability by ambulance RT. Their findings were that there was no significant difference between median RT in the survivors vs. non-survivors groups, nor was there a difference between observed and expected deaths. Mortality risk was however significantly reduced for those patients in whom ambulance RT was five minutes or less (Blackwell & Kaufman, 2002).

2.2. Emergency Medical Services (EMS)

EMS is a significant part of healthcare service delivery and much research has been carried out in this area of study. An EMS is defined as ''a system that provides for the arrangement of personnel, facilities and equipment for the effective and coordinated delivery in an appropriate geographical area of health care services under emergency conditions'' (Walz, 2010). Emergency Medicine is a specialty based on the knowledge and skills required for the prevention, diagnosis and management of urgent and emergency aspects of illness and injury affecting patients of all age groups with a full spectrum of undifferentiated physical and behavioral disorders. It is a specialty in which time is critical (Organization, 2008).

The practice of Emergency Medicine encompasses the pre-hospital and in hospital triage, resuscitation, initial assessment and management of undifferentiated urgent and emergency cases until discharge or transfer to the care of another physician or health care professional. It also includes involvement in the development of pre-hospital and in-hospital emergency medical systems.

A typical EMS receives a request for medical service which usually arrives by phone and is answered by a dispatcher, who inputs the information by asking some predefined questions, and determines the priority of the request calls. When a request becomes known to the dispatching system, the dispatcher checks with available ambulances and assigns the request to an ambulance. In this process, there are some possible criteria for the decision. For example, the nearest available ambulance may be chosen; or some other criteria can also be embedded in the decision support system for dispatching. The crew of the ambulance may need to take some first-aid measures for the patient. When the service is completed, the ambulance takes the patient to a hospital. Sometimes, the patient may appoint a hospital in case the incident is not very urgent; otherwise, the ambulance transport the patient to a hospital, which has the available resources for treating the patient and is the nearest from the call's scene. When the ambulance arrives at the hospital, the crew starts to unload the patient and deliver him (or her) to the corresponding department in the hospital. Then the whole service for the request is finally completed. The ambulance becomes idle (available) again and goes to a waiting location if there are not new requests assigned to it; otherwise, the ambulance needs to set off to the next call's scene immediately (Zhen, Wang, Hu, & Chang, 2014). A generic model showing the working of an EMS system see Figure 2.2 is represented by solid and dotted lines is the static dispatch model where ambulances are only dispatched from bases. On the other hand, the model represented by a combination of solid and dashed lines is a multi-location dispatch model, where the ambulances may be dispatched from wherever they are (Pinto, Silva, & Young, 2015).

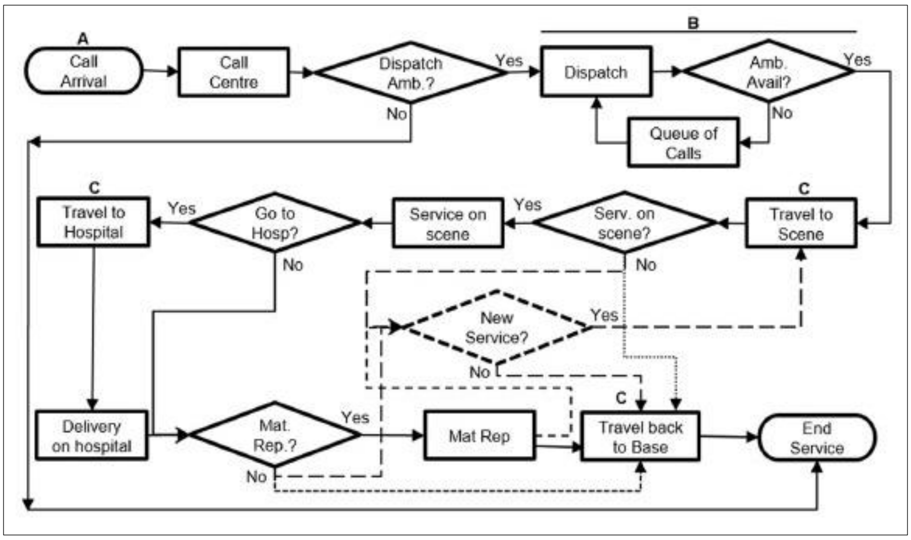


Figure 2.2. *The Working of an Emergency Medical System*

Source: *Pinto, Silva, & Young, 2015*

2.3. Geographic Information Systems (GIS)

Geographic Information Systems (GIS) potentially offers far greater power for manipulation and analysis of data than had been available with earlier systems, broadly aimed at map or image reproduction, but also place greater demands on data accuracy and availability (Martin, 1996). Different authors have used different words to define what GIS is, but the common factor has been that almost all of them mention what it does and its components and this therefore makes the differing definitions of GIS look similar in that way. ''GIS is a set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes'' (Carver, Cornelius, & Heywood, 2006).

''GIS is a digital system for the acquisition, management, analysis and visualization of spatial data for the purposes of planning, administering and monitoring the natural and socioeconomic environment. It represents a digital model of geography in its widest sense'' (Gottfried, 2003). ''GIS is a collection of computer hardware, software, and geographic data for capturing, storing, updating, manipulating, analyzing, and displaying all forms of geographically referenced information'' (Galati, 2006).

''A GIS is a combination of skilled persons, spatial and descriptive data, analytic methods, and computer software and hardware all organized to automate, manage, and deliver information through geographic presentation'' (Zeiler, 1999). GIS is one of the most important components of any approach to global problem solving. It has been applied by a number of disciplines to a correspondingly wide range of problems. Governments, nongovernmental organizations, businesses, and educational institutions all now use GIS technology (Bernhardsen, 2002).

Most writers seem to agree on the definition of GIS since most of the definitions include phrases like data capture, processing, updating, analyzing, storing, output, which is majorly what a GIS does and also includes people, data, methods, hardware, software which are the components of GIS and therefore it is safe to concur that most authors use the functions and components of GIS to define it.

2.3.1. Components of GIS

Like any system that is a whole constructed of parts, a GIS can also be viewed as a combination of several parts that create the overall system, although variations exist in what exactly those parts might be, a GIS is generally considered to be composed of the following interrelated parts that follow the information systems definition closely (Tomaszewski, 2014). GIS can be viewed as a software package, the components being the various tools used to enter, manipulate, analyze and output data (Carver et al., 2006).

2.3.1.1. Software

Software is used for running GIS operations. For example, commercial GIS software packages such as Environmental systems research institute's ArcMap or open-source web mapping environments such as Open Layers (Tomaszewski, 2014).

2.3.1.2. Hardware

Hardware is the computer system on which a GIS operates. Today, GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations (Buckley & Reid, 1990).

2.3.1.3. People

GIS technology is of limited value without the people who manage the system and develop plans for applying it to real world problems. GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. The identification of GIS specialists versus end users is often critical to the proper implementation of GIS technology (Buckley & Reid, 1990).

2.3.1.4. Methods or knowledge

A successful GIS operates according to a well-designed implementation plan and business rules, which are the models and operating practices unique to each organization. As in all organizations dealing with sophisticated technology, new tools can only be used effectively if they are properly integrated into the entire business strategy and operation. To do this properly requires not only the necessary investments in hardware and software, but also in the retraining and/or hiring of personnel to utilize the new technology in the proper organizational context. Failure to implement a GIS without regard for a proper organizational commitment will result in an unsuccessful system (Buckley & Reid, 1990).

2.3.1.5. Data

Perhaps the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house, compiled to custom specifications and requirements, or occasionally purchased from a commercial data provider. A GIS can integrate spatial data with other existing data resources, often stored in a corporate DBMS. The integration of spatial data often proprietary to the GIS software), and tabular data stored in a DBMS is a key functionality afforded by GIS (Buckley & Reid, 1990). Data will always be the more important component of a GIS see Figure 2.3. Representation of the earth's features, which is the conceptual core of GIS, is fundamentally based on data and hence why significant discussion of GIS data is always made (Tomaszewski, 2014).

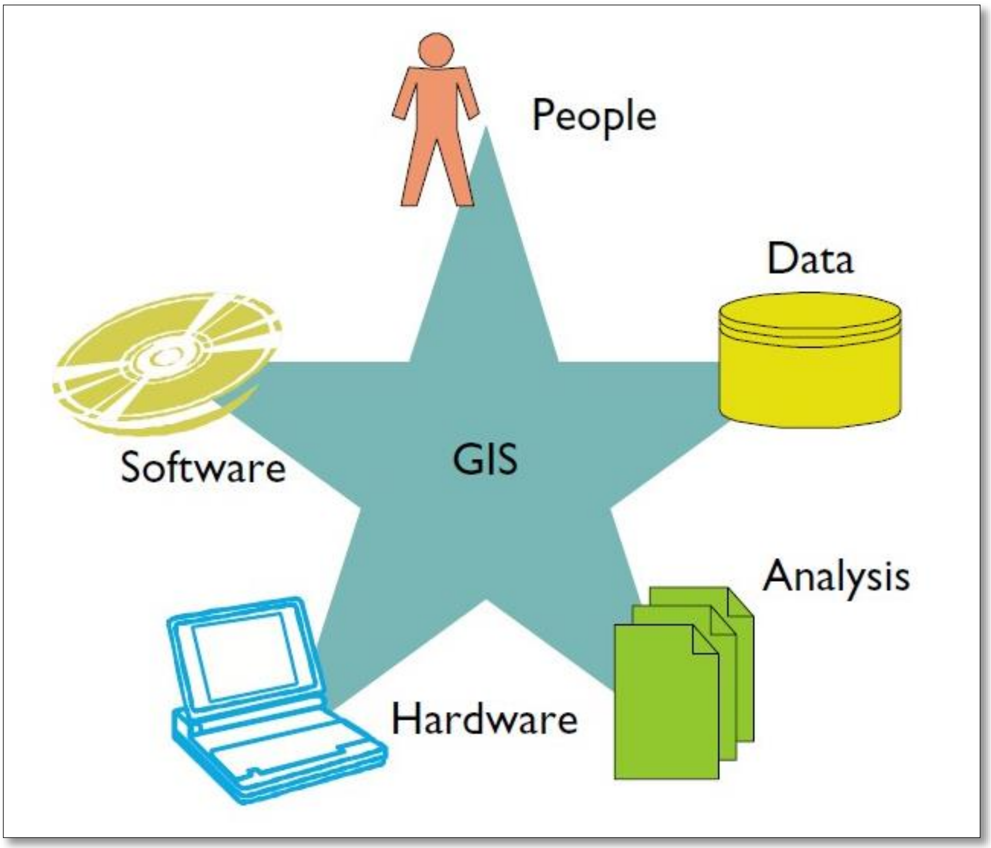


Figure 2.3. *Components of GIS*

Source: *Zeiler, 1999*

2.3.2. Representation of GIS data

Data in a GIS platform is represented as either spatial data (location related) or attribute data (descriptive data about the spatial data) for example data about a plot of land is captured by its location in form of longitude and latitude (which is its spatial data) and then other related data concerning the plot like the owner details, the land tenure system, its size and value which are its attribute data.

2.3.2.1. Spatial data

All GIS software has been designed to handle spatial data (also referred to as location data). Spatial data are characterized by information about position, connections with other features and details of non-spatial characteristics. Spatial data may include: latitude and longitude as a geographical reference. This reference can be used to deduce relationships with nearby features of interest. Data structures provide the information that the computer requires to reconstruct the spatial data model in digital form. There are many different data structures in use in GIS. This diversity is one of the reasons why exchanging spatial data between different GIS software can be problematic. However, despite this diversity data structures can be classified according to whether they are used to structure raster or vector data (Carver et al., 2006).

2.3.2.2. Attribute data

An attribute is regarded as a property inherent in a spatial entity. For example, the ownership of a land parcel is an attribute of the land parcel. Characteristics, variables, and values of spatial entities in GIS are described by attribute data. The natural or real world can be represented in either of two ways: continuous or discrete representation. According to their continuous or discrete nature, attribute data can also be classified as categorical attribute data or continuous attribute data (Shi, 2009).

In addition to the geometry map of features (spatial data), a GIS can store attributes of the map features. For instance the GIS database may store a map of tax parcel boundaries. Attached to each parcel will be a database record containing its attributes. These might include the name of the owner, the street address, and the assessed value of the property. GIS enables one to search and display spatial data based on attribute criteria (Korte, 2001).

Spatial data models

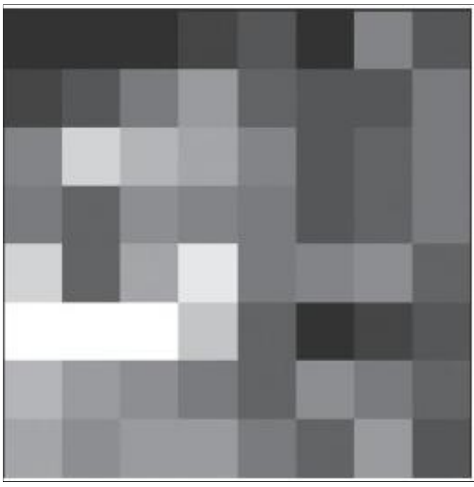
A model is simply a means of representing 'reality' and spatial data models provide abstractions of spatially referenced features in the real world (Lloyd, 2010). At present there are two main ways in which computers can handle and display spatial entities. These are the raster and vector approaches.

Geographic information systems utilize two spatial primary data models to manipulate and structure geographic data: the raster data model and the vector data model. Like any complex data structure, raster and vector data have a myriad of different realizations that vary in complexity through use, appearance, format, and file size. Although distinctly different, these affiliate data structures share two characteristics: (1) They visually represent real-world features, and (2) they are subject to orientation within the real world (Galati, 2006).

2.3.2.1.1. Raster spatial data model

The raster spatial data model is one of a family of spatial data models described as tessellations. In the raster world individual cells are used as the building blocks for creating images of point, line, area, and network and surface entities (Carver et al., 2006). Raster data are essentially gridded data (equivalent to a bitmap) with an attribute value attached to each cell of the grid. A poly grid is a similar concept where a range of attribute values is attached to each cell see Figure 2.4 (Craglia & Maheswaran, 2004).

Raster data structures characterize continuous data (such as imagery) and are exceptionally strong where boundaries and point information are not well defined. Raster data provide data as a pixel grid, whereby each pixel or cell is a feature capable of retaining properties and attributes (Galati, 2006).



45	44	44	43	42	44	38	42
43	42	34	35	41	42	42	39
38	32	34	35	38	42	41	39
39	41	37	38	39	42	41	39
32	41	35	31	39	38	37	41
29	29	28	33	41	44	43	42
34	36	37	39	41	37	39	41
35	37	36	36	39	41	36	42

Figure 2.4. *Raster Data Illustration Using (Left) Grey Scales and (Right) Numerically Associated Values*

Source: *Lloyd, 2010*

2.3.2.1.2. Vector spatial data model

A vector spatial data model uses two-dimensional Cartesian (x, y) co-ordinates to store the shape of a spatial entity. In the vector world the point is the basic building block from which all spatial entities are constructed. The simplest spatial entity, the point, is represented by a single (x, y) coordinate pair. Line and area entities see Figure 2.5 are constructed by connecting a series of points into chains and polygons. Vector data structures characterize discrete data (such as roads, pipelines and topographic features) and are exceptionally strong where distinct boundaries and point information are well defined. This data structure is constructed on ordered two- and three-dimensional coordinates ([x, y] and [x, y, z], respectively). Features are represented as geometric shapes defined through single or grouped coordinates on a set grid (Carver et al., 2006).

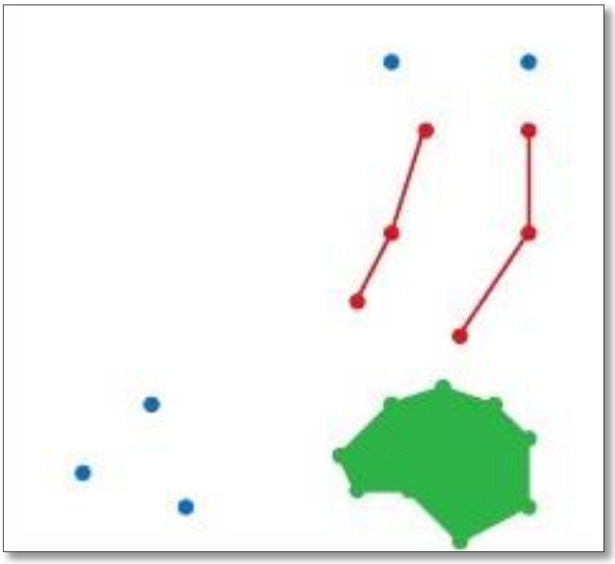


Figure 2.5. *Vector Spatial Data Model Represented By Points, Lines and Polygons.*
Source: *Carver et al., 2006*

The representation of vector data see Figure 2.5 generally combines the entity data with associated attribute data kept in a separate file through a database management system, and then link them together. It means that the entity data and corresponding attribute data in the form of tables can be stored and linked through a software linkage for example ArcGIS, QGIS software link vector data to its attribute data by using a database management system (Reddy, 2008).

2.3.3. Application areas of GIS

In the past, a map served as the major tool for illustrating and developing informed decisions by using spatial information. Now, GIS are available in almost all institutions dealing with spatial study. GISs are becoming powerful environments for managing large volumes of data. The main characterization of GIS is the ability of describing each entity by spatial data through its location as well as through shape (Faiz & Krichen, 2012). GIS technology provides an inter disciplinary approach to problems. It goes beyond conventional spreadsheet and database tables, helping us discover and visualize new data patterns and relationships that would have otherwise remained invisible (Boulos, Roudsari, & Carson). The analytic and visual power of GIS technology has made it attractive to many. Some of the vital areas where GIS technology is being successfully applied are;

2.3.3.1. Application of GIS in fleet management

GIS technology is currently integral in fleet management especially responding to incoming work orders, deciding how to efficiently deploy vehicles according to location, and vehicle capacity and minimizing costs in the process. In a study carried out in Santiago, a fleet management model for Santiago fire department was proposed with the help of GIS technology which would improve the maximization of the number of fire incidences successfully attended to in time and the model if implemented, an increase in standard response of between 6% and 20% was projected (Pérez, Maldonado, & López-Ospina, 2016). Another study basing on GIS technology for fleet management, was conducted to enhance market service and enterprise operations through a large-scale GIS-based distribution system which was able to reduce the distribution cost, increase the efficiency, satisfy customer demand, and improve service quality (Gu, Foster, & Shang, 2016).

2.3.3.2. Application of GIS in precision agriculture

In a study conducted in Latvia, GIS technology was successfully used to estimate the total size (in hectares) and location of agricultural land which was suitable for short rotation woody crop production basing on several criteria of restrictions such as crop suitability, agricultural land use status, soil and slope restrictions, designated territories of protection. This without doubt confirms the paramount importance of GIS technology in prescription farming where specific types of crops are grown where they are supposed to be grown to increase crop yield while minimizing input costs (Abolina, Volk, & Lazdina, 2015).

GIS technology was used to aid in crop scouting, soil sampling, irrigation and application of fertilizers which was a success in as far as finding out the different soil properties and appropriate crops were planted which increased the economic profitability by 29.89% as a result of crop yield increment which proved the efficiency of precision agriculture over traditional farming methods (El Nahry, Ali, & El Baroudy, 2011).

2.3.3.3. Application of GIS in crime mapping

Criminology is an interdisciplinary field specialized in studying causes and motives of criminal behavior in the hope of controlling and reducing crimes. To achieve such an important and security related objective, criminologists are trying to perform their analysis based on many techniques such as measures of spatial autocorrelation, kernel density smoothing and hierarchical cluster analysis (Grubesic & Mack, 2008).

A study carried out to determine the prevalence of crime in different communities in the United States of America using GIS technology found out that, neighborhoods which are characterised with high levels of unemployment, low education levels, and poor housing conditions together with high rates of alcohol abuse are associated with violent crimes and property crimes which are both associated with relative deprivation (defined by income inequality) and low social capital (Gale, Magzamen, Radke, & Tager, 2011).

2.3.3.4. Application of GIS in disaster management

GIS technology is of paramount importance in as far as management of disasters like landslides, earthquakes, floods, droughts, mudslides, and fires are concerned. Information management is a crucial component of emergency response. The ability of emergency officials to access information in an accurate and timely manner maximizes the success of the efforts. Since most of the information used in disaster management has a geographic dimension, geo-technologies have a large capacity to contribute to emergency management. The capabilities of geo-technologies to capture, store, analyze, and visualize spatial data in emergency management are significant towards saving lives and property (Nayak & Zlatanova, 2008).

GIS were designed to support geographical inquiry and, ultimately, spatial decision making. The value of GIS in emergency management arises directly from the benefits of integrating a technology designed to support spatial decision making into a field with a strong need to address numerous critical spatial decisions. For this reason, new applications of GIS in emergency management have flourished in recent years along with an interest in furthering this trend (Cova, 1999).

2.3.3.5. Application of GIS in health

GIS is a powerful tool that can be utilized to identify and display geographic patterns of disease; assess environmental exposures; estimate incidence, prevalence, and survival statistics; and expose health disparities to communicate clearly with the public, business, and political leaders (NCI, 2006). The relationship between Geography and health dates back to the time of the Greek doctor, Hippocrates (5th-4th centuries B.C), people have studied the effect of location on one's health. For example, early medicine studied the differences in diseases experienced by people living at high versus low elevation. It was easily understood that those living at low elevations near waterways would be more prone to malaria than those at higher elevations or in drier, less humid areas (Meade, 2010).

Cartographic techniques have been used effectively to portray differing intensities of diseases. Three major areas of concern in this regard are: distribution of diseases, distribution of health promoting and retarding factors and distribution of agents and hosts of micro-organisms causing diseases. Geographers have also studied the possible factors responsible for diseases of various kinds. The frequent occurrence of lung cancer in Andhra Pradesh, India was traced by medical geographers to widespread consumption of tobacco in one form or the other by the common people, especially the farmers. Heart ailments in Punjab and Haryana, India were related to use of non-vegetarian foods and too fast life style (Misra, 2007).

Health geography did not gain prominence until 1854 though when cholera gripped London. As more and more people became ill, they believed that they were becoming infected by vapours escaping the ground. John Snow, a doctor in London, believed that if he could isolate the source of the toxins infecting the population they and cholera could be contained. As part of his study, Snow plotted the distribution of deaths throughout London on a map see Figure 2.6. After examining these locations, Snow found a cluster of unusually high deaths near a water pump on Broad Street (Meade, 2010).

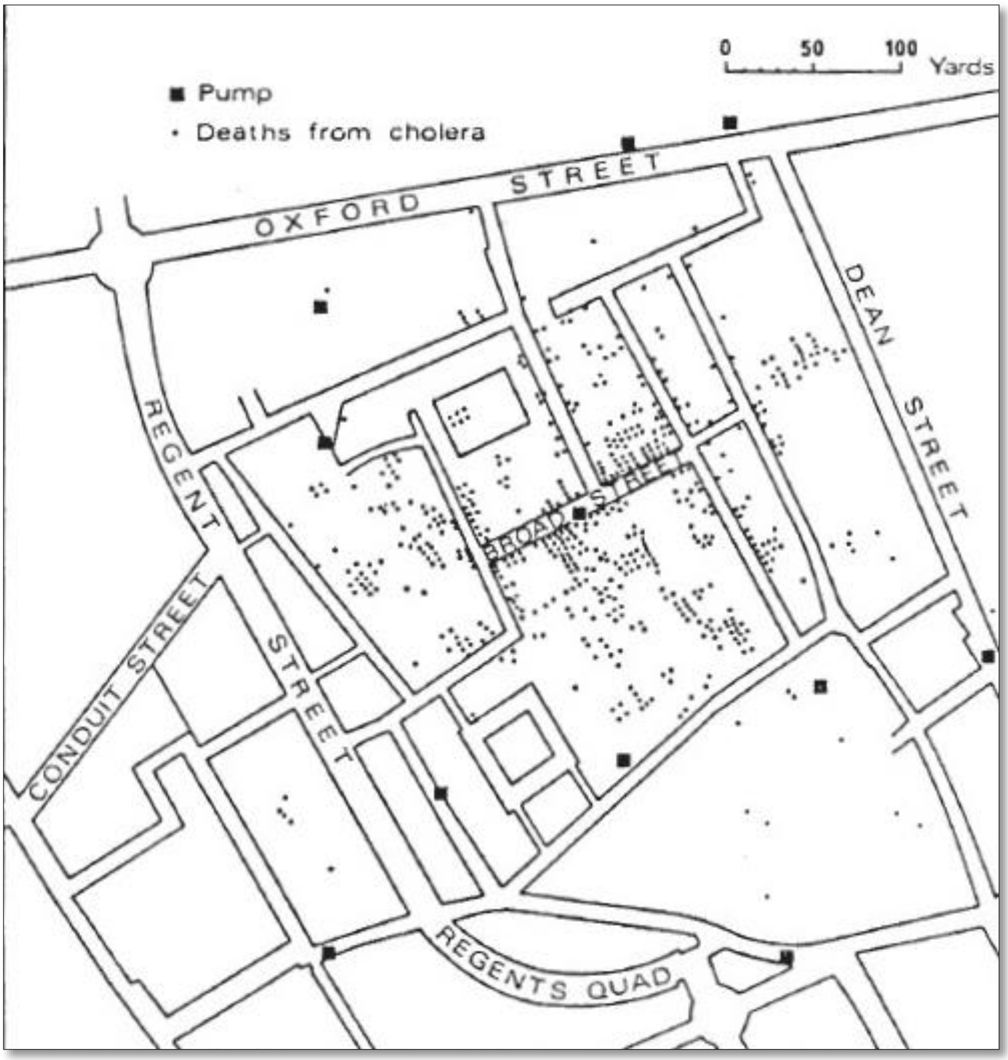


Figure 2.6. *The Cluster of Cholera Cases Found Near the Pump of Broad Street (Seen in the Centre of this Image) Led to the Conclusion that this Pump was the Cholera Source*

Source: *Meade, 2010*

GIS technology has been integral in healthcare planning especially EMS planning. A geographic information systems based study was conducted to ensure equity distribution of healthcare facilities making use of geographical accessibility analysis to ensure a high degree of equitable access is obtained. (Mokgalaka, Mans, Smit, & McKelly, 2013) GIS technology has previously been applied to locate potential areas of high and low rates of survival from OHCA, as well as to determine optimal locations for EMS resources. A study carried out to investigate the effect of ambulance RT reduction on survival of victims of cardiac arrest using GIS was successful producing a reduction of 1 minute of ambulance RT due to use of GIS technology which in turn increased patient survival chances by 4.6% (Sund, 2010).

By using GIS technology, a study was carried out where a framework was designed and implemented for assessing ambulance response performance which as a result facilitated easy and rapid identification of anomalous calls that may adversely affect the overall operating performance evaluation (Peters & Hall, 1999). To ascertain the role of GIS technology in the United Kingdom's National Health Service, a study was conducted which found out that using GIS technology facilitated strategic healthcare planning in recent health-care restructuring and new technological developments in the health service. GIS technology has been taken up by analysts, planners, managers and public health consultants working within the United Kingdom's National Health Service (Higgs & Gould, 2001).

2.3.4. Application of GIS technology in ambulance management

By integrating a variety of associated technologies including Global Positioning Systems (GPS), Automatic Vehicle Location (AVL), Computer Aided Dispatch (CAD), routing algorithms, electronic maps and in-vehicle navigation to provide real time tracking, dispatching and routing of emergency vehicles, GIS technology has been a blessing to EMS system in general. GIS technology is beginning to be used by healthcare agencies in the planning of EMS deployment. GIS provides EMS planners with the ability to organise and manipulate large volumes of spatially referenced ambulance demand call data and to communicate spatial concepts to decision makers responsible for service deployment planning. By using GIS, decision makers are able to visualize data in map form and understand geographic patterns and trends in ambulance response performance that would otherwise be difficult to ascertain (Peters & Hall, 1999).

A GIS technology based plan was successfully implemented to reduce average ambulance RTs from 10.1 minutes to 7.1 minutes hence increasing patient survival chances. GIS technology has been integral in emergency medical services and continue to play a significant role in that area (M. E. Ong et al., 2009). A study carried out to investigate if an ambulance deployment strategy basing on geospatial-time analysis of ambulance demand calls making use of GIS would result into significant reduction of ambulance RTs for out of OHCA. The results were positive and the average ambulance RT was reduced without increasing on the number of ambulances making use of GIS technology (Ong et al., 2010).

2.3.5. The role of GIS in facility location

GIS technology has proved useful in facility allocation from firefighting equipment allocation, ambulance allocation to serve demands within a short time after notice, and to retail stores' allocation to service most customers. One of the important extension in GIS software which can obtain, store and analyse data related to location is network analyst. Network analyst can dynamically model realistic network condition to a given data and cost attributes to analyse problems such as vehicle routing, closest facility and service area. Clearly, GIS can be applied for choosing sites, target marketing, planning distribution network, responding to emergencies that include the problem of geographical phenomenon (Sarkar, 2007). GIS being a system that is capable of capturing, analyzing, and presenting data that is associated with geographical locations, it allows the precise mapping and display of ambulance call volumes and candidate base locations. Moreover, it facilitates the estimation of travel times across the existing road networks. GIS can thus provide a more rigorous basis for constructing ambulance deployment plans (Lam et al., 2015).

2.4. Ambulance Location Models

Most optimization models for ambulance location allocation were formed by modifying the already existing models and that is the major reason as to why the study opted to discuss the prominent models from which most of the optimization models today are derived from for example Backup coverage model 1 (BACOP1) combines some aspects from Location set covering model (LSCM) and Maximal coverage location problem (MCLP). Tandem equipment location model (TEAM) and facility-location, equipment-emplacement technique (FLEET) are derived from MCLP.

Facility allocation plays an important role in logistic decisions. Each day, many enterprises resort to quantitative methods to estimate the best or more economical way to meet clients' demand for goods or services. In some cases, the availability of the service can be associated with a time or distance to an existing facility. In this case, the decision maker has to find the best location to open the facilities in order to satisfy most of the demand (Pereira, Coelho, Lorena, & De Souza, 2015).

The study of location models for ambulance location has undergone two distinct phases of evolution. During the first phase deterministic static models emerged and probabilistic static models emerged during the second. The next phase of evolution constitutes the emergency of dynamic models paralleling the strides made in the information technologies; gains in hardware and also software, the development of powerful meta-heuristics (Rajagopalan, 2006). Traditionally, emergency facility location problems deal with decisions from two aspects: which sites should be selected as depots for facilities (ambulances) and how many facilities (ambulances) should be placed in each depot, given demand points and potential facility sites. Plenty of models have been developed to solve facility location problems. Most of these models simplify the facility location problems by treating emergency calls generated from discrete demand points (Li, Zhao, Zhu, & Wyatt, 2011).

Over a long period of time , many ambulance location and relocation models have been proposed to solve the location and relocation problems (Azizan, Lim, Hatta, & Gan, 2012), Additional flexibility of the EMS system can be achieved if relocations during the day are allowed. In order to emphasize the effectiveness of the proposed dynamic model, MCLP will again be maximized, allowing flexible locations and penalizing relocations during the day. The same number of ambulances is used, flexible locations and relocations are allowed and the double coverage is maximized (Degel, 2015).

2.4.1. Maximal coverage location model (MCLP)

The MCLP is a location model which seeks the maximum population which can be served within a stated service distance or time given a limited number of facilities. MCLP is a facility location problem which aims to select some location candidates to install facilities, in order to maximize the total demand of clients that are located within a covering distance to an existing facility and reduce the number of uncovered clients (R. Church & Velle, 1974). In a standard MCLP, one seeks location of a number of facilities on a network in such a way that the covered population is maximized. A population is covered if at least one facility is located within a pre-defined distance of it. This pre-defined distance is often called coverage radius. The choice of this distance has a vital role and affects the optimal solution of the problem to a great extent. MCLP is of paramount importance in practice to locate many service facilities such as schools, parks, hospitals and emergency units (Davari, Zarandi, & Hemmati, 2011).

Many other location models were derived directly from MCLP to achieve some specific objectives. For example, tandem equipment location model (TEAM) and facility-location, equipment emplacement technique (FLEET) are derived from MCLP. Generally, MCLP as an ambulance location model can be defined on a graph that consists of a set of demand points, a set of possible ambulance location sites and a set of shortest travel times between the demand point and the possible location site. As the objective of MCLP see Equation 2.1 is to maximize the coverage (total demand points covered) by using a limited number of ambulances (Azizan et al., 2012).

MCLP can be mathematically expressed as see Equation 2.1.

$$\text{Maximize } z = \sum_{I \in v} d_I y_I$$

Subject to:

$$\sum_{I \in W_i} x_j \geq y_1 \quad i \in V$$

$$\sum_{I \in W_i} x_j = p$$

$$x_I \in \{0,1\} \; j$$

$$y_I \in \{0,1\} \; i \in V \tag{2.1}$$

The notations used in the equations are the same with that used in [1]. Objective (1) is to maximize the total demand coverage while the constraint (2) means that a demand point *I* is covered if and only if an ambulance is located at *Wi*. The constraint (3) is to restrict the number of available ambulances (R. Church & Velle, 1974). In the MCLP originally proposed by Church and Revelle (1974), d denotes the demand of vertex i, and p is the number of available ambulances. The binary variable yi is equal to 1 if and only if vertex i is covered by at least one ambulance (Brotcorne, Laporte, & Semet, 2003).

The objective of MCLP is to find the set of ambulance sites that covers the most demands. In other words, for a given number of ambulances and possible location sites, it finds the locations that can maximize the ambulances coverage (total demands covered). We can get the maximum coverage by increasing the number of ambulances but the drawbacks are the cost increment and the decrease in efficiency of the ambulance utilization (Pons & Markovchick, 2002). MCLP based ambulance deployment strategy results into maximization of coverage of demand areas with a limited number of ambulance resources which does not require additional costs of ambulance fleet enlargement makes it the most attractive strategy for optimal ambulance deployment.

2.4.2. Double coverage model (DCM)

The double coverage model (DCM) was developed to solve the double coverage problem for a given set of locations and a given number of ambulances. The objective is to maximize the demand covered by two ambulances within a small radius *r* > 0, while all demands have to be covered by at least one ambulance within a larger radius *R* > *r* (Doerner, Gutjahr, Hartl, Karall, & Reimann, 2005). The model does not only have a positive impact on the avoidance of undersupply, but also increases the degree of adequate coverage significantly. Over all periods it is clearly evident that maximising the empirically required coverage leads to a higher number of well supplied-inhabitants and a correspondingly better higher degree of required coverage during the day (Degel, 2015). A study conducted to solve an ambulance location problem with a modified double-coverage objective function under single coverage constraints for eight provinces of Austria was a success. (Doerner et al., 2005).

The DCM is mathematically represented as see Equation 2.2;

$$\max f(z) = \sum_{i=1}^{n} \lambda_i y_i$$

Subject to the constraints

$$\sum_{j=1}^{m} \delta_{ij} z_j \geq 1 \ (v_i \in V)$$

$$\sum_{i=1}^{m} \lambda_i X_i \geq w \sum_{i=1}^{n} \lambda_i$$

$$\sum_{j=1}^{m} y_{ijzj} \geq x_i + y_i (v_i \in V)$$

$$y_i \leq x_i \ (v_i \in V)$$

$$\sum_{j=1}^{m} z_{j=p}$$

$$z_{j \leq p_j} (v_{n+j \in W})$$

$$x_{i,} y_i \in \{0,1\} \ (v_i \in V)$$

$$z_j \text{ integer } (v_n + j \in W) \qquad (2.2)$$

The objective represents the maximization of the total demand covered at least twice within *r*. Note that the variables *xi* and *yi* can be computed from the variables *zj,* such that the objective can be written as a function of *z*. Constraints (2) and (3) express single and double coverage requirements. Constraints (2) ensure that all demand is covered within *R* distance units. Constraints (3) ensure that a proportion *w* of all demand is covered within the small radius *r*. Constraints (4) link the coverage of the demand nodes with the assignment of ambulances. The left-hand side of constraints (4) counts the number of ambulances covering *vi* within the small radius *r*, while the right-hand side represents the level of coverage of *vi*: it is equal to 1 if *vi* is covered exactly once within the small radius *r*, and equal to 2 if it is covered at least twice within the small radius *r*. Constraints (5) ensure that a vertex *vi* cannot be covered at least twice when it is not covered at least once. Constraints (6) and (7) impose limits on the maximum number of ambulances located over all potential locations and on each single location, respectively. Finally, constraints (8) and (9) are the usual binary and integrality requirements for the decision variables (Doerner et al., 2005). With all of its strengths of ensuring double coverage for each demand area, the double coverage model of ambulance deployment strategy requires a large fleet of ambulances for its implementation and therefore inapplicable in situations of limited resources like this particular one.

2.4.3. Location set covering model (LSCM)

The LSCM was developed in 1971. This early model for EMS planning is a binary integer linear optimization problem, i.e., a linear optimization problem where the variables may only take values 0 or 1. The goal of this model is to cover all demand points with a minimum number of ambulance location sites. We introduce one variable for every j ∈ J, which indicates whether there should be an ambulance station at that location (Toregas, Swain, ReVelle, & Bergman, 1971). LSCM aims at minimizing the number of ambulances with keeping the coverage of all the demand points. It introduces binary decision variables zi, i ∈M, which is equal to 1 if an ambulance is located at i and 0 otherwise. Also introduced the set of potential station covering the demand point j is Mj = {i ∈ M: di j <D, where D is the

distance to be determined as a coverage standard. Then mathematical formulation of LSCM is given as see Equation 2.3 (R. L. Church & Gerrard, 2003).

LSCM

$$\min \sum_{i \in M} z_i$$

$$\text{s.t} \sum_{i \in M_j} z_j \geq 1, j \in N$$

$$z_j \in \{0,1\}, i \in N \tag{2.3}$$

The constraints (2) mean that every demand point must be covered by at least one ambulance station. At the heart of the set covering and maximal covering models is the notion of coverage. Demands at a node are generally said to be covered by a facility located at some other node if the distance between the two nodes is less than or equal to some exogenously specified coverage distance (R. L. Church & Gerrard, 2003). Typically, the coverage distance is the same for all demand nodes, though additional restrictions on the set of candidate locations that can cover any particular demand node may be added. Such additional restrictions might reflect the ease of travel between population centers and a candidate site for a local clinic (Daskin & Dean, 2005).

The LSCM identifies the minimum number of facilities and their locations which ensure that all demand points are within a maximal service distance of a facility. The shortcomings associated with the LSCM are that it assumes that we have an 'infinite' number of ambulance facilities available, so it gives an indication on the number of facilities that are needed to cover all demand points. In reality, there is always a fixed number of ambulance fleet available. Furthermore, the model only makes sure that each demand node is covered once. If the ambulance from the location that covers this node is busy with another incident, this can mean that the demand node will be left uncovered especially in high demand areas.

2.5. Static and Dynamic Ambulance Deployment

It is widely believed that the strategy for ambulance resource deployment has a significant impact on ambulance RT. In dynamic ambulance deployment, when an ambulance becomes available again after accomplishing tasks associated with the previous patient, the ambulance can be assigned a new incident, or it is sent to a standby point where much demand is expected according to the time of the day. Ambulance relocation problem is more difficult to tackle since it has to be solved more frequently at very short notice. When siting emergency vehicles, relocation decisions must periodically be made in order not to leave areas unprotected (Brotcorne et al., 2003)

A study was carried out to assess the efficiency of dynamic methods of ambulance deployment by carrying out simulations based on real-time data. The conclusion to prefer dynamic means of deployment was reached at after assessing the performance of static deployment in comparison with dynamic ambulance deployment plans (Gendreau, Laporte, & Semet, 2001). A study was carried out where a dynamic ambulance deployment plan was implemented basing on geospatial-time distribution of ambulance calls ensured a significant reduction in ambulance RTs with low costs incurred. Same number of ambulances was used but they were deployed dynamically thus an ambulance would not go back to its base station after a service but be relocated to an area of expected higher demand according to the time (Ong et al., 2010). Static ambulance deployment models are discouraged due to an important shortcoming of these models which is that they may no longer guarantee adequate coverage as soon as ambulances dispatched to a call become unavailable. So in a static deployment plan a station is left uncovered once its ambulance goes to service a call which is not the case with dynamic ambulance deployment (Brotcorne et al., 2003).

Both the LSCM and MCLP approaches are static models and do not consider the possibility that a particular ambulance will be busy to answer ambulance demand calls when it is needed hence problems of cross coverage (or multiple overlapping demands). In order to handle the issue of cross coverage, several deterministic and stochastic approaches have been proposed. These models include the backup coverage models (BACOP) (Hogan & ReVelle, 1986) and the double standard model (DSM). Another deterministic model which explicitly considers the problem of backup coverage is the DCM (Gendreau, Laporte, & Semet, 1997). Even though the BACOP, DSM or DCM provides for the cross coverage, thereby mitigating the probability of the nearest ambulances being unavailable to answer ambulance demand calls, these models did not consider stochastic demands.

Static models are useful at the strategic level but lack the flexibility at the operational level. While demands vary spatially and temporally, to maximize the coverage of ambulance demand calls, idle EMS facilities siting in low demand areas are needed to move to busier areas. In other words, decision makers need to re-deploy facilities to provide better coverage (Li et al., 2011). The optimization of flexible demand coverage in combination with significant variations in travel time and emergency demand during the day requires a dynamic allocation of ambulances. Dynamic allocation means relocating ambulances during the day, but it also means using time-dependent ambulance fleet size. Additionally flexible ambulance locations are modeled to increase the flexibility of the system (Degel, 2015).

Dynamic ambulance deployment strategy basing on MCLP using SSM was found to be an ideal ambulance deployment plan to ensure maximum demand node coverage with a small ambulance fleet size which would realize a significant decrease in average ambulance RT. Normally, MCLP is considered whenever there are insufficient resources or budget constraints to cover the demand of all the nodes. Most scholars have maintained that MCLP as an early optimization model, has an important shortcoming in that it may no longer guarantee adequate coverage as soon as ambulances dispatched to a call become unavailable. This study has clearly taken care of this short coming by using SSM where ambulance fleet is deployed according to demand and this ensures that areas with expected higher demands will have more ambulances allocated to cover them such that in case ambulances are dispatched other ambulances are always there to serve the high demand.

Given the limited fleet size of 17 ambulances to service 85 parishes, MCLP which ensures the maximization of the total demand covered with a small fleet size was preferred for this study. MCLP determines sites which serve the maximum portion of demand within the distance or travel time standard given a limited number of facilities. This latter formulation addresses the concern that complete coverage of all demands within a distance or travel time standard may be technically and economically infeasible and unlike LSCP, MCLP ensures that much but not all of the ambulance demand is covered using limited resources. And as much as MCLP is a static optimization model, it was used in this study to develop 4 different deployment plans according to different times of the day and the origin of ambulance demand calls which makes it dynamic since different deployment plans were developed for different six-hour periods improving the efficiency of EMS healthcare service delivery both theoretically and practically. MCLP was successfully implemented in simulation work to study the performance of EMS delivery (Lim, Mamat, & Bräunl, 2011), meanwhile (Eaton et al., 1985) successfully applied MCLP to reorganize the EMS in Austin, Texas.

3. METHODOLOGY

This chapter explains the research design and methods/hypothesis which were used to achieve the objectives of the study.

3. 1. Study Area

Odunpazari District of Eskişehir Province is located between latitude 39°45’32’ N and longitude 30°31’33’ E. The District is located in Eskişehir Province in the North Western part of the Central Anatolian region of Turkey on an altitude of 788 m (2.585 ft.) and a population 376,650 according to Turkish Bureau of Statistics 2014.

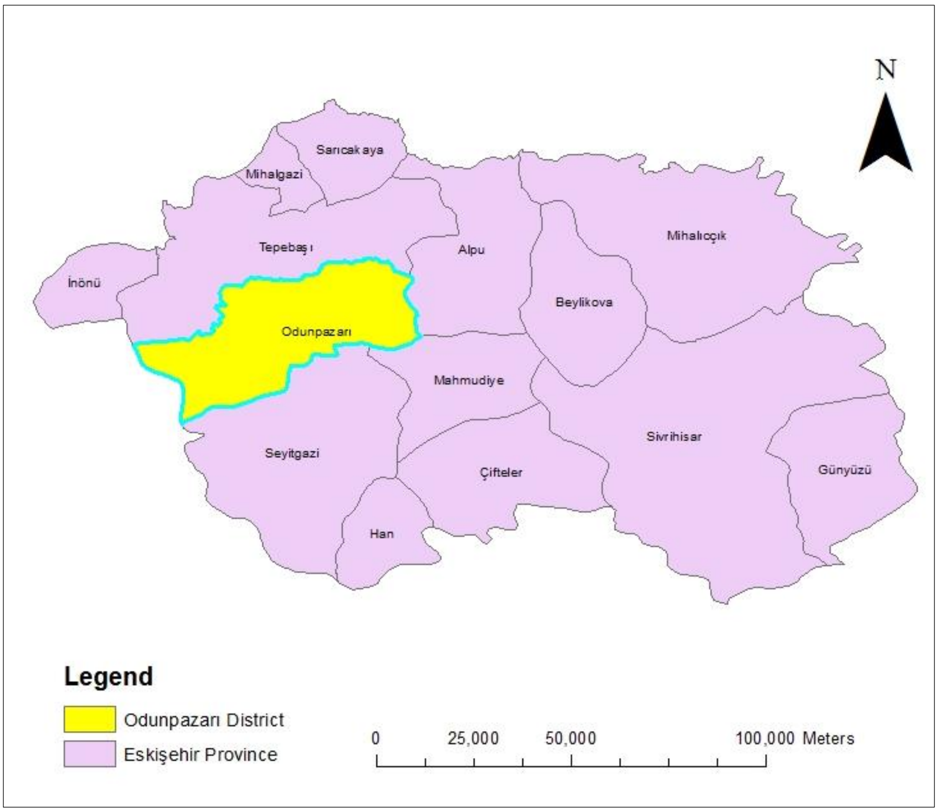


Figure 3.1. *The location Of Odunpazarı District*

Due to Odunpazarı’s high altitude and its dry summers, night temperatures in the summer months are cool. Precipitation levels are low, but precipitation can be observed throughout the year. Odunpazarı District borders; Alpu and Mahmudiye Districts in the East, Tepebaşı District in the North, Seyitgazi District in the South, and Kutahya Province in the west see Figure 3.1. Odunpazarı District has 85 parishes see Figure 3.2.

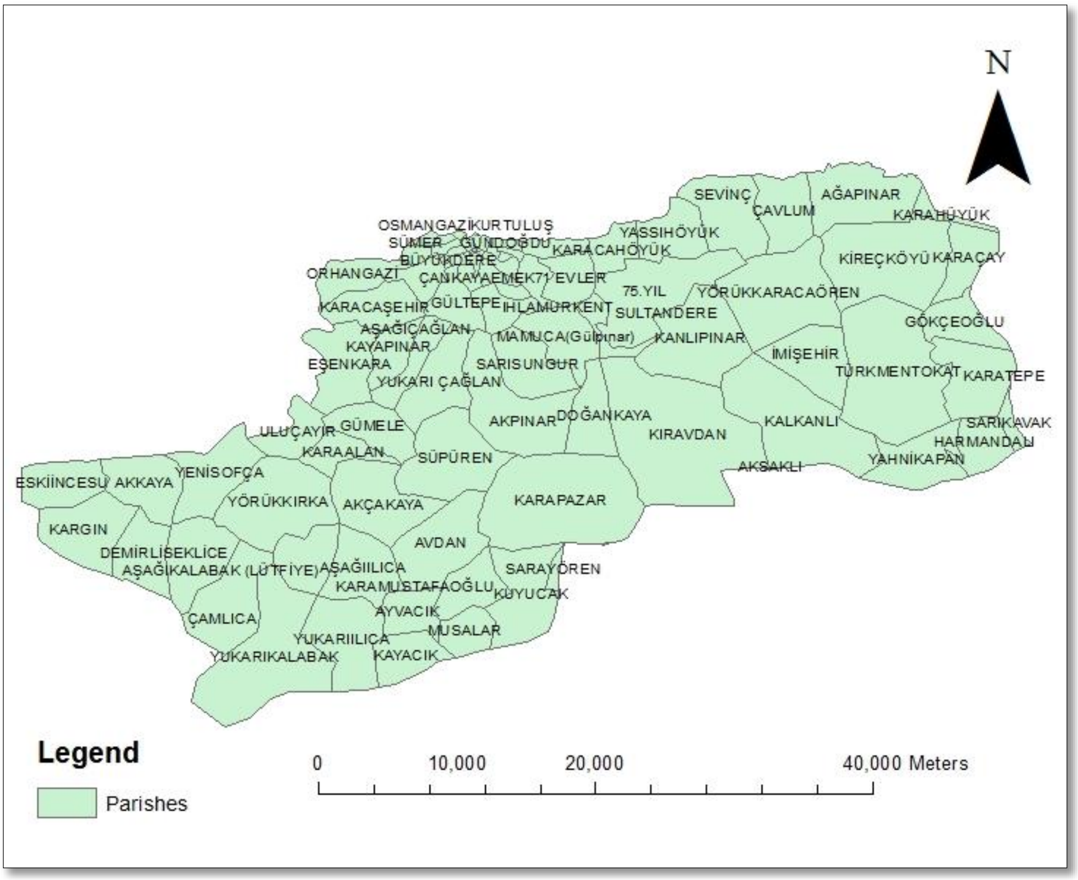


Figure 3.2. *The parishes of Odunpazarı District*

3.1.1. EMS system of Odunpazarı District

The EMS of Odunpazarı District according to the Eskişehir province Directorate of Health which manages it, operates the national '112' emergency telephone service. The system is supported by a centralized dispatching unit that uses computer-aided dispatch, medical dispatch protocols, global positioning satellite-based automatic vehicle locating systems, and road traffic monitoring systems. The system has a fleet of 17 ambulance vehicles which answer approximately 20,260 calls annually. Operationally, the closest available ambulance is always dispatched to respond to an emergency call received by the centralized dispatching system. The Odunpazarı District EMS, operates and maintains 17 ambulance vans which are permanently located at 17 permanent base stations distributed all over its 85 parishes see Figure 3.3. Emergency ambulance patients are first attended to, then delivered to the nearest public hospital in or outside the District which have well equipped modern Emergency Medical Departments with competent emergency health workers.

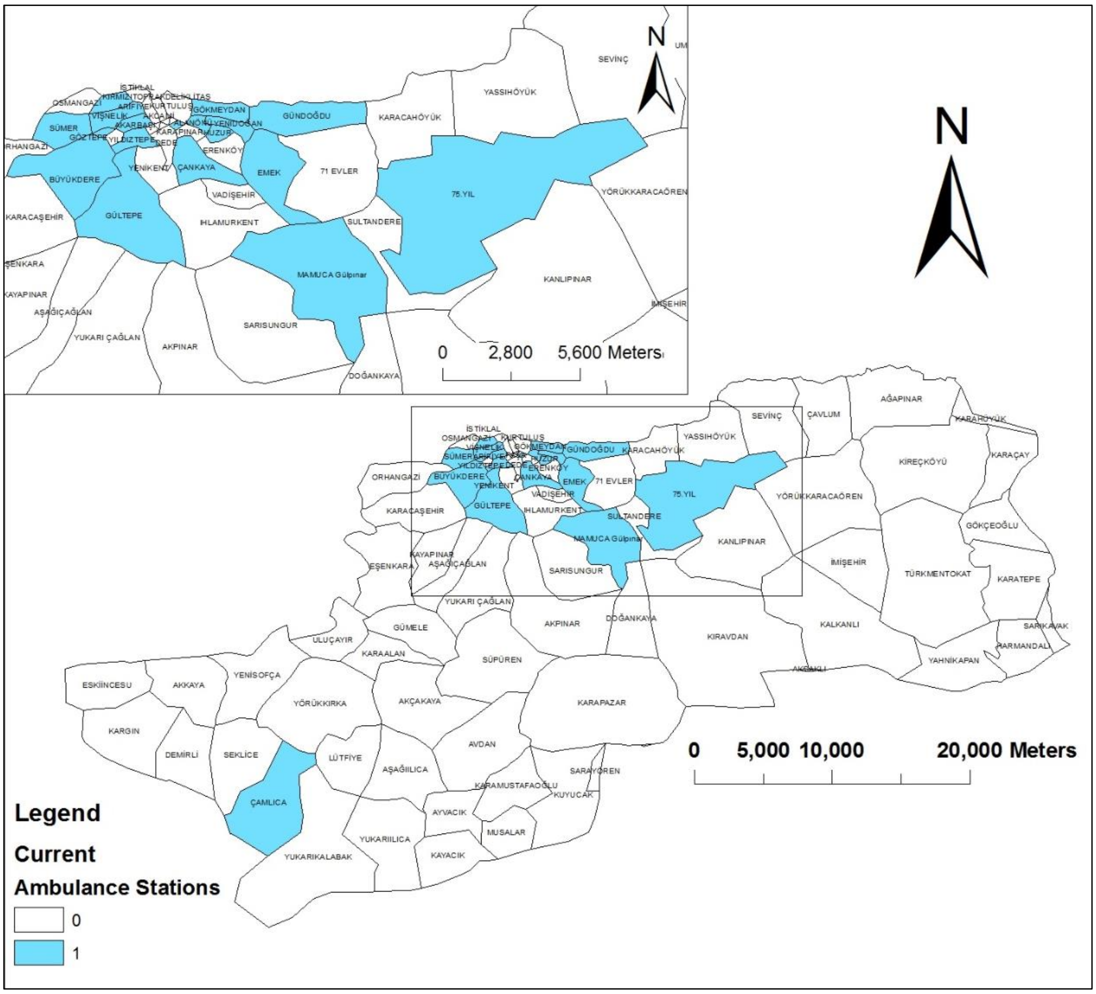


Figure 3.3. *The Current Ambulance Deployment Plan for Odunpazarı District*

The fleet of 17 ambulances for Odunpazarı District is shared among Akarbaşı, Alanönü, Büyükdere, Çamlıca, Çankaya, Emek, Gökmeydan, Gülpınar, Gültepe, Gündoğdu, Huzur, Kırmızıtoprak, Sümer, Vişnelik, Yenidoğan, Yıldıztepe, and 75.Yıl (Sultandere) parishes see Figure 3.3. Each of these parishes has one ambulance allocated to it. When an ambulance receives a call, it goes to service the call then it comes back to its permanent station. Büyükdere, Yenidoğan, Emek, Kırmızıtoprak, Vişnelik, and Gökmeydan registered the highest number of ambulance calls between them and therefore much higher ambulance demand should be expected here. When these single ambulances that were allocated to each one of them is busy servicing a call then the high demand areas remain uncovered and therefore ambulance demand that is received after will not have a ready ambulance to service it. It is therefore logical to allocate much more ambulances to parishes where much higher ambulance demand is expected.

Sümer, Gündoğdu and Huzur parishes receive small numbers of ambulance demand calls and therefore it would be appropriate to move ambulances deployed there to neighboring higher ambulance demand parishes such as Büyükdere, Emek, Yenidoğan, and Çankaya to increase demand coverage and reduce ambulance RT as a result. 75 Yil parish has a permanent ambulance station where one ambulance is deployed, this parish has Teksan industrial area and therefore the ambulance should be moved at night to residential areas where higher ambulance demands are expected since people move from workplaces to residential areas.

3.2. Data Collection

Ambulance demand calls' data (registered between January 1st to December 31st 2014) collected from the Eskişehir province Directorate of Health was used for the study. The ambulance demand calls' data had enough patient details for example district, parish, age and hospital to enable data analysis. The ambulance calls' data also includes; calling time, the ambulance dispatch time, on scene arrival time, out of scene departure time, hospital arrival time and base returning time. Ambulance demand calls' data which did not have addresses, call time, ambulance arrival time and did not require ambulance dispatch were not included in the study. Patient characteristics, call circumstances, EMS RTs were recorded. Geographic location of ambulance calls was recorded. For this particular study 20,260 valid ambulance demand calls were used.

Road speed limit data was obtained from the Directorate for Roads of the Republic of Turkey see Table 3.1. The speed limit data specifies the maximum speed on every kind of roads from major highways, to built-up areas, to lanes, and finally on one-way small streets. The Odunpazarı District road network shape file data on which network analysis was carried out was obtained from the Eskişehir province Directorate of GIS see Table 3.1. The road network data obtained included the names of roads, the types of roads, the length of the roads in meters, and the direction of the road.

Table 3.1. *Data Collection*

S/N	Name of Data	Source
1	Ambulance Demand Calls' Data	Eskişehir Province Directorate of Health
2	Road Network Data	Eskişehir Province Directorate of GIS
3	Road Speed Limit	General Directorate for Roads of Republic of Turkey

3.2.1. Data preparation

The road network data obtained from the Eskişehir province Directorate of GIS did not have mapped turn features on the network. Turn features for the road network were mapped with reference to google maps. The speed limit on the road network was captured from the Directorate for Roads of the Republic of Turkey which put its speed limits as follows;

- 90 kilometres per hour for a two way major highway
- 50 kilometres per hour for roads in a built-up area.
- 30 kilometres per hour for small and one-way streets.

The road network for Odunpazarı District see Figure 3.4 and the road network of the northern part of Odunpazarı District see Figure 3.5 were used for the study.

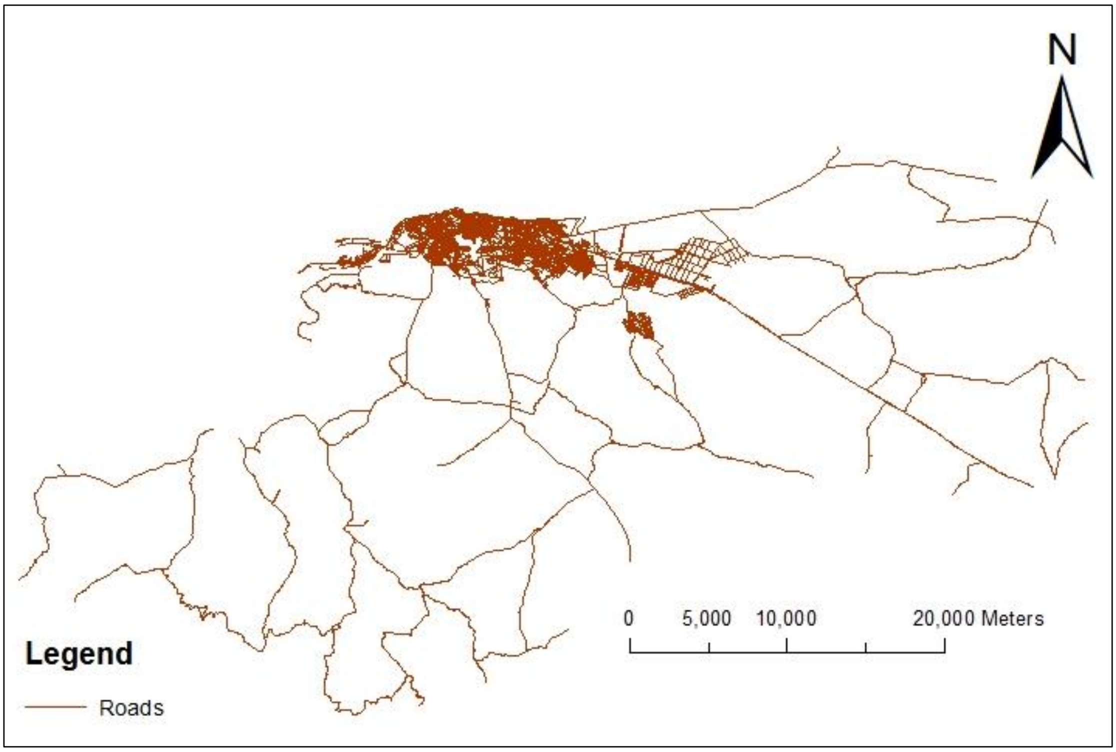


Figure 3.4. *Road Network for Odunpazarı District*

The northern part of the Odunpazarı District road network is clearly seen. See Figure 3.5.

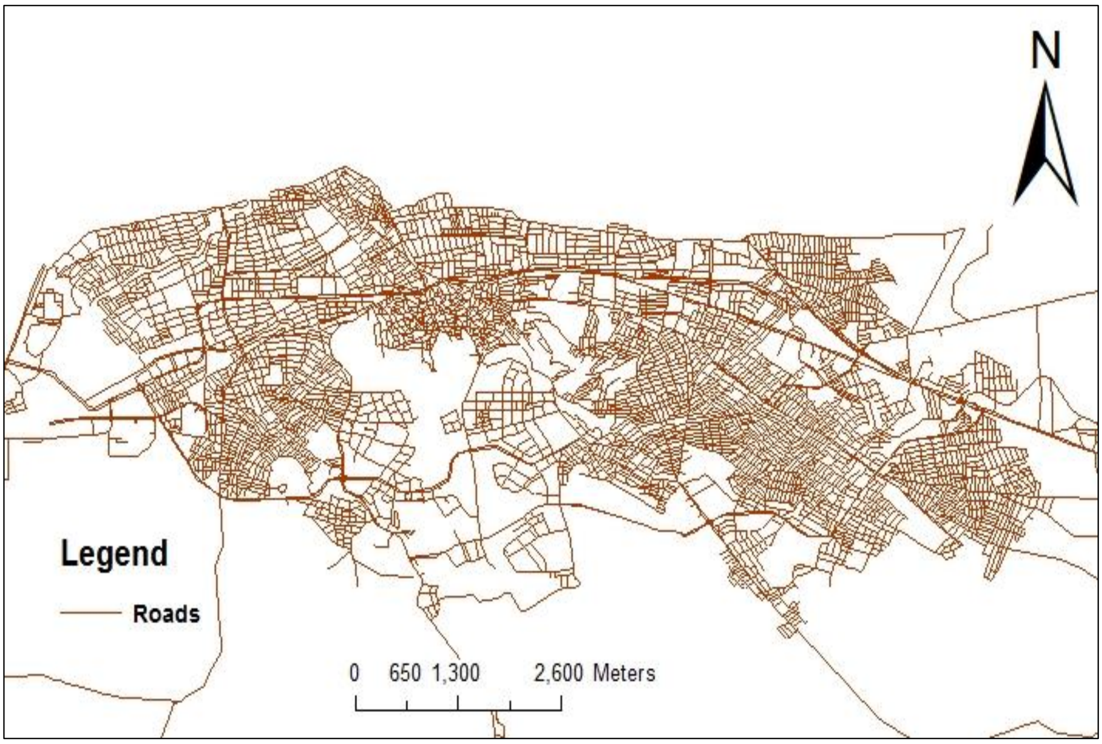


Figure 3.5. *Road Network for the Northern Part of Odunpazarı District*

For network analysis to be carried out, the road network data has to have the elevation fields, the distance in this case in meters, the length of the road, and the time together with the speed it takes to manoeuvre through the road. The length of the road is measured in meters and the speed is measured in meters per minute see Figure 3.6. The elevation field determines connectivity from one road to another if they are at the same level for example elevation 1 and elevation 1 they can be able to connect but if they are at different levels for example elevation 2 and elevation 1 they cannot be able to connect since one might be a flyover road. The road network might have movement restrictions such as one-way roads which only permit traffic flow in one direction only and the double carriage allows traffic to flow in both directions. The junction field shows which roads are connected together at which point the from junction states which road a junction is connected from and to junction which road a junction is connected to.

Table

Roads

Adi	Tipi	f_junc	t_junc	SolMah	uzunluk	Speed	F_ELEV	T_ELEV	Oneway	Minutes
Yoncalık Sk.	Sokak	383234	383238	Büyükdere Mh.	96	30000	1	1	1	0.192
Şahlanış Sk.	Sokak	383229	383235	Büyükdere Mh.	51	30000	1	1	1	0.102
Hanımeli Sk.	Sokak	383235	383236	Büyükdere Mh.	94	30000	1	1	1	0.188
Erbay Sk.	Sokak	383233	383236	Büyükdere Mh.	47	30000	1	1	1	0.094
Erbay Sk.	Sokak	383236	383242	Büyükdere Mh.	51	30000	1	1	1	0.102
Şahlanış Sk.	Sokak	383235	383240	Büyükdere Mh.	34	30000	1	1	1	0.068

0 (0 out of 12459 Selected)

Roads

Figure 3.6. *Road Network Properties*

Turn features on a road network indicate whether and where turns are allowed on a road junction see Figure 3.7 example of turns are U-turn, right turn and left turn. The turn features help to model our road network shape files to the real word road network by applying turn restrictions where they are.

Table

Turns

OBJECTID *	SHAPE *	Edge1End	Edge1FCID	Edge1FID	Edge1Pos	Edge2FCID	Edge2FID	Edge2Pos	Edge3FCID	Edge3FID	Edge3P
2	Polyline	Y	14	7137	0.652944	14	7442	0.224788	<Null>	<Null>	<Null>
3	Polyline	Y	14	7443	0.792422	14	7445	0.06223	<Null>	<Null>	<Null>
6	Polyline	N	14	10807	0.57771	14	7436	0.638472	<Null>	<Null>	<Null>
8	Polyline	Y	14	10426	0.783925	14	7343	0.199561	<Null>	<Null>	<Null>
9	Polyline	Y	14	7345	0.70155	14	10429	0.188586	<Null>	<Null>	<Null>
10	Polyline	Y	14	10429	0.73713	14	7351	0.209835	<Null>	<Null>	<Null>

1 (0 out of 6309 Selected)

Turns

Figure 3.7. *Turn features on the Odunpazarı District Road Network*

The ambulance demand calls' data collected from the Eskişehir Province Health Directorate had addresses including the parish, street/road name and plot number which were used to pin point the exact location of the origin of the ambulance demand calls. The addresses which included the parish, street name and plot number were entered into *Google Earth* and the exact longitude and latitude location in degrees of the origin of the ambulance demand calls were known and plotted on the Odunpazarı District map for all the 20,260 ambulance demand calls. Ambulance demand calls were used as the demand to be serviced by the facilities (ambulances).

For a specific example, the latitude and longitude location of GÖKMEYDAN MAH, SARAR CD, No: 17, was captured by entering that address into the Google Earth search engine and the exact location was shown in centre of the picture see Figure 3.8. The latitude and longitude of the address is shown in the right bottom corner of the picture as lat 39.766880 and lon 30.548067 highlighted in green. The search engine where the address was entered is highlighted in yellow in the upper left corner and the location of the address is highlighted in red at the centre of the picture.

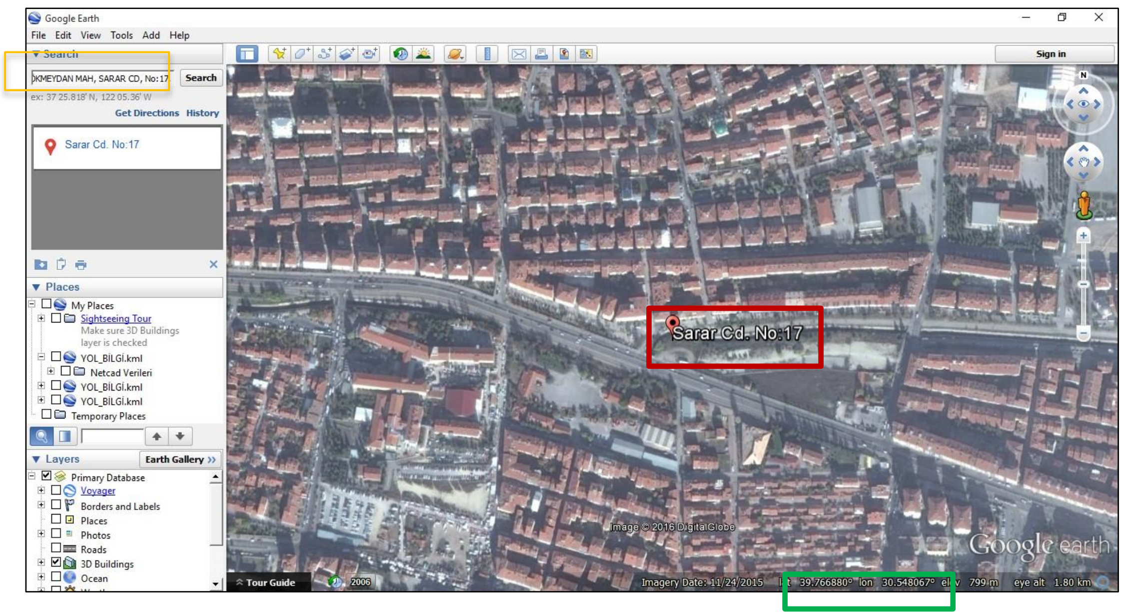


Figure 3.8. *Capturing the longitude latitude location of street address by using Google Earth*

3.3. Primary Data Analysis

Data analysis was performed using Microsoft excel and Microsoft Access, presenting descriptive statistics and frequencies (Microsoft 2013 Redmond, Washington). Locations of origins of ambulance demand calls and locations of optimal ambulance stations were mapped and determined using ArcMap and Network Analyst Location Allocation tool respectively using ArcGIS Software (ArcGIS10.3, ESRI Redlands, California). This was geographically displayed according to parishes and correlated with other factors including time of the day.

3.4. Geospatial-time Distribution of Ambulance Demand Calls and Location Allocation.

The study using system status management made use of two strategies to reallocate the ambulance fleet to ensure reduction of ambulance RTs which were;

(i) Geospatial-time distribution of ambulance calls and

(ii) Location Allocation.

This study based on geospatial-time distribution of ambulance demand calls with the help of SSM to produce an efficient ambulance deployment strategy. The study also made use of the SSM and ArcGIS Network Analyst Location Allocation tool to come up with ambulance deployment locations within 5 minutes of drive time to ambulance demand areas so as to reduce ambulance RTs. It has been noticed that acute medical events such as cardiac arrests are not random events, but rather have definite time-geographic distribution patterns. This is related to the underlying population demographics and movement patterns. Using GIS technology, we are able to depict such time-geographic patterns to aid the planning for ambulance deployment (Lam et al., 2015). Geographic information systems facilitate modelling of events in simulations and for planning. For example, SSM is a technique using GIS that matches the movement of ambulances in anticipation of where next they will be needed (Ong et al., 2010).

3.4.1. System status management

SSM is a technique for matching the movement of ambulances in anticipation of where they will be needed next by using historical temporal and geographic ambulance response data. It is also a key tool for high-performance ambulance or EMS systems (Ong et al., 2010). The concept of SSM was introduced to EMS by consultant Jack Stout. It is a computer-based system where historical call data are used to deploy the ambulance fleet for optimal RTs and to predict where the next cluster of calls is likely to occur. SSM has become the most widely accepted management methodology for managing EMS resources. SSM strategy has been used to improve RT performance without the need to deploy more ambulances and to set up new ambulance base locations (Stout, 1989).

The information generated by this technique is used to make decisions regarding the dynamic positioning of ambulance units throughout a service area. This dynamic positioning involves moving units periodically to respond to variations in call volume within the service area, resulting in less dependence on multiple fixed stations or bases and freeing capital for vehicle maintenance and improvement. SSM is one such technique that is helping EMS systems deliver the superior service their patients deserve (Hough, 1986). SSM uses flexible, real-time management of the deployment of resources to meet ambulance demand patterns (M. E. H. Ong et al., 2009). One of the earliest studies of simulation application to an EMS problem suggested that location of vehicles at a position within an area of demand (as opposed to a hospital) improved ambulance RT than deploying more ambulances on the same location (Savas, 1969).

3.4.1.1. System status plan

''A SSP matches the deployment of system resources (ambulances) with demands (ambulance demand calls) and can be realized through a set of posting pyramids (Lam et al., 2014)''. SSM leverages on the relationship between call volumes and ambulance deployment to derive deployment plans that dynamically assign ambulance resources according to projected ambulance demand patterns. During operations, the SSP will guide the assignment of ambulances to bases according to the number of ambulances that are available within the system (Alanis, Ingolfsson, & Kolfal, 2013). In a typical SSP, there could be a number of posting pyramids across different times of the day that are adapted to ambulance demand call volumes that fluctuate across time (Lam et al., 2014). Geospatial-time distribution of ambulance demand calls using location allocation was used in this study to derive an optimal SSM strategy that aims to achieve maximum demand coverage without increase in the number of ambulances.

3.4.2. Geospatial-time distribution of ambulance demand calls

Odunpazari District EMS has a total of 17 ambulances in 17 different permanent base stations. Ambulances serve their calls then get back to their base stations after delivering patients to hospitals. This uneven spatial distribution of ambulance resources is largely responsible for high ambulance RTs. Logically, ambulance resources should be deployed in accordance with ambulance demand calls (demand) and the ever changing population according to different times of the day using SSM. Locations of ambulance demand calls were spot mapped using ArcGIS software 10.3 so as to determine geospatial call patterns. A system status plan was developed to assign ambulances to different locations according to four time ranges .Four time range maps showing ambulance locations according to demand of ambulance calls were created and these are;

00:00 to 06:00 hrs

- Midnight to early morning time range, in this time range mainly the population is static and much of it always in residential areas for resting.

06:00 to 12:00 hrs

- Early morning to noon time range, in this time range most people are at their desks in their workplaces therefore areas with company and institution offices and industrial areas have a larger population than residential areas.

12:00 to 18:00 hrs

- After noon to early evening there is an equal divide where most part of the population is still at work and another part going home.

18:00 to 24:00 hrs

- Early evening to midnight, in this time range a large section of the population is mobile since they are commuting from their places to their homes either using public or private means of transport.

The ambulance demand calls data were organised according to the time they were registered and the parish they originated from. Ambulance demand calls' data was organised according to periods between 00:00 to 06:00 hrs, 06:00 to 12:00 hrs, 12:00 to 18:00 hrs and 18:00 to 24:00 hrs see Table 3.2.

Table 3.2. *Ambulance Demand Calls for Odunpazarı District Received Between 00:00 to 06:00 hrs, 06:00 to 12:00 hrs, 12:00 to 18:00 hrs and 18:00 to 24:00 hrs.*

Parish	00:00 - 06:00hrs	06:00 - 12:00hrs	12:00 - 18:00hrs	18:00 - 24:00hrs
Ağapınar	2	3	1	3
Akarbaşı	124	223	324	261
Akcami	12	12	23	18
Akçağlan	28	35	46	47
Akçakaya	0	0	0	0
Akkaya	0	0	0	0
Akpınar	12	8	20	48
Alanönü	41	93	105	102
Arifiye	44	233	352	186
Aşağı Çağlan	1	1	1	1
Aşağılıca	0	0	0	0
Avdan	0	0	0	0
Ayvacık	0	0	0	0
Büyükdere	237	326	579	443
Cunudiye	5	14	15	25
Çamlıca	92	206	284	241
Çankaya	65	113	135	125
Çavlum	0	0	1	4
Dede	18	36	49	51
Deliklitaş	71	147	247	167
Demirli	0	0	0	0
Doğankaya	0	0	0	0
Emek	200	356	476	475
Erenköy	70	115	132	138
Eşenkara	1	0	1	0

Gökmeydan	137	235	309	338
Göztepe	15	27	36	39
Gülpınar	3	5	2	7
Gültepe	76	106	114	144
Gümele	0	0	0	0
Gündoğdu	42	105	156	143
Harmandalı	0	0	0	0
Huzur	39	67	102	124
Ihlamurkent	76	96	146	147
İmişehir	1	1	0	0
İstiklal	98	131	263	195
Kalkanlı	0	0	0	0
Kanlıpınar	5	1	4	4
Karaalan	0	0	0	0
Karacahöyük	0	1	0	1
Karacaşehir	1	2	4	6
Karaçay	0	0	0	0
Karahüyük	0	0	0	0
Karamustafa	0	0	0	0
Karapazar	0	0	0	1
Karapınar	20	26	34	41
Karatepe	0	0	0	0
Kargın	0	0	0	0
Kayacık	0	0	0	1
Kayapınar	0	0	0	0
Kıravdan	0	0	0	0
Kırmızıtoprak	157	223	324	267
Kireç	0	0	0	0
Kurtuluş	147	221	311	267
Kuyucak	0	0	0	0
Lütfiye	0	0	0	0
Musalar	0	0	0	0
Orhangazi	42	86	94	103
Orta	6	14	10	10
Osmangazi	68	93	108	124
Paşa	8	13	40	16
Sarısungur	0	0	0	1
Seklice	0	0	0	0
Sevinç	4	9	6	16
Sultandere	7	6	25	12
Sümer	40	50	62	57

Süpüren	0	0	0	0
Şarkiye	6	28	14	14
Türkmentokat	0	0	0	0
Uluçayır	0	1	0	0
Vadişehir	0	0	0	0
Vişnelik	130	246	400	297
Yahnikapan	0	0	0	0
Yassıhöyük	1	2	3	2
Yenidoğan	178	770	916	377
Yenikent	65	138	169	139
Yenisofça	1	0	0	2
Yıldıztepe	51	86	105	86
Yukarıçağlan	0	0	0	0
Yukarıılıca	0	0	0	0
Yukarıkalabak	0	0	0	0
Yürükkaracaören	0	0	0	0
Yürükkırka	0	0	0	0
71 Evler	99	167	232	229
75.Yıl Sultandere	68	103	180	161
Totals	**2614**	**4980**	**6960**	**5706**

The total number of valid ambulance demand calls between 00:00 to 06:00hrs was 2,614 out of the total 20,260 see Table 3.2 ambulance demand calls and these calls were plotted onto the Odunpazarı District road network map as demand points. The total valid ambulance demand calls received between 06:00 to 12:00hrs was 4,980 out of the 20,260 calls see Table 3.2 and these ambulance demand calls were plotted onto the Odunpazarı road network data as demand points to aid ambulance allocation.

The total number of valid ambulance demand calls that were received between 12:00 to 18:00hrs was 6,960 out of the 20,260 number of calls. All the valid ambulance demand calls in this time range were plotted onto the Odunpazarı District road network map as demand points. The total number of valid ambulance demand calls received between18:00 to 24:00hrs was 5,706 calls out of 20,260 see Table 3.2 overall valid ambulance demand calls. These calls were plotted onto the Odunpazarı District road network as demand points. The ambulance fleet of 17 vehicles was distributed according to the demand and location of ambulance calls in these 4 different time ranges. Areas with much higher call demands were covered with much more ambulances than areas with less call demands. The major reason as to why the Odunpazarı District ambulance fleet was moved in respect to different times of the day is to cater for high call demand areas because call demand locations change according to different times of the day. For example more ambulances were deployed in residential areas at night than work places and more ambulances were deployed near workplaces during day times than nights.

3.4.3. Location allocation

Location planning of healthcare facilities is essentially a matter of devising the best distribution plan of a predetermined number of facilities, as defined by some generally accepted criteria (Feeny & Guyatt, 1986). A study carried out by (Comber, Brunsdon, & Green, 2008) successfully used a GIS based network analysis strategy to analyse the equity of access to community goods and services by different people in Leicester city considering distance and drive time from residential areas.

The study used the ArcGIS Network Analyst location allocation tool to see Figure 3.9 select optimal ambulance stations among candidate stations that would ensure a large number of ambulance demand areas are reached within 5 minutes of drive time. Input to this tool included candidate ambulance stations, to provide EMS services, and demand points, which consume the ambulance services. The objective was to find the ambulance stations that supply the ambulance demand points most efficiently. The tool solves this problem by allocating the most ambulance demand to ambulance stations and minimizes overall travel. The output included the solution ambulance stations, ambulance demand points associated with their assigned ambulance stations, and lines connecting ambulance demand points to their respective ambulance stations. Location allocation analysis was carried out on the road network data of Odunpazari district basing on MCLP optimization model.

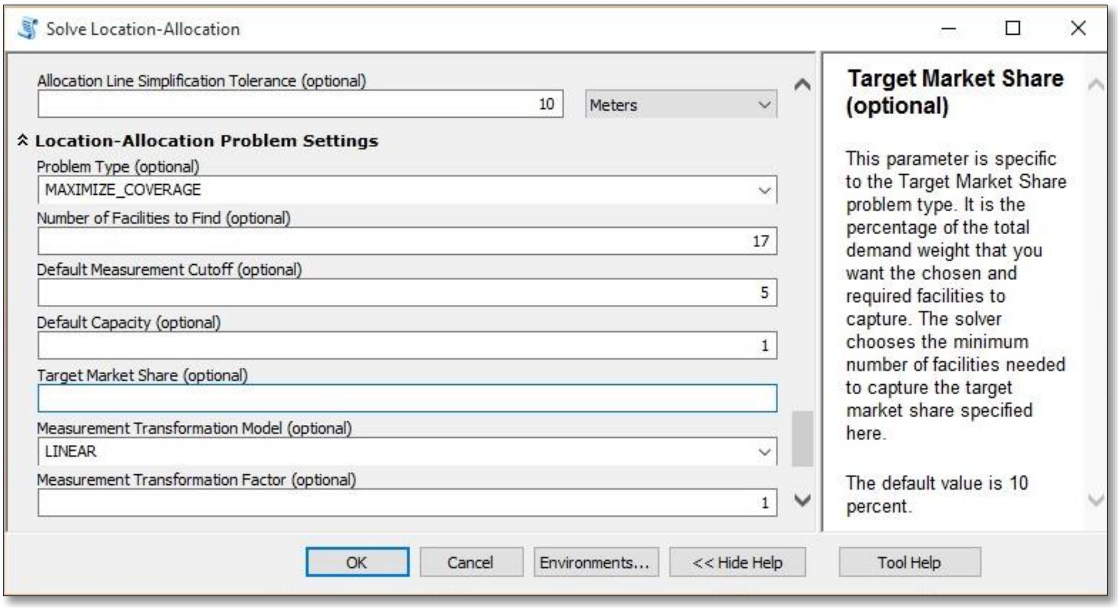


Figure 3.9. *Solve Location Allocation Tool Used For Optimal Ambulance Station Allocation*

The ambulance fleet size dedicated for Odunpazarı District is 17 ambulances and therefore the location allocation tool see Figure 3.9 was used to find optimal ambulance locations within a cut off period of 5 minutes from the demand areas. As it can be clearly observed see Figure 3.9, MCLP optimization model was used to allocate the ambulance fleet so as to ensure maximum ambulance coverage with few ambulances. 17 ambulances were allocated to 55 parishes which registered ambulance demand calls. The Odunpazarı District ambulance fleet of 17 vehicles was allocated to make sure demand areas which are parishes where ambulance calls originate from receive service in 5 minutes. For the uncertain travel time delays, ideal travel times based on the characteristics of Eskişehir Province's road network (e.g., speed limits, nature of intersections, type of roads) will be first estimated using ArcGIS10.3 (ESRI, Redlands, CA). The travel time uncertainties were modeled using the correction factors estimated from the historical travel time data.

3.5. Software Packages Used

3.5.1. Microsoft office 2010

Microsoft office software package was used for data analysis especially Microsoft excel spreadsheet was used to clean and analyse the raw ambulance demand calls data. Using Microsoft excel ambulance demand calls data without enough details like the origin of the call, the time of the call and the time the ambulance reached a demand area were excluded. Microsoft excel software made it easy to work with large records of data and manipulate it to get the desired information. Microsoft access software was used to sort out data since the ambulance demand calls data was of the whole Eskişehir province so queries were run in Microsoft access to only filter out ambulance demand calls data of only Odunpazarı District. Microsoft word software was used to write this thesis report since it is embedded with tools which make it the most appropriate document editing program.

3.5.2. Arcgis software 10.3

ArcGIS software suit produced by ESRI in California is the leading Geo-informatics software vendor. The ArcGIS software suit contains packs like ArcMap, Arc Scene, ArcCatalog, Arc Scene and ArcGIS Web. This software suite enables complete analysis and manipulation of geographic data to come up with information which is largely used for decision making.

ArcGIS software was used to;

- Produce maps of origins of ambulance demand calls in different parishes of Odunpazarı District.
- Build a network dataset using the road network data obtained from the Eskişehir Province Directorate of GIS on which network analysis was carried out.
- Location allocation by finding optimal locations where ambulances can be stationed to serve incoming demands within a specified drive time and as a result reduce ambulance RT.

3.5.2.1. Arcgis network analyst

ArcGIS Network Analyst provides network-based spatial analysis tools for solving complex routing problems. It uses a configurable transportation network data model, allowing organizations to accurately represent their unique network requirements. You can plan routes for an entire fleet, calculate drive-times, locate

facilities and solve other network related problems. A network is a system of interconnected elements, such as edges (lines) and connecting junctions (points) that represent possible routes from one location to another. People, resources, and goods tend to travel along networks: cars and trucks travel on roads, airliners fly on predetermined flight paths, oil flows in pipelines. By modeling potential travel paths within a network, it is possible to perform analyses related to the movement of the oil, trucks, or other agents on the network. The most common network analysis is finding the shortest path between two points.
ArcGIS network analyst tool can be used to answer questions like;

- Which ambulances or patrol cars can respond quickest to an incident?
- What is the quickest way to get from one point to another point?
- Which houses are within five minutes of a fire station?
- What market areas does a business cover?
- How can a fleet of delivery or service vehicles improve customer service and minimize transportation costs?

The road network data of Odunpazarı District which was used to create a *Network Dataset* on which analysis was carried out. A network dataset models a real network and it has components such as turns features, road connections, elevations, nodes which are junctions joining different roads together. Road networks are always represented by line feature classes in GIS therefore, line shape files modelling roads are just individual lines until a *Network Dataset* is made which joins the line features together into a virtual road network. The road network data obtained included the names of roads, the types of roads, the length of the roads in meters, and the direction of the roads. The road network dataset was created see Figure 3.10 to join the line shape files into a network.

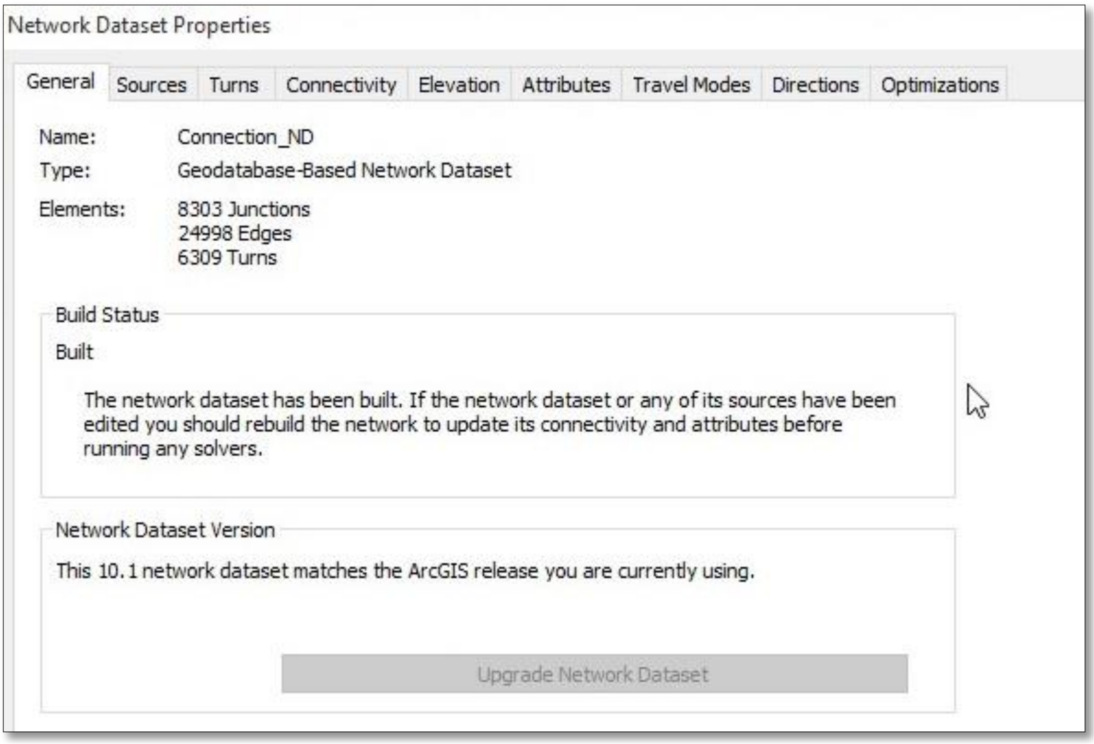


Figure 3.10. *Network Dataset Properties*

The Network Dataset formed from the Odunpazarı District road network data see Figure 3.10 was a Geodatabase based network dataset which had in total 8,303 junctions, 24,998 edges, and 6,309 turns. Endpoint network dataset connectivity policy ensures that roads (line features) connect to each other at endpoints. Network attributes are properties of the network that control navigation. Common examples see Figure 3.11 are cost attributes that function as impedances over the network and restriction attributes that prohibit traversal in either directions or one direction, like one-way roads.

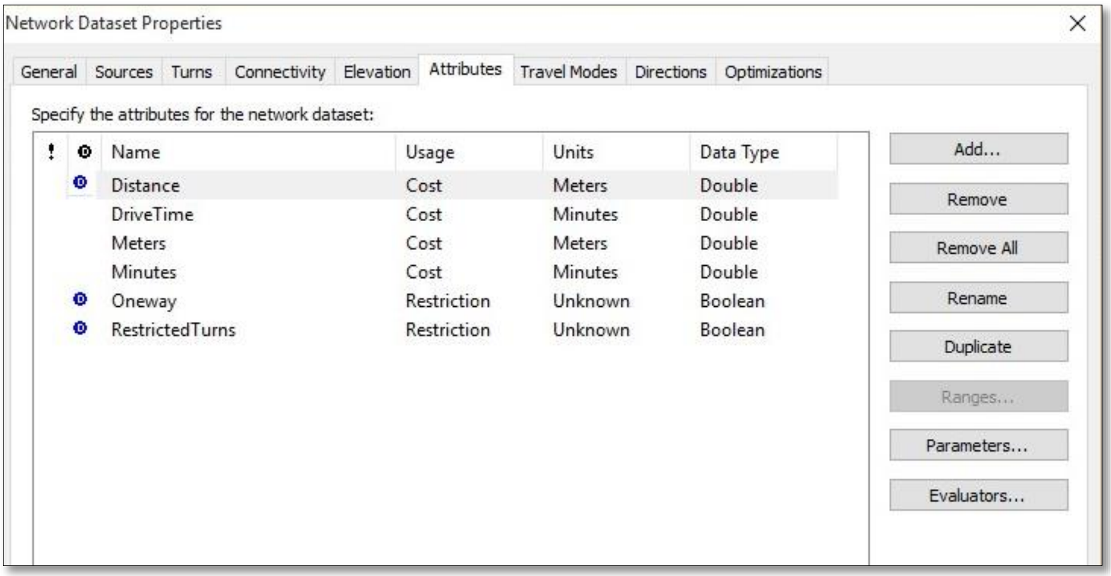


Figure 3.11. *Network Dataset Properties*

The distance in this network dataset was measured in meters, while drive time was measured in minutes see Figure 3.11. The restriction attributes were One-way and Restricted turns. The time it takes to drive on a road was computed by the equation $d = s * t$ where the speed was known and the distance in meters known, then the maximum time to drive on a road was given by $t = d/s$.

4. RESULTS AND DISCUSSIONS

In this chapter, results are presented, interpreted, and discussed in line with the research objectives, conceptual framework and the methodology as per the hypotheses used. Optimal ambulance deployment locations were determined according to demand.

4.1. Origin of Ambulance Demand Calls

The origin of ambulance demand calls registered from different parishes of Odunpazarı District see Figure 4.1and the time interval they were received were plotted as ambulance demand points to be reached by ambulance services.

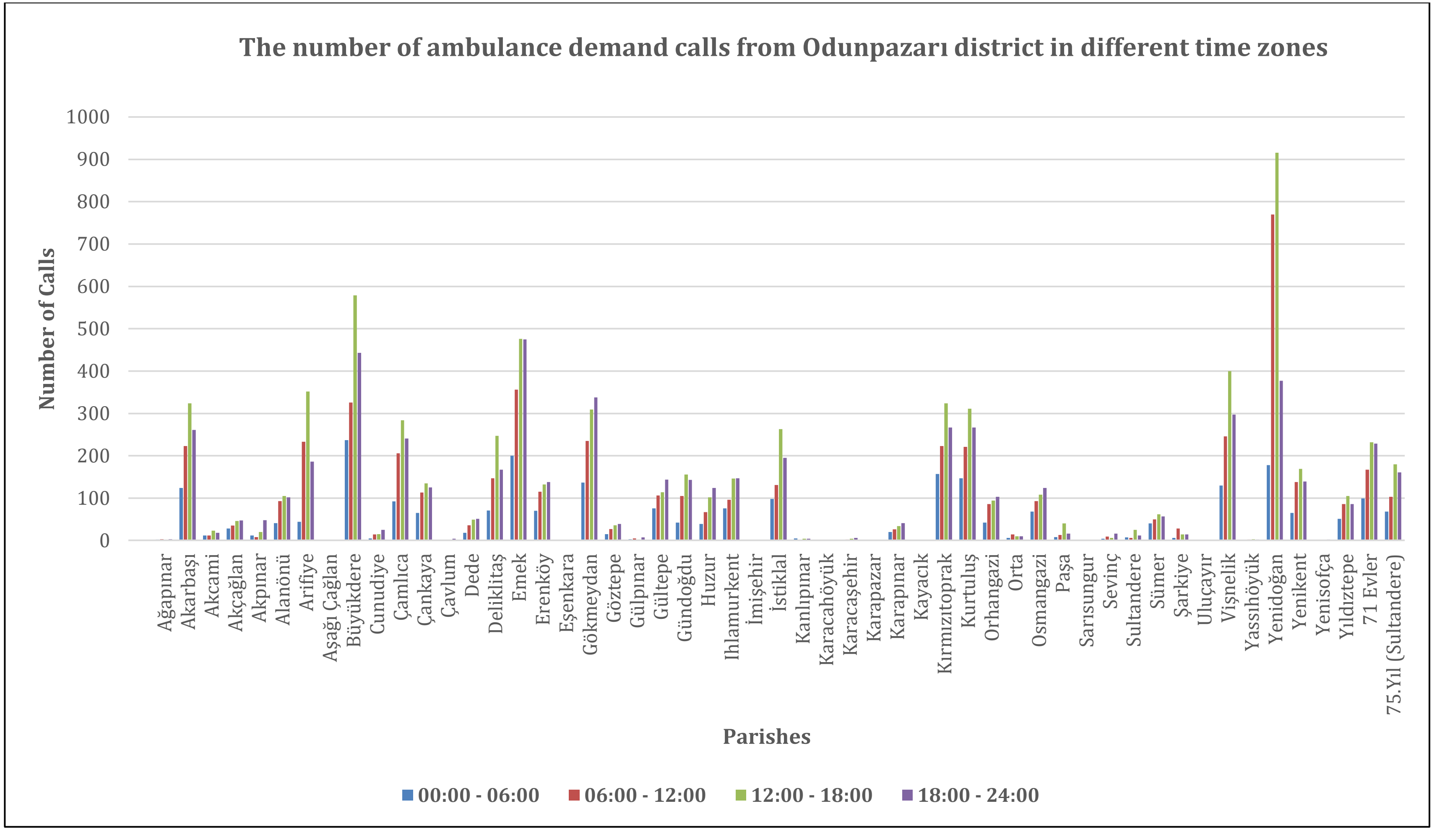


Figure 4.1. *Ambulance Demand Calls Originating Parishes of Odunpazarı District for the Year 2014 According To Different Periods*

Yenidoğan parish had the highest total number of valid ambulance demand calls which were 2,241 followed by Büyükdere parish with 1,585 calls, followed by Emek parish 1,507 calls which was followed by Vişnelik parish with 1,073 calls and Gökemydan parish with 1019 calls for the year 2014 as see Figure 4.1. Parishes Akçakaya, Akkaya, Aşağılıca, Avdan, Ayvacık, Demirli, Doğankaya, Gümele, Harmandalı, Kalkanlı, Karaalan, Karaçay, Karahüyük, Karamustafa, Karatepe, Kargın, Kayapınar, Kıravdan, Kireç, Kuyucak, Lütfiye, Musalar, Seklice, Süpüren, Türkmentokat, Vadişehir, Yahnikapan, Yukarıçağlan, Yukarıılıca, Yukarıkalabak, Yürükkaracaören and Yürükkırka of Odunpazarı District did not register a single valid ambulance demand calls see Figure 4.1.

While only parishes of Ağapinar, Akarbaşı, Akcami, Akçağlan, Akpinar, Alanönü, Arifiye, Aşağı Çağlan , Büyükdere, Cunudiye, Çamlica, Çankaya, Çavlum , Dede, Deliklitaş , Emek, Erenköy, Eşenkara, Gökmeydan, Göztepe, Gülpinar, Gültepe, Gündoğdu, Huzur, Ihlamurkent, İmişehir, Istiklal, Kanlipinar, Karacahöyük, Karacaşehir, Karapazar, Karapinar, Kayacik, Kirmizitoprak, Kurtuluş, Orhangazi, Orta, Osmangazi, Paşa, Sarisungur, Sevinç, Sultandere, Sümer, Şarkiye, Uluçayir, Vişnelik, Yassihöyük, Yenidogan,Yenikent,Yenisofça,Yildiztepe,71 Evler,75.Yil registered ambulance demand calls see Figure 4.1 .

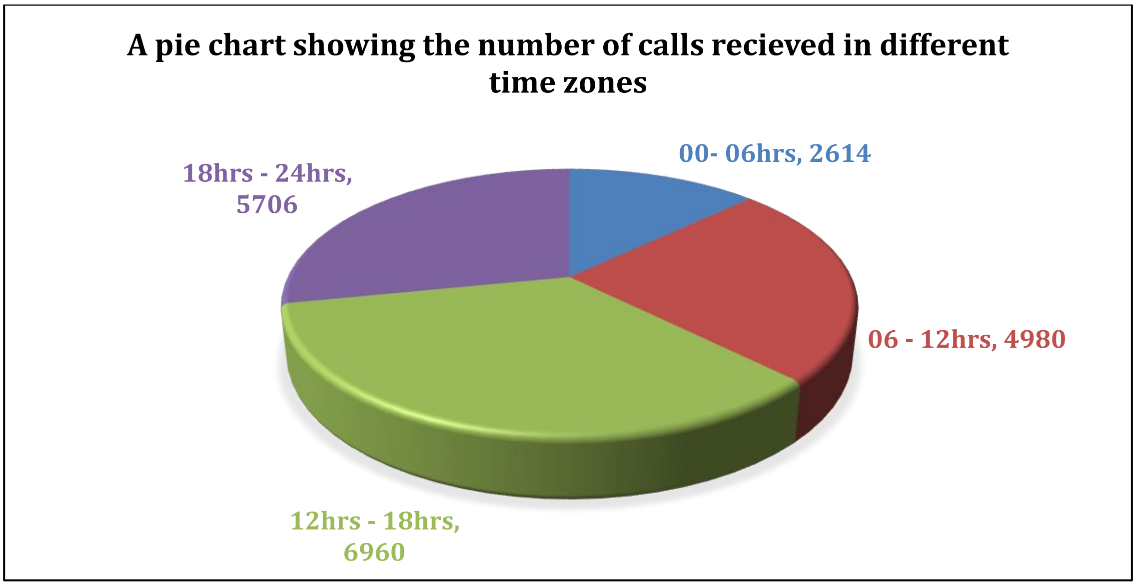


Figure 4.2. *The Total Ambulance Demand Calls In Odunpazarı District Received At Different Periods The Year 2014*

The pie chart indicates the total number of valid ambulance demand calls which were received according to the different time zones. Ambulance demand calls in each time zone were aggregated as a percentage of the total number of calls received in the year 2014 see Figure 4.2*.* Between 00:00 - 06:00hrs a total of 2,614 valid ambulance demand calls were received in the year 2014 which account for 13% of total number of valid ambulance demand calls received see Figure 4.2 . Between 06:00 - 12:00hrs a total of 4,980 valid ambulance demand calls were received which account for 25% of total number of valid ambulance demand calls received in the year 2014 see Figure 4.2.

Between 12:00 - 18:00hrs a total of 6,960 valid ambulance demand calls were received in the year 2014 which account for 34% of total number of valid ambulance demand calls received as is indicated in *Figure 4.2* . Between 18:00 - 24:00hrs a total of 5,706 valid ambulance demand calls were received in the year 2014 which account for 28% of total number of valid ambulance demand calls received see Figure 4.2. Ambulance demand calls received between 00:00 to 06:00 hrs see Figure 4.3 were used as demand points the period between 00:00 to 06:00 hrs.

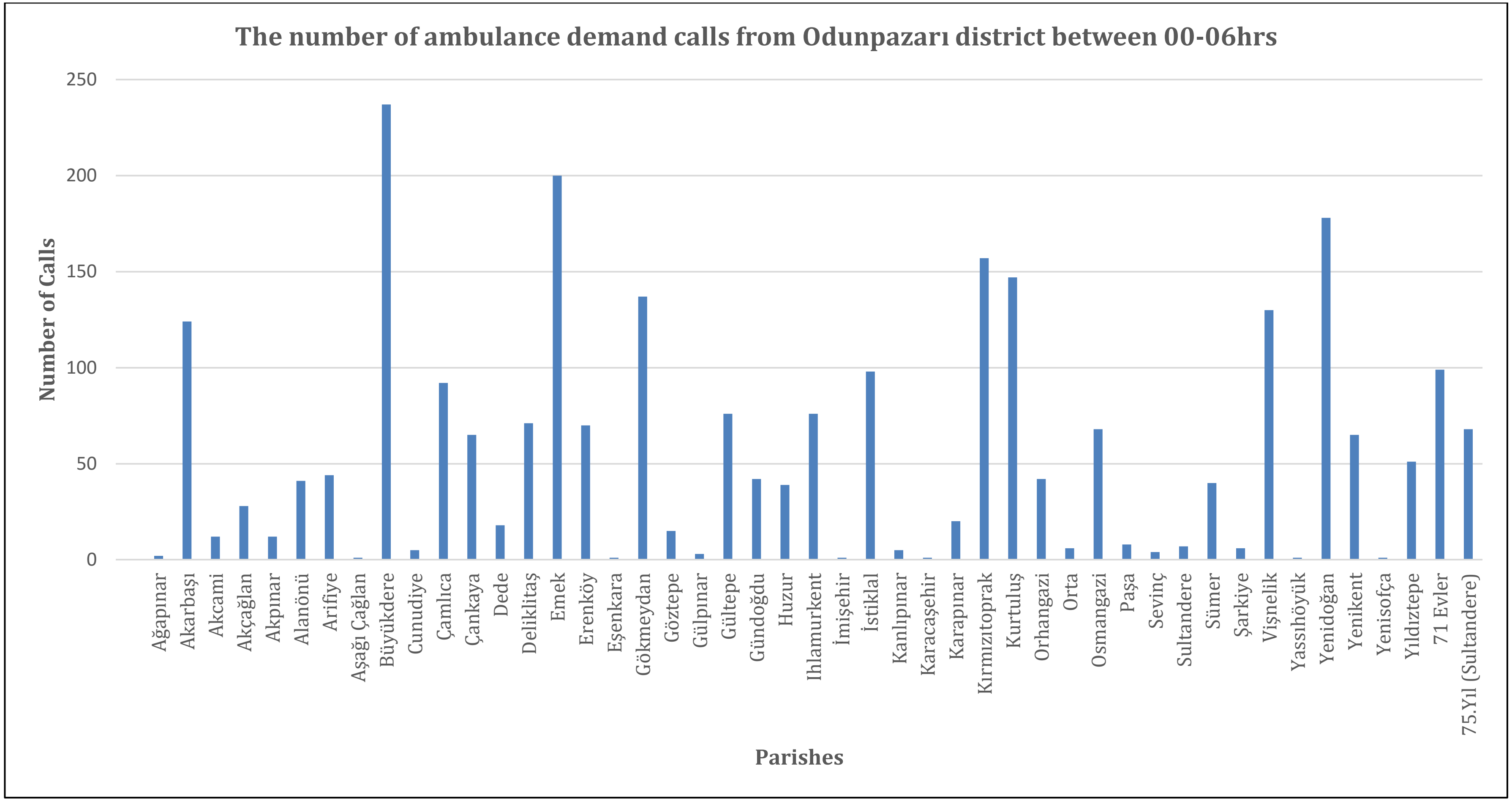


Figure 4.3. *Ambulance Demand Calls Received In Different Parishes of Odunpazarı District Between 00:00 to 06:00 hrs*

The parishes in Odunpazarı District that registered the highest numbers of valid ambulance demand calls in the year 2014 between 00:00 to 06:00hrs were; Büyükdere parish had 237 which was the highest number of calls followed by Emek parish at 200 calls, Yenidoğan parish at 178 and Kırmızıtoprak parish at 157 calls see Figure 4.3. Ambulance demand calls received between 06:00 to 12:00 hrs see Figure 4.4 were used as demand points the period between 06:00 to 12:00 hrs

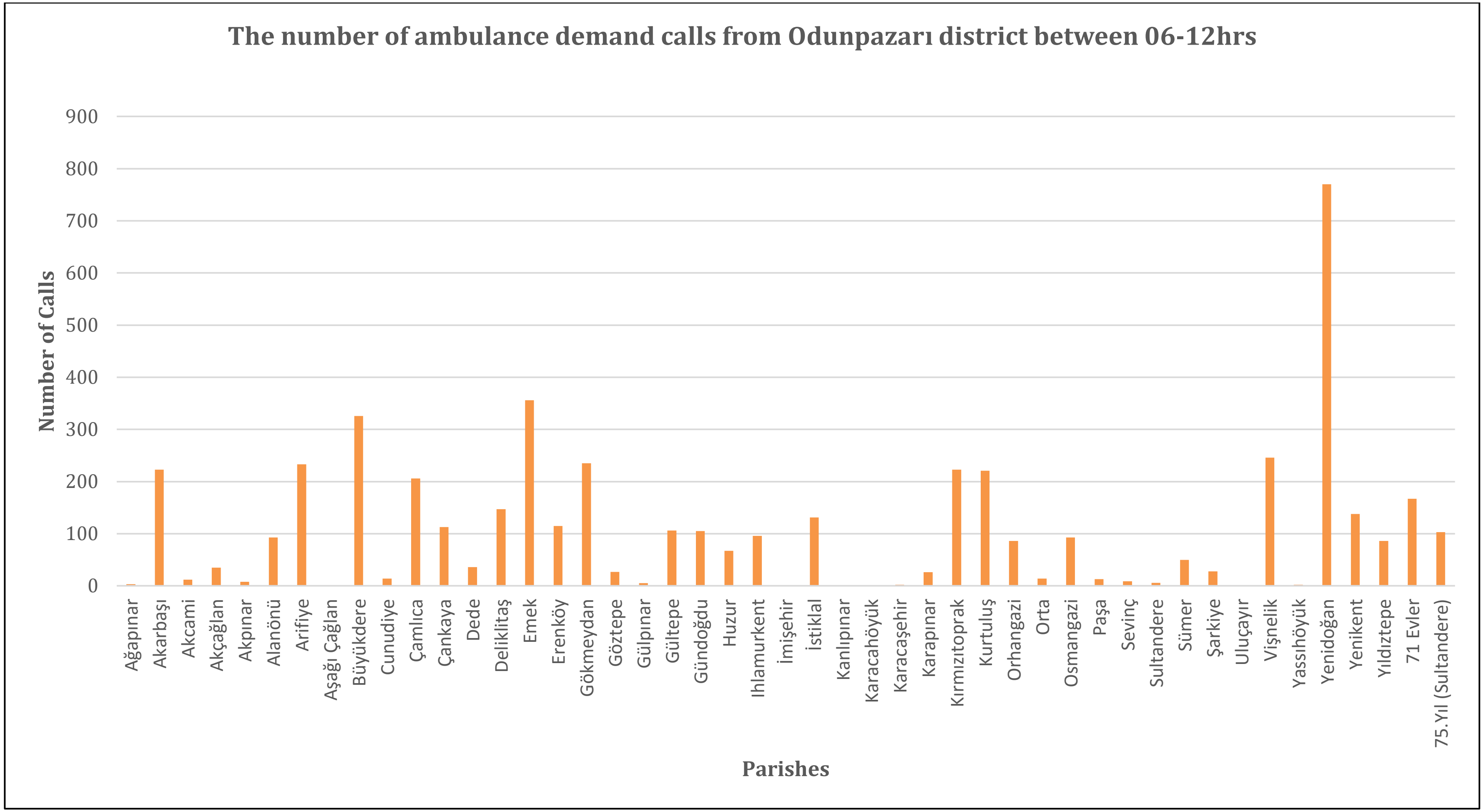


Figure 4.4. *Ambulance Demand Calls Received In Different Parishes of Odunpazarı District Between 06:00 to 12:00 hrs*

The parishes in Odunpazarı District that registered the highest numbers of valid ambulance demand calls in the year 2014 received between 06:00 to 12:00hrs were; Yenidoğan parish registered 770 calls which was the highest followed by Emek parish with 356 calls, Büyükdere parish with 326 calls, Vişnelik parish with 246 calls, Gökmeydan parish with 235 calls, Arifiye parish with 233 calls, Akarbaşı and Kirmizitoprak parishes with 223 calls and Kurtuluş parish with 221 calls as see Figure 4.4. Ambulance demand calls received between 12:00 to 18:00 hrs see Figure 4.5 were used as demand points the period between 12:00 to 18:00 hrs.

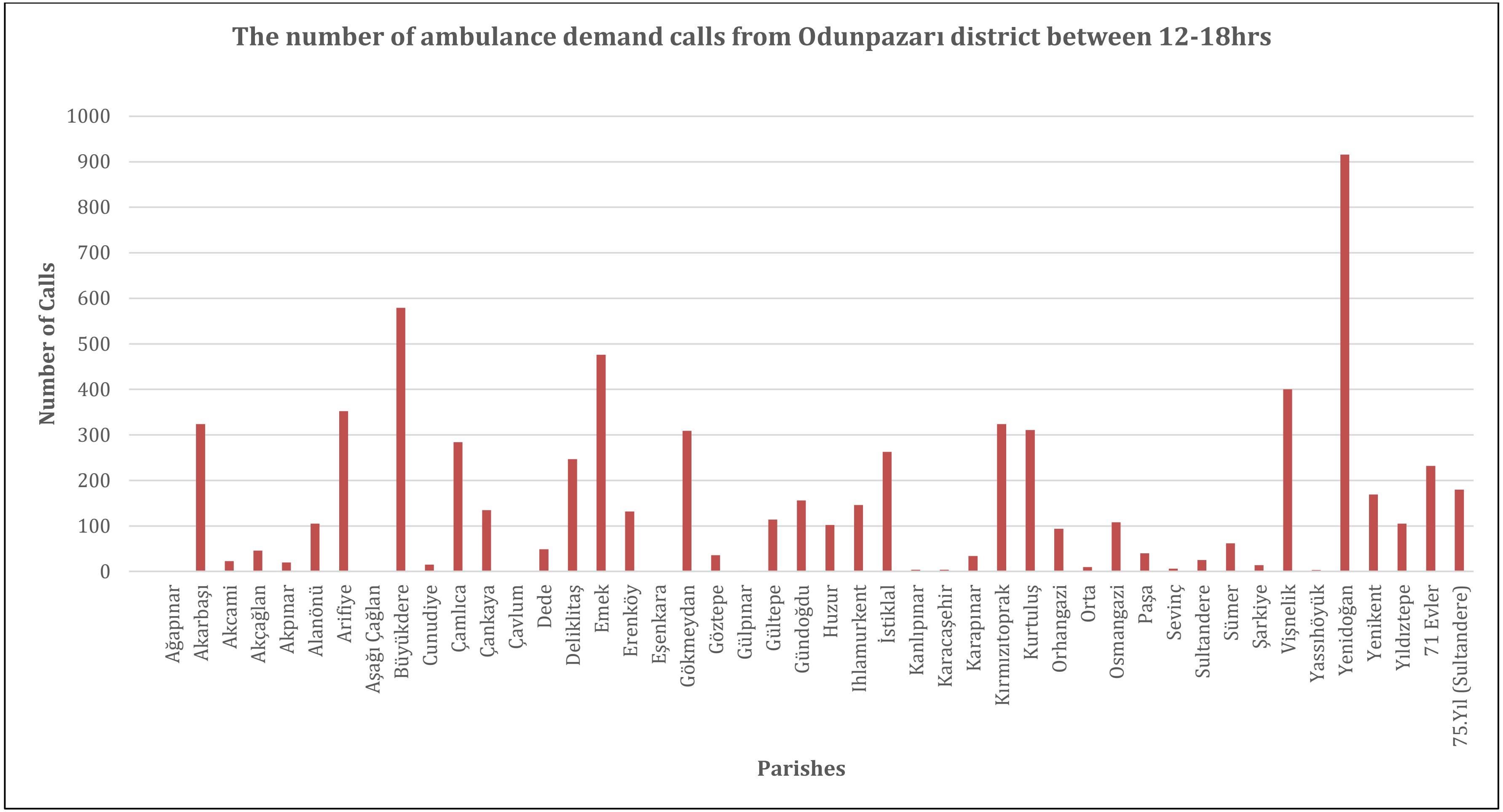


Figure 4.5. *Ambulance Demand Calls Received In Different Parishes of Odunpazarı District Between 12:00 to 18:00 hrs*

The parishes in Odunpazarı District that registered the highest numbers of valid ambulance demand calls received between 12:00 to 18:00hrs were; Yenidoğan parish had the highest number of calls which was 916 followed by Büyükdere parish with 579 calls, Emek parish with 476 calls, Vişnelik parish with 400 calls, Arifiye parish with 352 calls, Akarbaşı and Kirmizitoprak parishes with 324 calls, Kurtuluş parish with 311 calls, and Gökmeydan parish with 309 calls see Figure 4.5. Ambulance demand calls received between 18:00 to 24:00 hrs see Figure 4.6 were used as demand points the period between 18:00 to 24:00 hrs

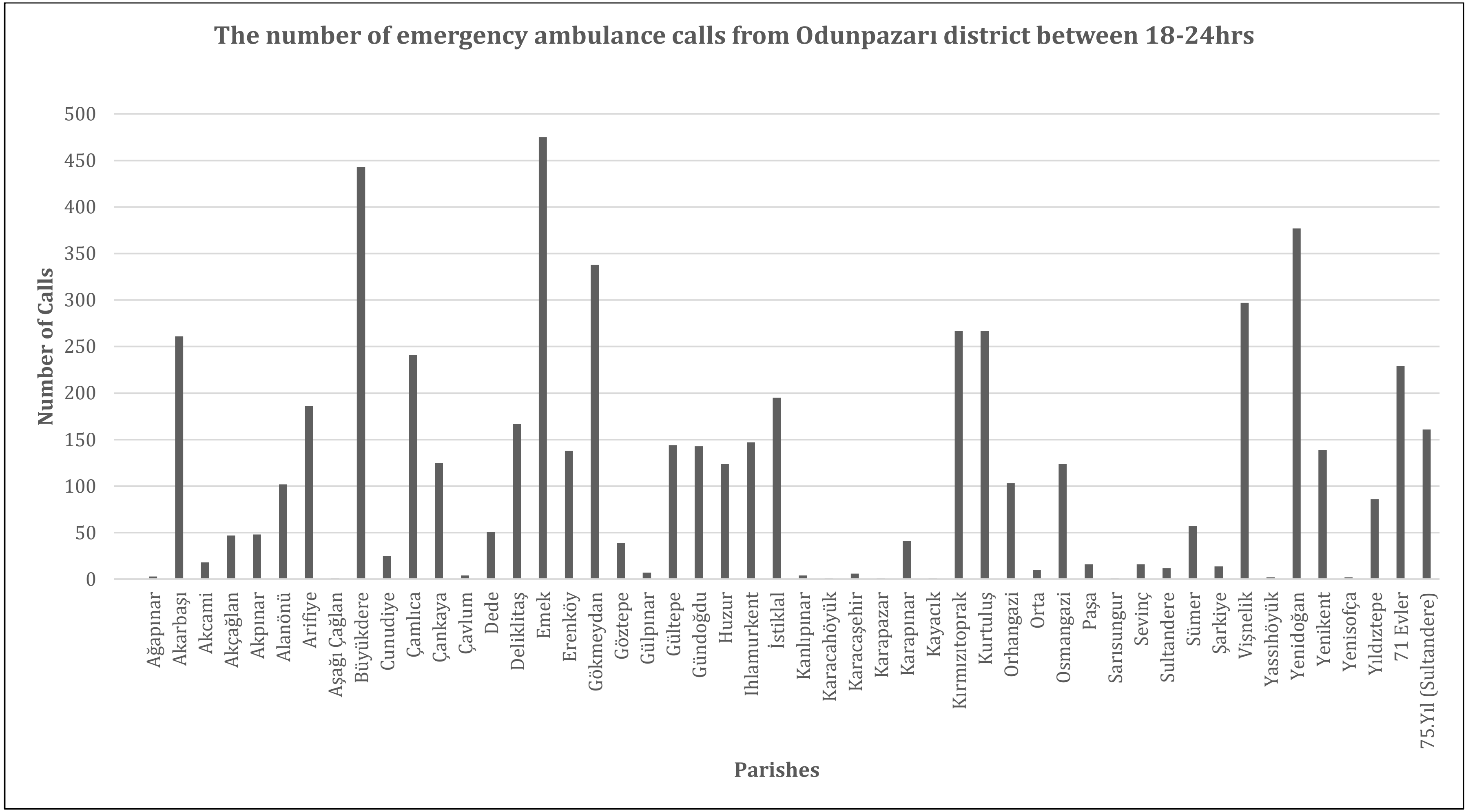


Figure 4.6. *Ambulance Demand Calls Received In Different Parishes of Odunpazarı District Between 18:00 to 24:00 hrs*

The parishes in Odunpazarı District that registered the highest numbers of valid ambulance demand calls in the year 2014 received between 18:00 to 24:00hrs were; Emek parish with 475 calls followed by Büyükdere parish with 443 calls, Yenidoğan parish with 377 calls, Gökmeydan parish with 338, Vişnelik parish with 297 calls, Kirmizitoprak and Kurtuluş parishes with 267 calls and Akarbaşı parish with 261 calls as see Figure 4.6. The origin ambulance demand calls for the year 2014 was spot mapped see Figure 4.7 to have a geographical view of the number of ambulance demand calls visa vie their locations.

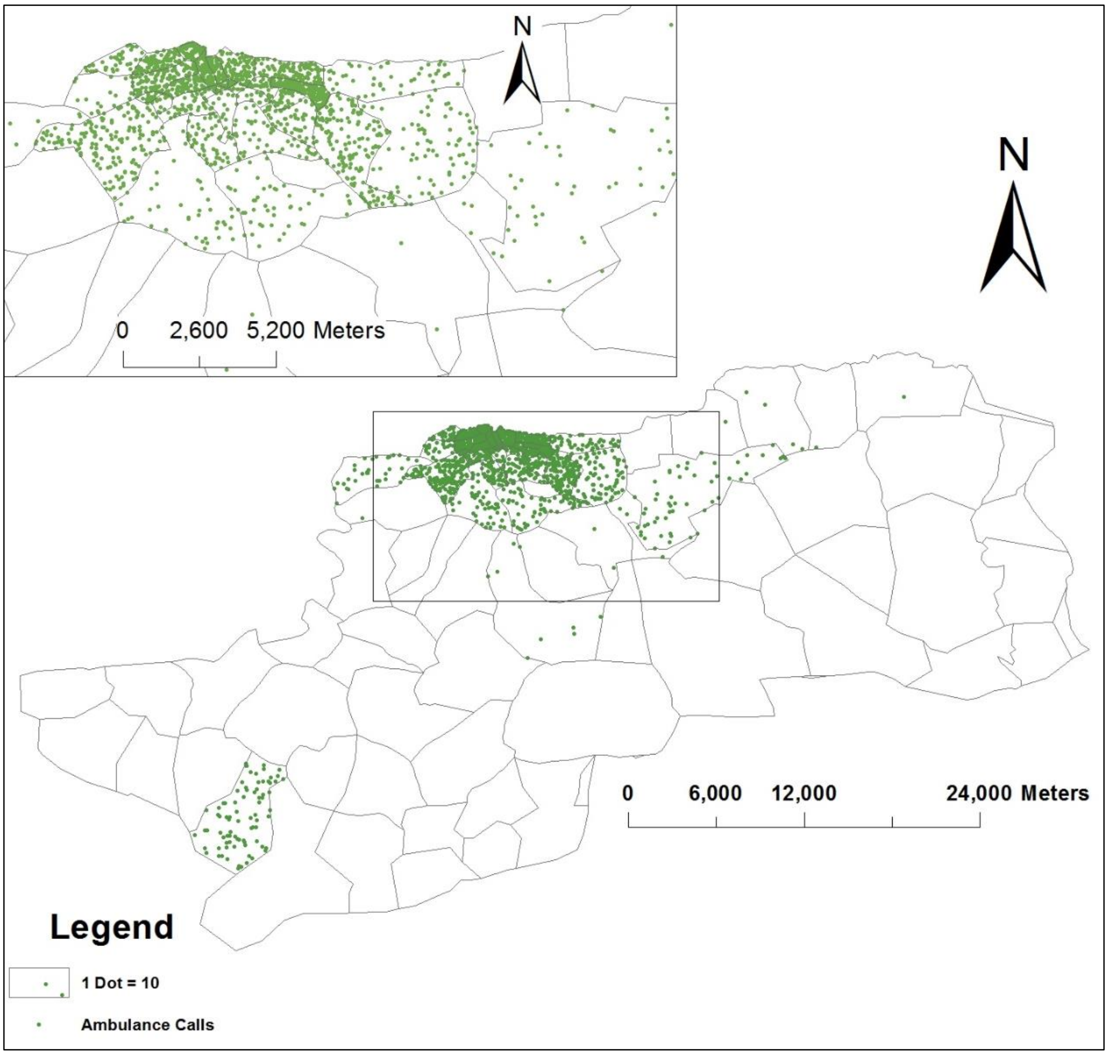


Figure 4.7. *The Origin of Ambulance Demand Calls Received in Odunpazarı District for the Year 2014*

4.3. Optimal Dynamic Ambulance Fleet Deployment

The Odunpazarı District ambulance fleet of 17 ambulances was optimally deployed in accordance with demand (ambulance calls) and the geospatial-time distribution of ambulance demand calls and as a result the average ambulance RT would be reduced from 10 minutes to 5 minutes for 77.6% of the 20,260 ambulance demand calls if this ambulance deployment plan was adopted by the Odunpazarı District EMS. This strategy involved bringing ambulances closer to demand areas such that when need arises an ambulance would travels for a short distance to reach a patient in need of emergency care especially out of hospital cardiac arrest victims. The location allocation tool see Figure 4.8 was used to find optimal stations where ambulances can be stationed.

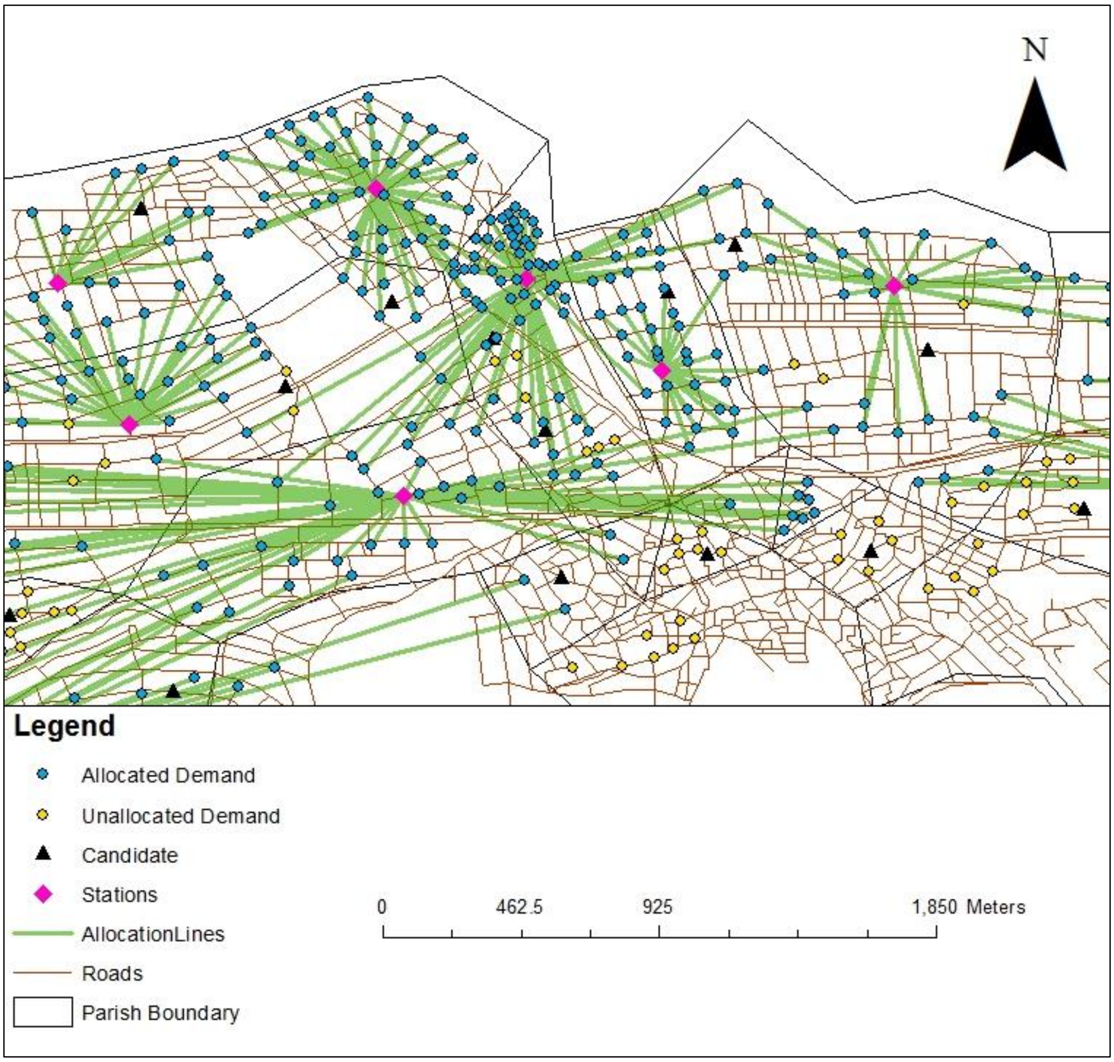


Figure 4.8. *The workıng of the ArcGIS Network Analyst Location Allocation Tool*

The ambulance deployment plan adopted was dynamic and therefore, ambulances change stations according to the time of the day and they are moved to areas where much demand is expected and this was realized by deploying ambulances in respect to 4 six hour interval periods which were; 00:00-06:00, 06:00-12:00, 12:00-18:00, and 18:00-24:00.

4.3.1. Ambulance deployment plan between 00:00-06:00 hrs.

Four different ambulance deployment plans were made starting with between 00:00 to 06:00 hrs see Figure 4.9 to ensure maximum coverage is achieved with a limited ambulance fleet size.

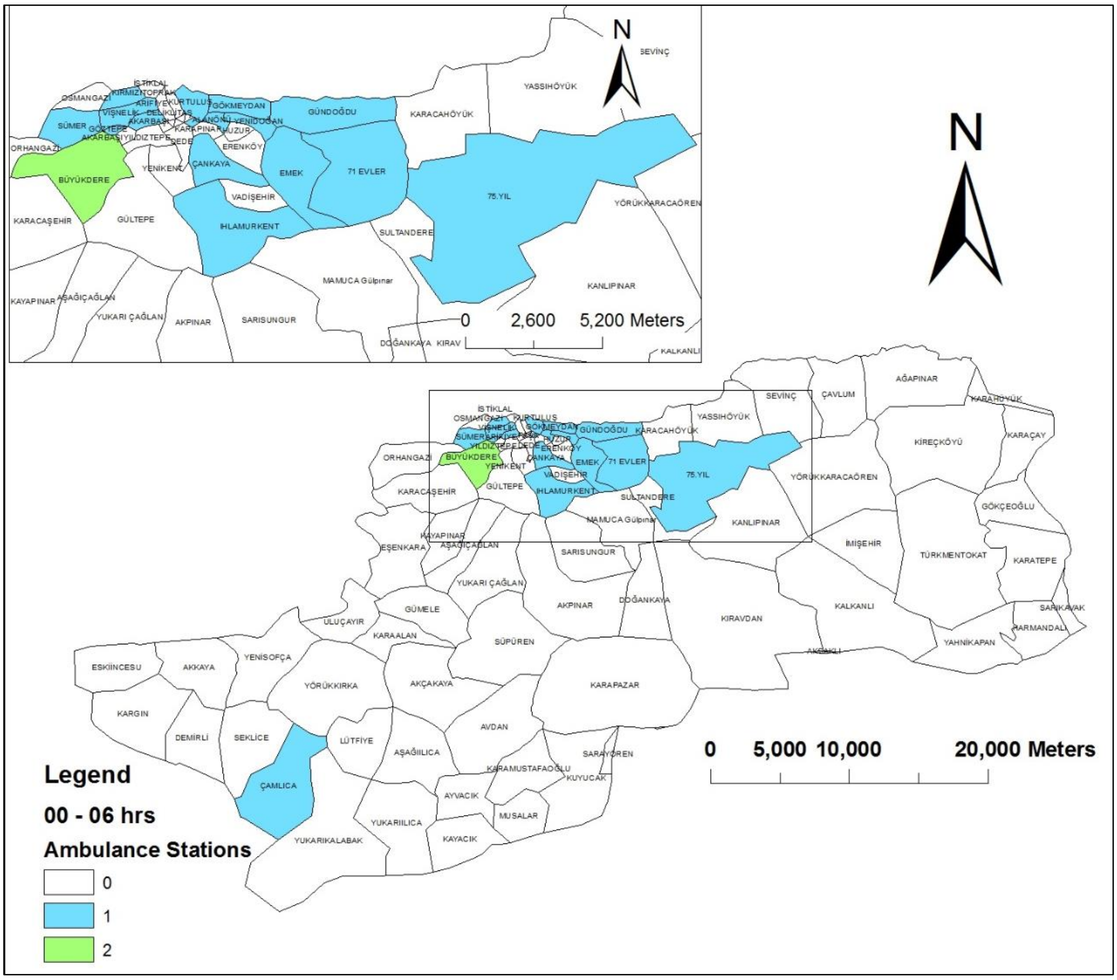


Figure 4.9. *Ambulance Deployment Plan 00:00-06:00 hrs*

Parishes of Ağapınar, Akcami, Akçağlan, Akçakaya, Akkaya, Akpinar, Arifiye, Aşağı Çağlan, Aşağıılıca, Avdan, Ayvacik, Cunudiye, Çavlum, Dede, Deliklitaş, Demirli, Doğankaya, Erenköy, Eşenkara, Göztepe, Gülpinar, Gültepe, Gümele, Harmandali, Huzur, İmişehir, Istiklal, Kalkanli, Kanlipinar, Karaalan, Karacahöyük, Karacaşehir, Karaçay, Karahüyük, Karamustafa, Karapazar, Karapinar, Karatepe, Kargin, Kayacik, Kayapinar, Kiravdan, Kireç, Kuyucak, Lütfiye, Musalar, Orhangazi, Orta, Osmangazi, Paşa, Sarisungur, Seklice, Sevinç, Sultandere, Süpüren, Şarkiye, Türkmentokat, Uluçayir, Vadişehir, Yahnikapan, Yassihöyük, Yenikent, Yenisofça, Yildiztepe, Yukarıçağlan, Yukariilica, Yukarikalabak, Yürükkaracaören and Yürükkirka did not have a single ambulance allocated to them between 00:00-06:00hrs due to no or less demand to cover see Figure 4.9. MCLP optimization model provides priority to areas with much demand so as to cover as much ambulance call demands as possible. This makes a total of 69 out of 85 parishes that did not have ambulance allocated to them and their average demand was 11.3 calls. Parishes Akarbaşı, Alanönü, Çamlica, Çankaya, Emek, Gökmeydan, Gündoğdu , Ihlamurkent, Kirmizitoprak, Kurtuluş, Sümer, Vişnelik, Yenidoğan, 71 Evler and 75.Yil of Odunpazarı District were allocated 1 ambulance each see Figure 4.10, Table 4.1 and their average demand was 106.4 ambulance demand calls. Parishes that did not have ambulances allocated to them in either the current arrangement or the proposed arrangement were represented by xx see Table 4.1.

Table 4.1. *The current ambulance Deployment Plan used by Odunpazarı District is compared with the proposed deployment plan between 00:00 to 06:00 hrs*

Parish	Current Ambulance Position	Proposed Ambulance Position 00:00 – 06:00 hrs
Akarbaşı	30.518284, 39.765982	30.510634, 39.764141
Alanönü	30.540175, 39.763127	30.535698, 39.766161
Büyükdere	30.492979, 39.739760	30.498499, 39.750434 30.502895, 39.752530
Çamlica	30.375492, 39.568073	30.368277, 39.544941
Çankaya	30.533132, 39.747517	30.547596, 39.747255
Emek	30.566992, 39.738238	30.559596, 39.751326
Gökmeydan	30.550264, 39.770360	30.545361, 39.770055
Gündoğdu	30.588050, 39.769290	30.566891, 39.770227
Gülpınar	30.583523, 39.709295	xx
Gültepe	30.499225, 39.726971	xx
Huzur	30.544363, 39.759700	xx

Ihlamurkent	xx	30.536264, 39.741129
Kirmizitoprak	30.503817, 39.772264	30.505369, 39.772480
Kurtuluş	xx	30.529898, 39.772440
Sümer	30.482497, 39.766172	30.495632, 39.766375
Vişnelik	30.506940, 39.767529	30.505725, 39.768871
Yenidoğan	30.550456, 39.763866	30.550449, 39.764258
Yıldıztepe	30.519878, 39.757119	xx
71 Evler	xx	30.580901, 39.749030
75.Yil	30.627296, 39.711961	30.618717, 39.736169

Büyükdere parish only was allocated 2 ambulances and it had a demand of 237 ambulance demand calls see Figure 4.10 and Table 4.1. 2,117 out 2,614 demand areas were covered between 00:00 to 06:00hrs which makes it 81% of all demand calls covered.

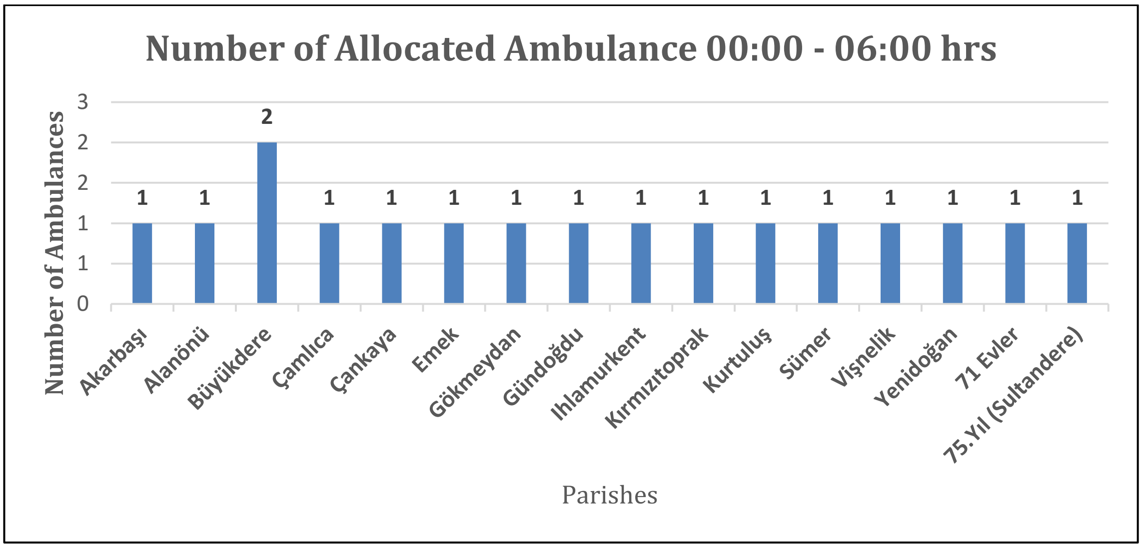


Figure 4.10. *Number of Ambulances Allocated per Parish Between 00:00 to 06:00 hrs*

The current ambulance deployment plan used by Odunpazarı District EMS is compared with the proposed ambulance deployment plan between 00:00 to 06:00 hrs see Figure 4.11. The current ambulance deployment plan is shown in set in the right corner above. There is no parish which is allocated two ambulances in the current ambulance deployment plan but in the proposed ambulance deployment plan for between 00:00 to 06:00 hrs Büyükdere parish was allocated two ambulances.

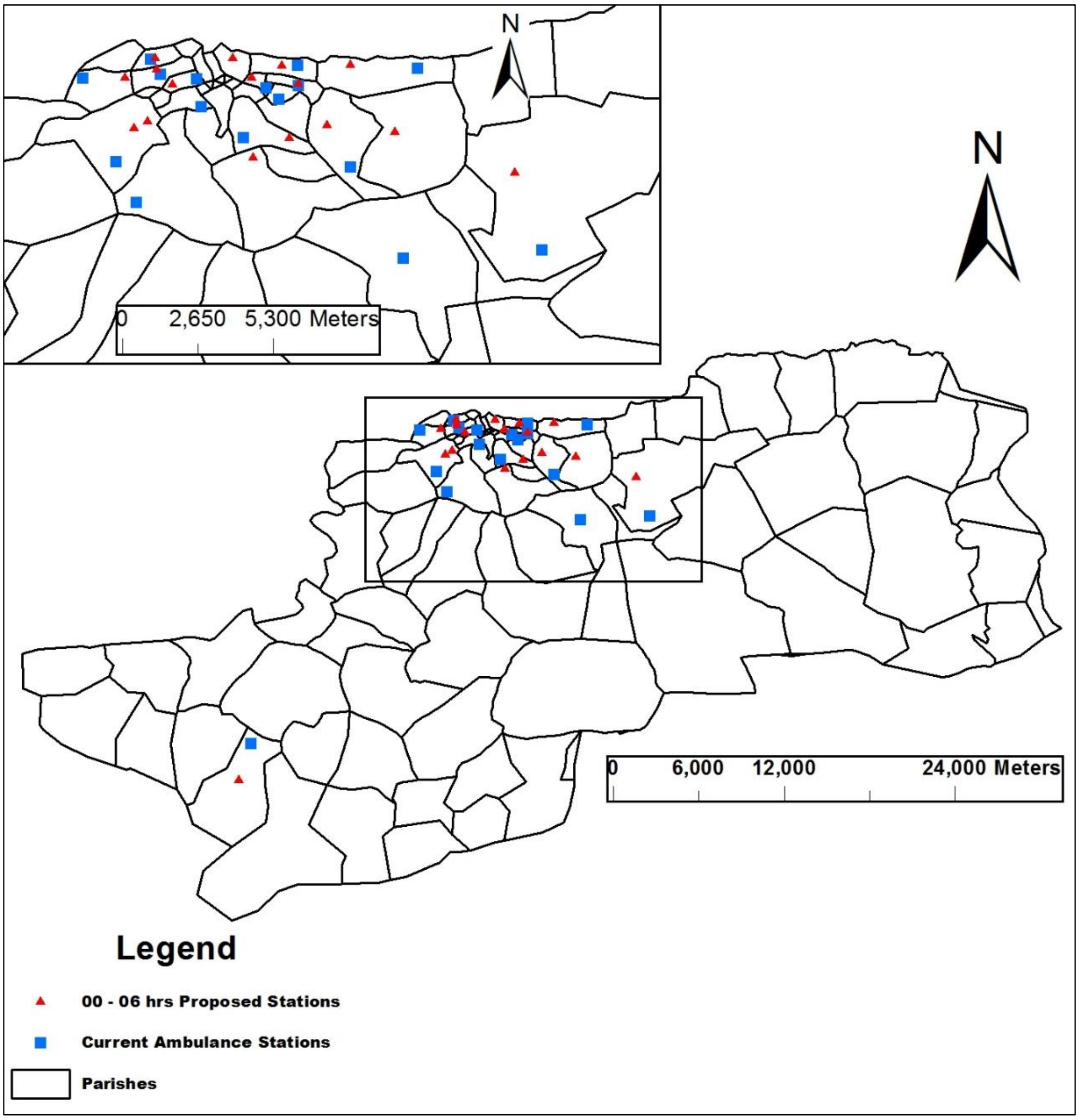


Figure 4.11. *Comparison between the Current and the Proposed Ambulance Deployment Plan For 00:00 to 06:00 hrs*

4.3.2. Ambulance deployment plan between 06:00-12:00hrs

An ambulance fleet deployment plan was made for a period between 06:00 to 12:00 hrs see Figure 4.12 to ensure maximum coverage is achieved

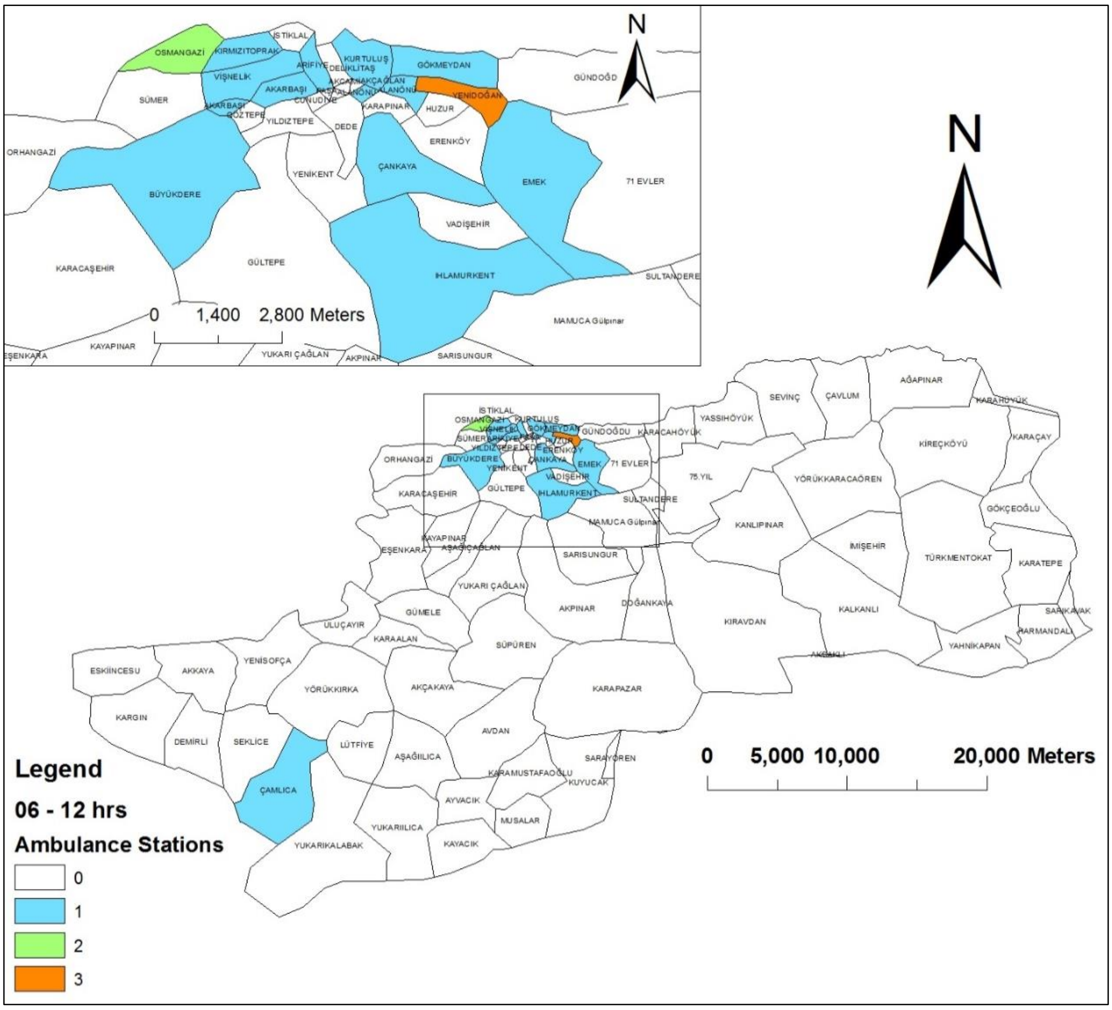


Figure 4.12. *Ambulance Deployment Plan Between 06:00-12:00 hrs*

Between 06:00 to 12:00hrs parishes Ağapınar, Akcami, Akçağlan, Akçakaya, Akkaya , Akpinar, Aşağı Çağlan, Aşağıılıca, Avdan, Ayvacik, Cunudiye, Çavlum, Dede, Deliklitaş, Demirli, Doğankaya, Erenköy, Eşenkara, Göztepe, Gülpinar, Gültepe, Gümele, Gündoğdu, Harmandali, Huzur, İmişehir, Istiklal, Kalkanli, Kanlipinar, Karaalan, Karacahöyük, Karacaşehir, Karaçay, Karahüyük, Karamustafa, Karapazar, Karapinar, Karatepe, Kargin, Kayacik, Kayapinar, Kiravdan, Kireç, Kuyucak, Lütfiye, Musalar, Orhangazi, Orta, Paşa, Sarisungur, Seklice, Sevinç, Sultandere, Sümer, Süpüren, Şarkiye, Türkmentokat, Uluçayir, Vadişehir, Yahnikapan, Yassihöyük, Yenikent, Yenisofça, Yildiztepe, Yukarıçağlan, Yukariilica, Yukarikalabak, Yürükkaracaören, Yürükkirka, 71 Evler and 75.Yil did not have any single ambulance allocated to them because there was less demand as compared to other areas and these 71 parishes had an average demand of 21.7 ambulance demand calls see Figure 4.12 and Table 4.3. Parishes Akarbaşı, Alanönü, Arifiye, Büyükdere, Çamlica, Çankaya, Emek, Gökmeydan, Ihlamurkent, Kirmizitoprak, Kurtuluş and Vişnelik of Odunpazarı District had 1 ambulance allocated to each and the average demand of the 12 parishes was 214.2 ambulance demand calls see Figure 4.13 and Table 4.2. Parishes that did not have ambulances allocated to them in either the current arrangement or the proposed arrangement were represented by xx see Table 4.2.

Table 4.2. *The current ambulance Deployment Plan used by Odunpazarı District is compared with The proposed deployment plan between 06:00 to 12:00 hrs*

Parish	Current Ambulance Position	Proposed Ambulance Position 06:00 – 12:00 hrs
Akarbaşı	30.518284, 39.765982	30.517176, 39.766217
Alanönü	30.540175, 39.763127	30.529957, 39.764583
Arifiye	**xx**	30.519309, 39.772381
Büyükdere	30.492979, 39.739760	30.503145, 39.751786
Çamlica	30.375492, 39.568073	30.371456, 39.544756
Çankaya	30.533132, 39.747517	30.545075, 39.748963
Emek	30.566992, 39.738238	30.562168, 39.754424
Gökmeydan	30.550264, 39.770360	30.545300, 39.769881
Gülpınar	30.583523, 39.709295	xx
Gültepe	30.499225, 39.726971	xx
Gündöğdü	30.588050, 39.769290	xx
Huzur	30.544363, 39.759700	xx
Ihlamurkent	**xx**	30.535993, 39.741763
Kirmizitoprak	30.503817, 39.772264	30.505832, 39.772740
Kurtuluş	**xx**	30.530971, 39.772200
Osmangazi	**xx**	30.489487, 39.770996 30.494000, 39.769600
Sümer	30.482497, 39.766172	xx
Vişnelik	30.506940, 39.767529	30.507285, 39.768258
Yenidoğan	30.550456, 39.763866	30.542000, 39.766413 30.548431, 39.764500 30.555631, 39.762223
Yıldıztepe	30.519878, 39.757119	xx
75 Yil	30.627296, 39.711961	**xx**

Osmangazi parish with a demand of 93 ambulance calls was allocated 2 ambulances. While Yenidoğan parish with a demand of 770 ambulance calls was allocated 3 ambulance see Figure 4.13. 3,984 out of 4,980 demand centres were allocated ambulances within a 5 minutes' drive time which makes it 80% of the ambulance demand calls covered with a 5 minute response time.

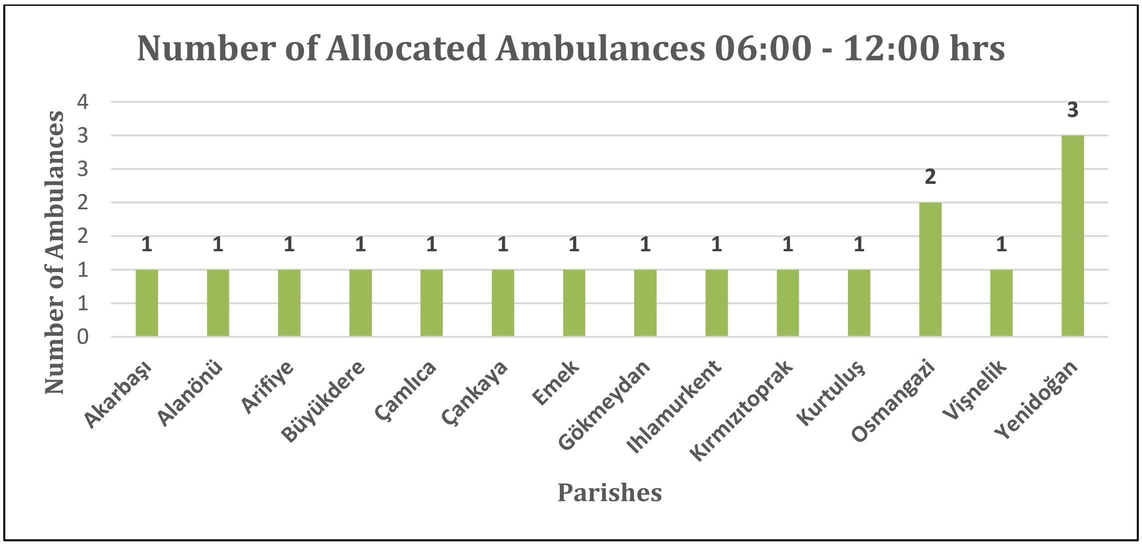


Figure 4.13. *Number of Ambulances Deployed in Different Parishes between 06:00 to 12:00 hrs*

The Odunpazarı District current ambulance deployment is compared with the proposed ambulance deployment plan for the period between 06:00 to 12:00 hrs see Figure 4.14. The current ambulance deployment plan is shown in set in the right hand upper corner. In the current ambulance deployment plan all the 17 ambulances are spread to 17 parishes therefore there is no single parish with more than one ambulance. In the proposed ambulance deployment plan for 06:00 to 12:00 hrs, Yenidoğan parish was allocated three ambulances while Osmangazi parish was allocated two ambulances.

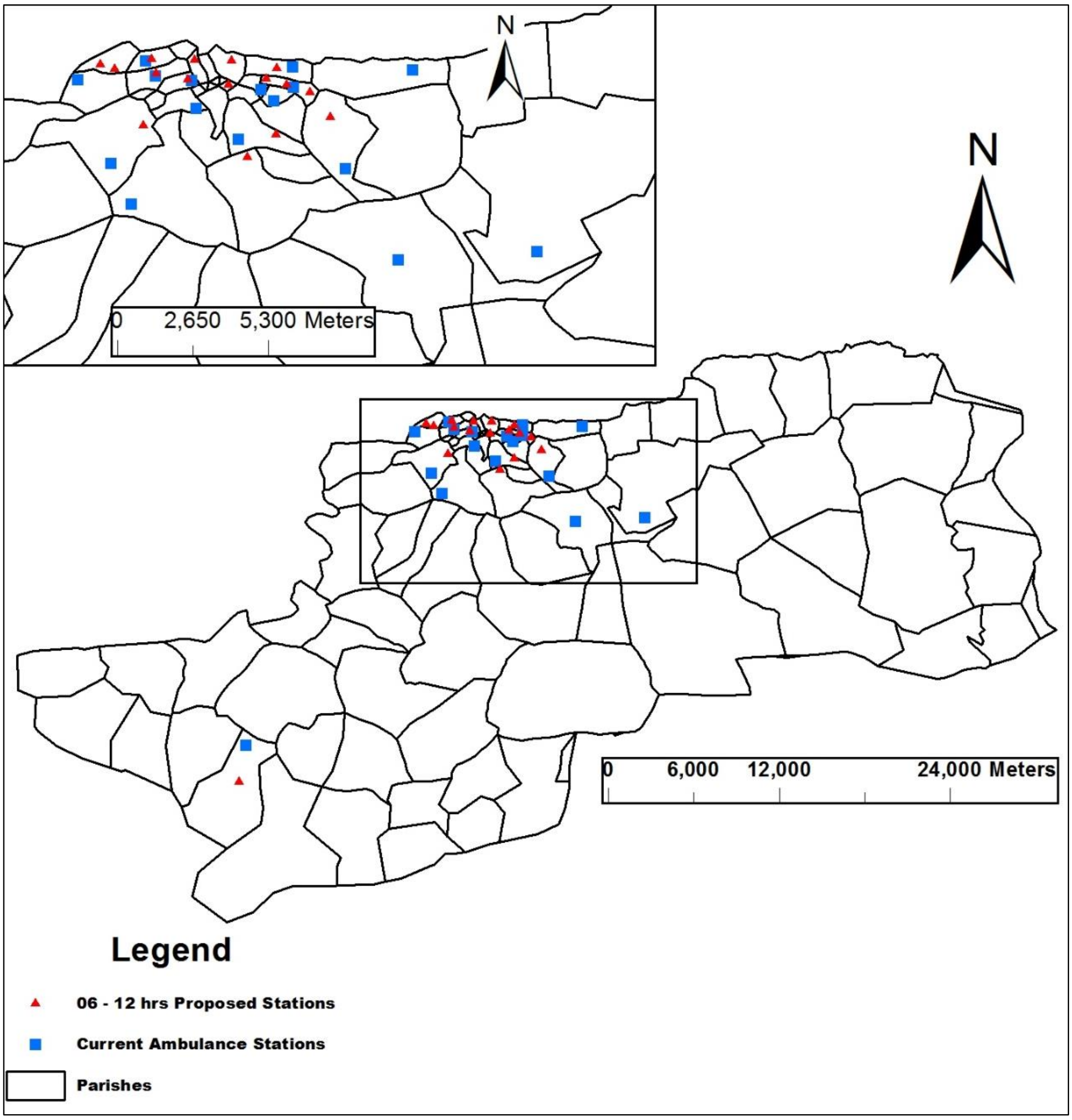


Figure 4.14. *Comparison Between the Current Ambulance Deployment Plan and the Proposed Deployment Plan Between 06:00 to 12:00 hrs*

4.3.3. Ambulance deployment plan between 12:00-18:00 hrs

An ambulance fleet deployment plan was made for a period between 12:00 to 18:00 hrs see Figure 4.15 to ensure maximum coverage is achieved

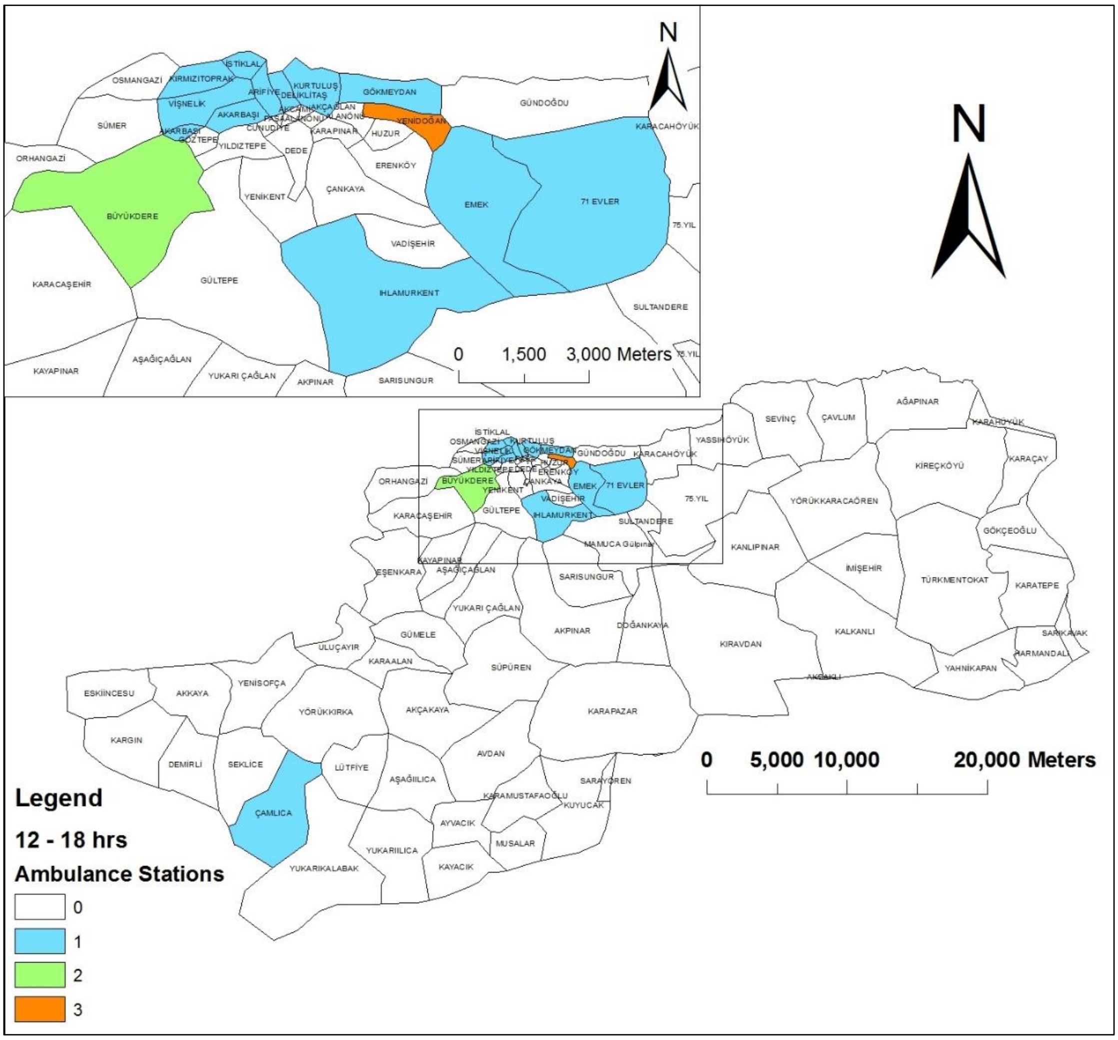


Figure 4.15. *Ambulance Deployment Plan For 12:00-18:00 hrs*

Parishes Ağapınar, Akcami, Akçağlan, Akçakaya, Akkaya, Akpinar, Alanönü, Aşağı Çağlan, Aşağıılıca, Avdan, Ayvacik, Cunudiye, Çankaya, Çavlum, Dede, Demirli, Doğankaya, Erenköy, Eşenkara, Göztepe, Gülpinar, Gültepe, Gümele, Gündoğdu, Harmandali, Huzur, İmişehir, Kalkanli, Kanlipinar, Karaalan, Karacahöyük, Karacaşehir, Karaçay, Karahüyük, Karamustafa, Karapazar, Karapinar, Karatepe, Kargin, Kayacik, Kayapinar, Kiravdan, Kireç, Kuyucak, Lütfiye, Musalar, Orhangazi, Orta, Osmangazi, Paşa, Sarisungur, Seklice, Sevinç, Sultandere, Sümer, Süpüren, Şarkiye, Türkmentokat, Uluçayir, Vadişehir, Yahnikapan, Yassihöyük, Yenikent, Yenisofça, Yildiztepe, Yukarıçağlan, Yukariilica, Yukarikalabak, Yürükkaracaören, Yürükkirka and 75.Yil of Odunpazarı District had no any single ambulance allocated to them between 12:00 to 18:00 hrs see Figure 4.15 and Table 4.3. These 71 parishes had an average demand of 25.3 ambulance demand calls. Parishes of Akarbaşı, Arifiye, Çamlica, Deliklitaş, Emek, Gökmeydan, Ihlamurkent, Istiklal, Kirmizitoprak, Kurtuluş, Vişnelik, and 71 Evler, had only 1 ambulance allocated to them see Figure 4.16 and Table 4.3. These 12 parishes had an average demand of 305.6 ambulance demand calls. Parishes that did not have ambulances allocated to them in either the current arrangement or the proposed arrangement were represented by xx see Table 4.3.

Table 4.3. *The current ambulance Deployment Plan used by Odunpazarı District is compared with the proposed deployment plan between 12:00 to 18:00 hrs*

Parish	**Current Ambulance Position**	**Proposed Ambulance Position 12:00 – 18:00 hrs**
Akarbaşı	30.518284, 39.765982	30.515844, 39.765917
Alanonü	30.540175, 39.763127	xx
Arifiye	**xx**	30.519522, 39.772456
Büyükdere	30.492979, 39.739760	30.502244, 39.748739 30.501445, 39.757510
Çamlica	30.375492, 39.568073	30.368265, 39.546269
Çankaya	30.533132, 39.747517	xx
Deliklitaş	**xx**	30.523629, 39.769670
Emek	30.566992, 39.738238	30.559599, 39.758074
Gökmeydan	30.550264, 39.770360	30.545913, 39.769726
Gülpınar	30.583523, 39.709295	xx
Gültepe	30.499225, 39.726971	xx
Gündöğdü	30.588050, 39.769290	xx
Huzur	30.544363, 39.759700	xx
Ihlamurkent	**xx**	30.536003, 39.740416
Istiklal	**xx**	30.515027, 39.775173
Kirmizitoprak	30.503817, 39.772264	30.505455, 39.772334
Kurtuluş	**xx**	30.530595, 39.772218
Sümer	30.482497, 39.766172	xx
Vişnelik	30.506940, 39.767529	30.507613, 39.768056
	xx	**xx**
Yenidoğan	30.550456, 39.763866	30.554334, 39.762613 30.548919, 39.764500 30.541960, 39.766050
Yıldıztepe	30.519878, 39.757119	xx
71 Evler		30.584630, 39.747600
75 Yıl	30.627296, 39.711961	**xx**

Büyükdere parish, with a demand of 539 ambulance calls was allocated 2 ambulances between 12:00 to 18:00 hrs see Figure 4.14. While Yenidoğan parish with a demand of 916 ambulance calls was allocated 3 ambulances between 12:00 to 18:00 hrs see Figure 4.16. 5,080 out of 6,960 demand points were reached within a 5 minute drive time which gives 73% of the total demand points covered within a 5 minute drive time between 12:00 to 18:00 hrs.

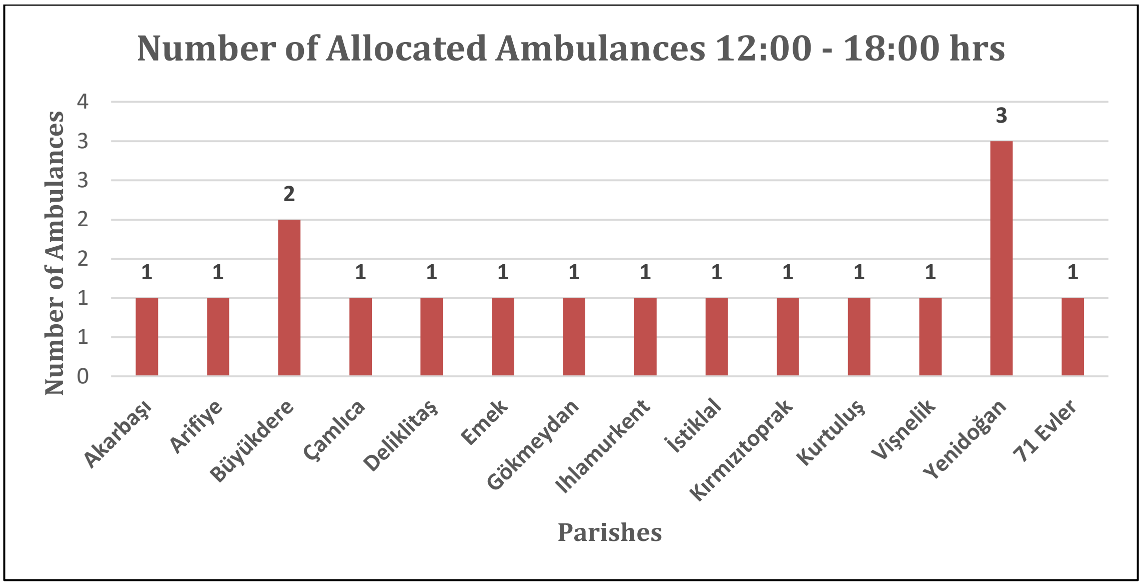


Figure 4.16. *The Number of Ambulance Deployed Per Parish between 12:00 to 18:00 hrs*

The current ambulance deployment plan used by Odunpazarı District EMS is compared with the proposed ambulance deployment for the period between 12:00 to 18:00 hrs see Figure 4.17. The current ambulance deployment plan is shown in set in the right corner. In the current ambulance deployment plan, no ambulance station has more than one ambulances allocated there while the proposed ambulance deployment plan for the period between 12:00 to 18:00 hrs has two ambulances allocated to Büyükdere parish and three ambulances allocated to Yenidoğan parish see Figure 4.17.

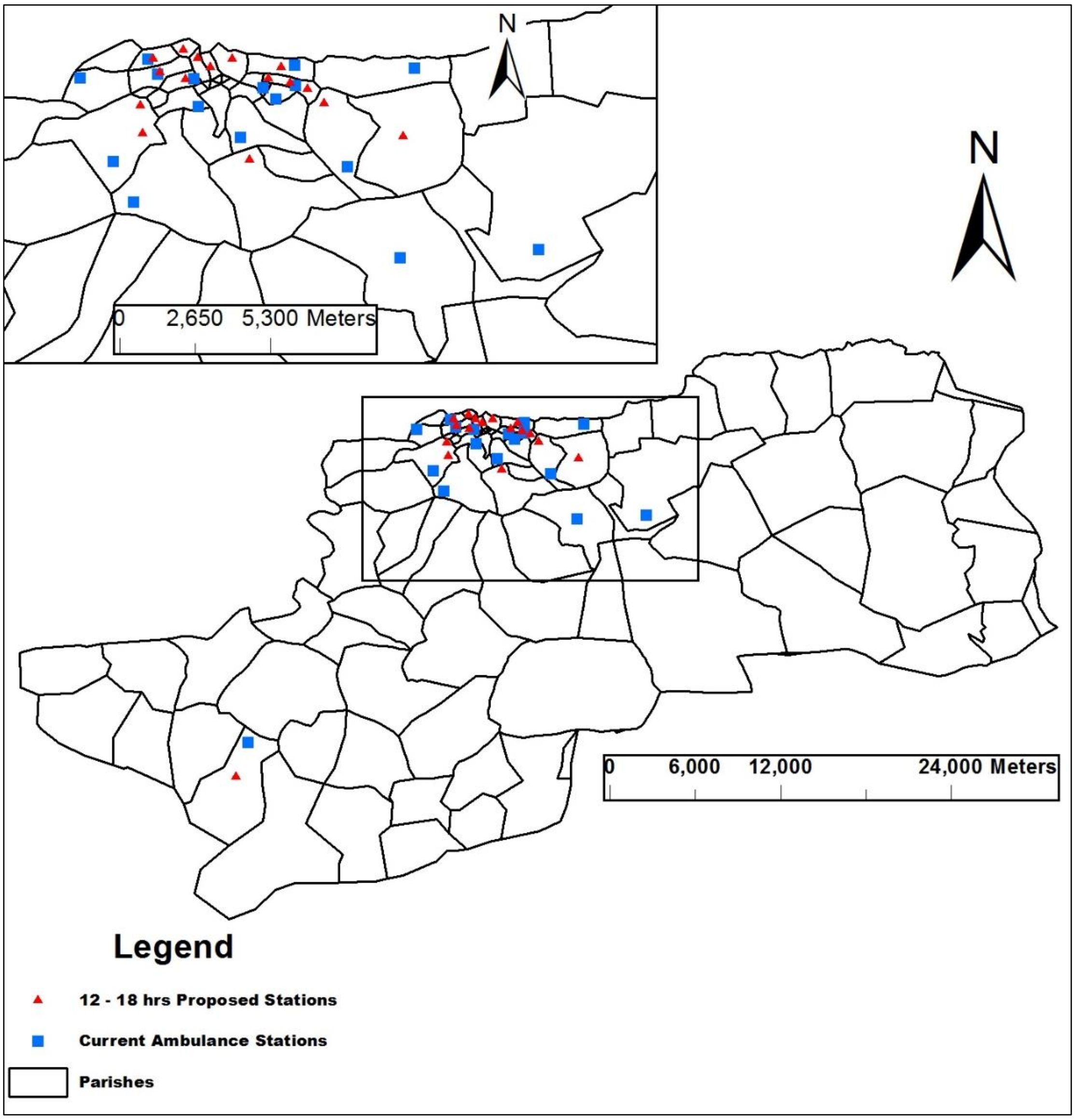


Figure 4.17. *Comparison Between the Current Ambulance Deployment Plans for Odunpazarı District with the Proposed Deployment Plan for 12:00 to 18:00 hrs*

4.3.4. Ambulance deployment plan between 18:00-24:00 hrs

An ambulance fleet deployment plan was made for a period between 18:00 to 24:00 hrs see Figure 4.18 to ensure maximum coverage is achieved with a limited ambulance fleet size.

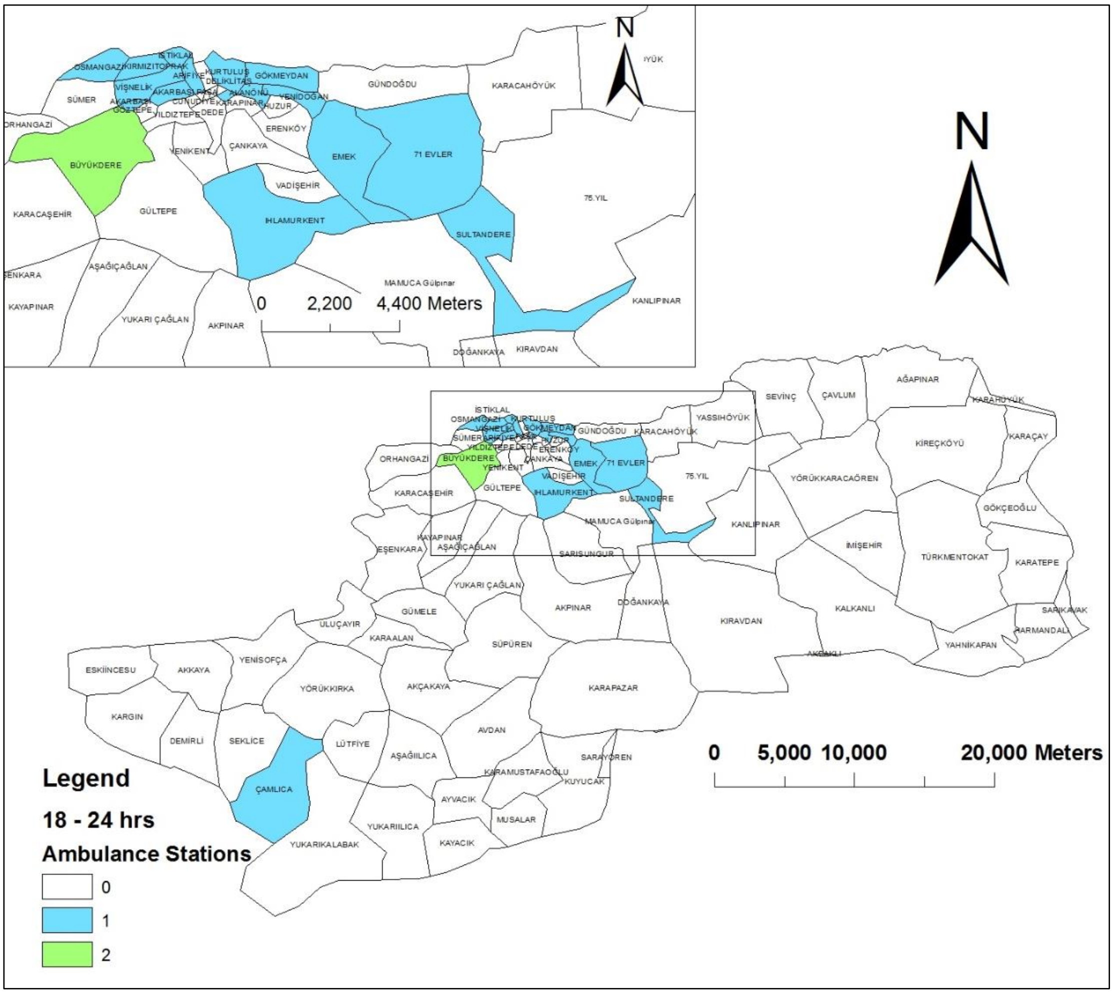


Figure 4.18. *Ambulance Deployment Plan 18:00-24:00 hrs*

Parishes of Ağapınar, Akcami, Akçağlan, Akçakaya, Akkaya, Akpinar, Aşağı Çağlan, Aşağıılıca, Avdan, Ayvacik, Cunudiye, Çankaya, Çavlum, Dede, Deliklitaş, Demirli, Doğankaya, Erenköy, Eşenkara, Göztepe, Gülpinar, Gültepe, Gümele, Gündoğdu, Harmandali, Huzur, İmişehir, Kalkanli, Kanlipinar, Karaalan, Karacahöyük, Karacaşehir, Karaçay, Karahüyük, Karamustafa, Karapazar, Karapinar, Karatepe, Kargin, Kayacik, Kayapinar, Kiravdan, Kireç, Kuyucak, Lütfiye, Musalar, Orhangazi, Orta, Paşa, Sarisungur, Seklice, Sevinç, Sümer, Süpüren, Şarkiye, Türkmentokat, Uluçayir, Vadişehir, Yahnikapan, Yassihöyük, Yenikent, Yenisofça, Yildiztepe, Yukarıçağlan, Yukariilica, Yukarikalabak, Yürükkaracaören, Yürükkirka and 75.Yil of Odunpazarı District were not allocated even a single ambulance between 18:00 to 24:00 hrs see Figure 4.18,Table 4.4. These 69 parishes had an average demand of 25.2 ambulance demand calls. Parishes Akarbaşı, Alanönü, Arifiye, Çamlica, Emek, Gökmeydan, Ihlamurkent, Istiklal, Kirmizitoprak, Kurtuluş, Osmangazi, Sultandere, Vişnelik, Yenidoğan and 71 Evler were allocated with 1 ambulance each between 18:00 to 24:00 hrs according see Figure 4.19, Table 4.4. These 15 parishes had an average demand of 234.5 ambulance calls. Parishes that did not have ambulances allocated to them in either the current arrangement or the proposed arrangement were represented by xx see Table 4.4.

Table 4.4. *The current ambulance Deployment Plan used by Odunpazarı District is compared with the proposed deployment plan between 12:00 to 18:00 hrs*

Parish	**Current Ambulance Position**	**Proposed Ambulance Position 12:00 – 24:00 hrs**
Akarbaşı	30.518284, 39.765982	30.512900, 39.763928
Alanönü	30.540175, 39.763127	30.529548, 39.764697
Arifiye	**xx**	30.520808, 39.768025
Büyükdere	30.492979, 39.739760	30.501924, 39.752222 30.498076, 39.748915
Çamlica	30.375492, 39.568073	30.368877, 39.542970
Çankaya	30.533132, 39.747517	xx
Emek	30.566992, 39.738238	30.562987, 39.751040
Gökmeydan	30.550264, 39.770360	30.545300, 39.770464
Gülpınar	30.583523, 39.709295	xx
Gültepe	30.499225, 39.726971	xx
Gündöğdü	30.588050, 39.769290	xx
Huzur	30.544363, 39.759700	xx
Ihlamurkent	**xx**	30.535739, 39.740725
Istiklal	**xx**	30.515135, 39.775601
Kirmizitoprak	30.503817, 39.772264	30.505825, 39.772774
Kurtuluş	**xx**	30.529824, 39.772592
Osmangazi	**xx**	30.493900, 39.772100
Sultandere	**xx**	30.608200, 39.725900

Sümer	30.482497, 39.766172	xx
Vişnelik	30.506940, 39.767529	30.509303, 39.768901
Yenidoğan	30.550456, 39.763866	30.549725, 39.764232
Yıldıztepe	30.519878, 39.757119	xx
71 Evler	**xx**	30.583081, 39.747420
75 Yil	30.627296, 39.711961	xx

Büyükdere parish was allocated 2 ambulances and this parish had a demand of 443 ambulance calls see Figure 4.19. 4,336 out of 5,706 demand points were serviced within a 5 minute drive time which gives 76% of ambulance demand calls between 18:00 to 24:00 hrs serviced within 5 minutes.

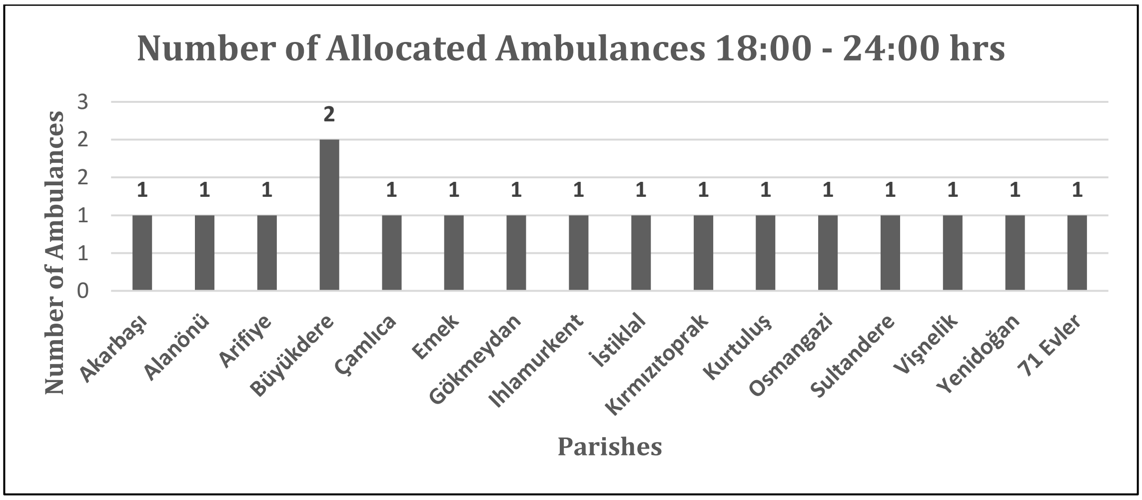


Figure 4.19. *The Number of Ambulances Deployed Per Parish between 18:00 To 24:00 hrs*

The current deployment plan for the ambulance fleet for Odunpazarı District EMS is compared with the proposed deployment plan for the period between 12:00 to 18:00 hrs see Figure 4.20. The current ambulance deployment plan has 17 ambulances in 17 different parishes and no single parish has more than one ambulance allocated there. The proposed ambulance deployment plan between 18:00 to 24:00 hrs has two ambulances allocated to Büyükdere parish and other 15 ambulances allocated to 15 other parishes see Figure 4.20.

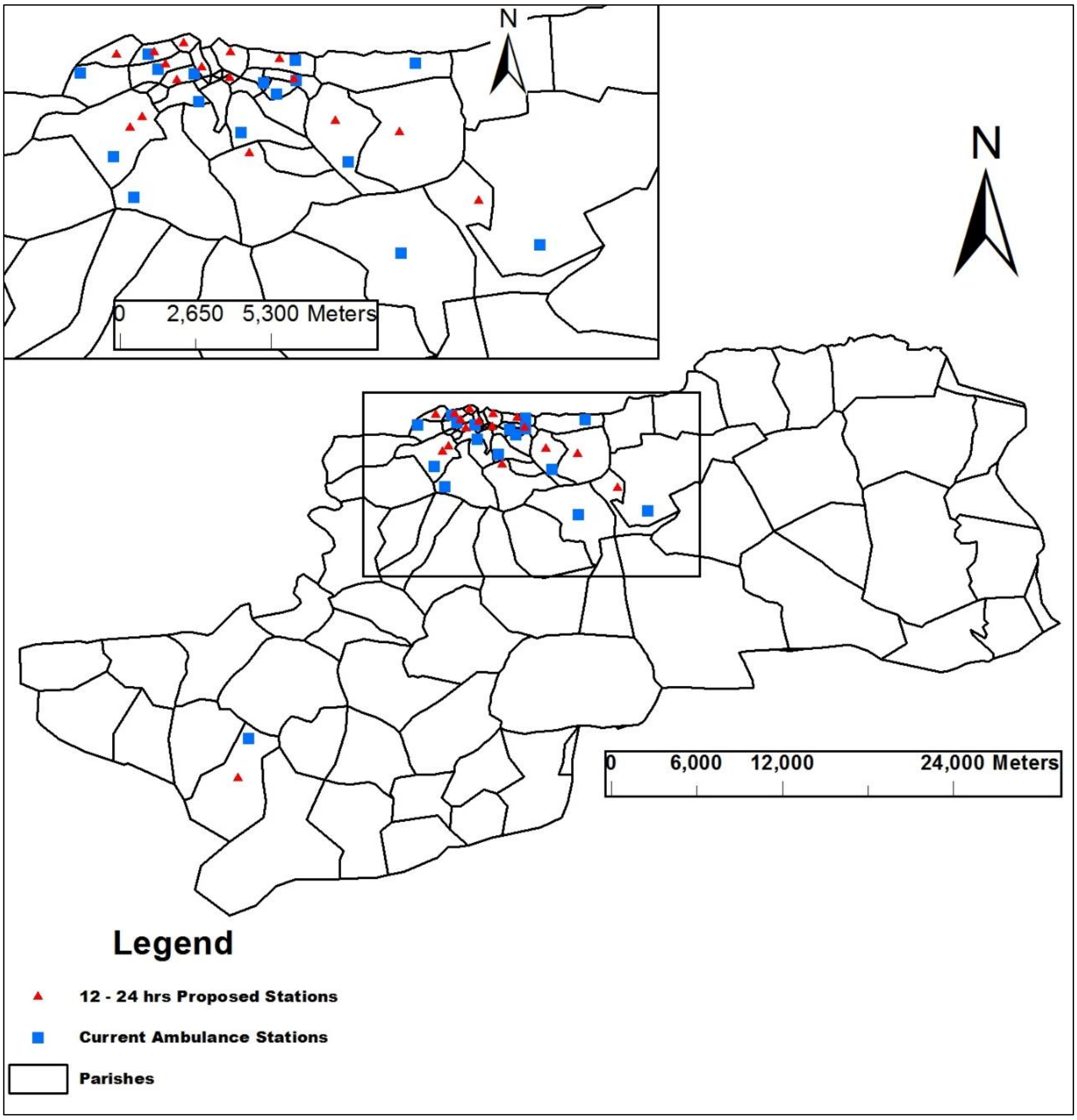


Figure 4.20. *Comparison Between the Current Ambulance Deployment Plans for Odunpazarı District with the Proposed Deployment Plan Between 18:00 to 24:00 hr*

Table 4.5. *The Number of Ambulances Deployed In Different Parishes of Odunpazarı District between 00:00 To 06:00 hrs, 06:00 To 12:00 hrs, 12:00 To 18:00 hrs and 18:00 To 24:00 hrs Together With The Number Of Calls Originating From Those Parishes.*

	00:00 - 06:00	00:00 - 06:00	06:00 - 12:00	06:00 - 12:00	12:00 - 18:00	12:00 - 18:00	18:00 - 24:00	18:00 - 24:00
Parish	**Number of Calls**	**Ambulances**	**Number of Calls**	**Ambulances**	**Number of Calls**	**Ambulances**	**Number of Calls**	**Ambulances**
Ağapınar	2	0	3	0	1	0	3	0
Akarbaşı	124	1	223	1	324	1	261	1
Akcami	12	0	12	0	23	0	18	0
Akçağlan	28	0	35	0	46	0	47	0
Akçakaya	0	0	0	0	0	0	0	0
Akkaya	0	0	0	0	0	0	0	0
Akpınar	12	0	8	0	20	0	48	0
Alanönü	41	1	93	1	105	0	102	1
Arifiye	44	0	233	1	352	1	186	1
Aşağı Çağlan	1	0	1	0	1	0	1	0
Aşağılıca	0	0	0	0	0	0	0	0
Avdan	0	0	0	0	0	0	0	0
Ayvacık	0	0	0	0	0	0	0	0
Büyükdere	237	2	326	1	579	2	443	2
Cunudiye	5	0	14	0	15	0	25	0
Çamlıca	92	1	206	1	284	1	241	1
Çankaya	65	1	113	1	135	0	125	0
Çavlum	0	0	0	0	1	0	4	0
Dede	18	0	36	0	49	0	51	0
Deliklitaş	71	0	147	0	247	1	167	0
Demirli	0	0	0	0	0	0	0	0

Doğankaya	0	0	0	0	0	0	0	0
Emek	200	1	356	1	476	1	475	1
Erenköy	70	0	115	0	132	0	138	0
Eşenkara	1	0	0	0	1	0	0	0
Gökmeydan	137	1	235	1	309	1	338	1
Göztepe	15	0	27	0	36	0	39	0
Gülpınar	3	0	5	0	2	0	7	0
Gültepe	76	0	106	0	114	0	144	0
Gümele	0	0	0	0	0	0	0	0
Gündoğdu	42	1	105	0	156	0	143	0
Harmandalı	0	0	0	0	0	0	0	0
Huzur	39	0	67	0	102	0	124	0
Ihlamurkent	76	1	96	1	146	1	147	1
İmişehir	1	0	1	0	0	0	0	0
İstiklal	98	0	131	0	263	1	195	1
Kalkanlı	0	0	0	0	0	0	0	0
Kanlıpınar	5	0	1	0	4	0	4	0
Karaalan	0	0	0	0	0	0	0	0
Karacahöyük	0	0	1	0	0	0	1	0
Karacaşehir	1	0	2	0	4	0	6	0
Karaçay	0	0	0	0	0	0	0	0
Karahüyük	0	0	0	0	0	0	0	0
Karamustafa	0	0	0	0	0	0	0	0
Karapazar	0	0	0	0	0	0	1	0
Karapınar	20	0	26	0	34	0	41	0

Karatepe	0	0	0	0	0	0	0	0
Kargın	0	0	0	0	0	0	0	0
Kayacık	0	0	0	0	0	0	1	0
Kayapınar	0	0	0	0	0	0	0	0
Kıravdan	0	0	0	0	0	0	0	0
Kırmızıtoprak	157	1	223	1	324	1	267	1
Kireç	0	0	0	0	0	0	0	0
Kurtuluş	147	1	221	1	311	1	267	1
Kuyucak	0	0	0	0	0	0	0	0
Lütfiye	0	0	0	0	0	0	0	0
Musalar	0	0	0	0	0	0	0	0
Orhangazi	42	0	86	0	94	0	103	0
Orta	6	0	14	0	10	0	10	0
Osmangazi	68	0	93	2	108	0	124	1
Paşa	8	0	13	0	40	0	16	0
Sarısungur	0	0	0	0	0	0	1	0
Seklice	0	0	0	0	0	0	0	0
Sevinç	4	0	9	0	6	0	16	0
Sultandere	7	0	6	0	25	0	12	1
Sümer	40	1	50	0	62	0	57	0
Süpüren	0	0	0	0	0	0	0	0
Şarkiye	6	0	28	0	14	0	14	0
Türkmentokat	0	0	0	0	0	0	0	0
Uluçayır	0	0	1	0	0	0	0	0
Vadişehir	0	0	0	0	0	0	0	0

Vişnelik	130	1	246	1	400	1	297	1
Yahnikapan	0	0	0	0	0	0	0	0
Yassıhöyük	1	0	2	0	3	0	2	0
Yenidoğan	178	1	770	3	916	3	377	1
Yenikent	65	0	138	0	169	0	139	0
Yenisofça	1	0	0	0	0	0	2	0
Yıldıztepe	51	0	86	0	105	0	86	0
Yukarıçağlan	0	0	0	0	0	0	0	0
Yukarıılıca	0	0	0	0	0	0	0	0
Yukarıkalabak	0	0	0	0	0	0	0	0
Yürükkaracaören	0	0	0	0	0	0	0	0
Yürükkırka	0	0	0	0	0	0	0	0
71 Evler	99	1	167	0	232	1	229	1
75.Yıl (Sultandere)	68	1	103	0	180	0	161	0
Totals	**2614**	**17**	**4980**	**17**	**6960**	**17**	**5706**	**17**

The proposed ambulance deployment plans for periods between 00:00 to 06:00 hrs, 06:00 to 12:00 hrs, 12:00 to 18:00 hrs and 18:00 to 24:00 hrs see Table 4.1 are optimal stations where ambulances should be places to reduce ambulance RT. The four ambulance plans proposed according to demand and time, allocated the Odunpazarı fleet of 17 ambulances according to time and demand. Büyükdere, Yenidoğan, Osmangazi, Emek, Kirmiz toprak, and Vişnelik parishes registered the highest number of ambulance demand calls and therefore were allocated the largest portion of the 17 ambulances for all the four periods. See Table 4.1.

5. CONCLUSION AND RECOMMENDATIONS

This chapter gives conclusions about the findings of the study in line with the objectives and with an emphasis on the verification of the hypotheses. Finally, recommendations are addressed to future researchers and to the health directorate of Eskişehir Province.

5.1. General Conclusion

If an optimal demand and time based ambulance deployment strategy is implemented, ambulance RTs can surely be reduced and this in turn helps to save lives. GIS as a powerful tool has proved its paramount importance since it has been applied in crime mapping, disaster management, fleet management, optimal site selection, precision agriculture and in health especially emergency medicine. This study used GIS technology to dynamically position the ambulance fleet of Odunpazarı District according to demand and time and as a result 77.6 of all demand areas were within reach in 5 minutes of drive time hence reducing the earlier average ambulance response time of 10 minutes which proved a success.

Every EMS is mainly assessed by their RT, the lower the ambulance RT of an EMS system the much more effective it is perceived. The study highly recommends a dynamic load responsive, demand based ambulance deployment strategy to ensure smooth operation of the Odunpazarı District EMS and ensure average ambulance RT reduction is realized. To reduce ambulance RT the study observed that areas with much demand should always be allocated a higher number of ambulances than areas with smaller demands as this ensures ambulance first aid services are accessed by those in need.

5.2. Recommendations

With a small ambulance fleet size like in the case of Odunpazarı District, the best option is to implement a demand and time based dynamic load responsive ambulance deployment plan making use of SSM and MCLP. MCLP ensures as much demand as possible is covered with a limited ambulance fleet size. The study highly recommends not only Odunpazarı District but the entire Eskişehir province EMS to adapt and implement this ambulance deployment plan which has been modelled using GIS technology.

This researcher highly recommends a drone based ambulance which was founded by Alec Momont a graduate student then at Delft University in the Netherlands in October 2014 where a call is placed to the EMS service then the EMS centre locates the origin of the call, then a drone is dispatched to the origin of the ambulance demand call. The ambulance drone is not prone to road network manoeuvres since it flies in space in a straight line using GPS technology and reaches the patient within 1 minute after it has been dispatched. The drone moves at 100 km/hr and delivers defibrillation services within a minute of a cardiac arrest. The ambulance-drone is capable of saving lives with an integrated defibrillator. The drone ambulance was developed specifically for Out of Hospital Cardiac Arrest victims which carries a defibrillator. The drone based ambulance should be put in place only for out of hospital cardiac arrest and the vehicle ambulances would take care of accident and other non-cardiac related cases.

REFERENCES

Abolina, E., Volk, T., & Lazdina, D. (2015). GIS based agricultural land availability assessment for the establishment of short rotation woody crops in Latvia. *Biomass and Bioenergy, 72*, 263-272.

Alanis, R., Ingolfsson, A., & Kolfal, B. (2013). A Markov chain model for an EMS system with repositioning. *Production and Operations Management, 22*(1), 216-231.

Andersson, T. (2005). Decision support tools for dynamic fleet management. *Doktorsavhandling, Linköpings Universitet, Sverige*.

Aringhieri, R., Carello, G., & Morale, D. (2007). Ambulance location through optimization and simulation: the case of Milano urban area. *Paper presented at the 38th Annual Conference of the Italian Operations Research Society Optimization and Decision Sciences*.

Azizan, M. H., Lim, C. S., Hatta, W., & Gan, L. C. (2012). Application of openstreetmap data in ambulance location problem*. Paper presented at the Computational Intelligence, Communication Systems and Networks (CICSyN), 2012 Fourth International Conference on.*

Berlin, G. N., & Liebman, J. C. (1974). Mathematical analysis of emergency ambulance location. *Socio-Economic Planning Sciences, 8*(6), 323-328.

Bernhardsen, T. (2002). *Geographic information systems: an introduction*: John Wiley & Sons.

Blackwell, T. H., & Kaufman, J. S. (2002). Response time effectiveness: comparison of response time and survival in an urban emergency medical services system. *Academic Emergency Medicine, 9*(4), 288-295.

Boulos, M., Roudsari, A., & Carson, E. Health Geomatics: An Enabling Suite of Technologies in Health and Healthcare (Methodological Review). *Journal of Biomedical Information 2001, 34: 195, 219*.

Brotcorne, L., Laporte, G., & Semet, F. (2003). Ambulance location and relocation models. *European journal of operational research, 147*(3), 451-463.

Buckley, D. J., & Reid, C. (1990). *The GIS Primer: An Introduction to Geographical Information Systems*: Forestry Canada.

Carver, S., Cornelius, S., & Heywood, D. (2006). *An Introduction to Geographical Information Systems*: Pearson Education Limited.

Church, R., & Velle, C. R. (1974). The maximal covering location problem. *Papers in regional science, 32*(1), 101-118.

Church, R. L., & Gerrard, R. A. (2003). The multi-level location set covering model. *Geographical Analysis, 35*(4), 277-289.

Comber, A., Brunsdon, C., & Green, E. (2008). Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and Urban Planning, 86*(1), 103-114.

Cova, T. J. (1999). GIS in emergency management. *Geographical information systems, 2*, 845-858.

Craglia, M., & Maheswaran, R. (2004). *GIS in public health practice*: CRC press.

Cummins, R. O., Ornato, J. P., Thies, W. H., & Pepe, P. E. (1991). Improving survival from sudden cardiac arrest: the "chain of survival" concept. *Circulation, 83*(5), 1832-1847.

Daskin, M. S., & Dean, L. K. (2005). Location of health care facilities *Operations research and health care* (pp. 43-76): Springer.

Davari, S., Zarandi, M. H. F., & Hemmati, A. (2011). Maximal covering location problem (MCLP) with fuzzy travel times. *Expert Systems with Applications, 38*(12), 14535-14541.

Degel, D. (2015). *Innovative Location Optimization for Rescue and Emergency Medical Services Adapting to a Dynamic Environment*: Logos Verlag Berlin GmbH.

Doerner, K. F., Gutjahr, W. J., Hartl, R. F., Karall, M., & Reimann, M. (2005). Heuristic solution of an extended double-coverage ambulance location problem for Austria. *Central European Journal of Operations Research, 13*(4), 325-340.

Eaton, D. J., Daskin, M. S., Simmons, D., Bulloch, B., & Jansma, G. (1985). Determining emergency medical service vehicle deployment in Austin, Texas. *Interfaces, 15*(1), 96-108.

Eisenberg, M. S., Copass, M. K., Hallstrom, A. P., Blake, B., Bergner, L., Short, F. A., & Cobb, L. A. (1980). Treatment of out-of-hospital cardiac arrests with rapid defibrillation by emergency medical technicians. *New England Journal of Medicine, 302*(25), 1379-1383.

El Nahry, A., Ali, R., & El Baroudy, A. (2011). An approach for precision farming under pivot irrigation system using remote sensing and GIS techniques. *Agricultural Water Management, 98*(4), 517-531.

Faiz, S., & Krichen, S. (2012). *Geographical information systems and spatial optimization*: CRC Press.

Feeny, D., & Guyatt, G. (1986). *Health care technology: Effectiveness, efficiency, and public policy*: IRPP.

Galati, S. R. (2006). *Geographic information systems demystified*.

Gale, S. L., Magzamen, S. L., Radke, J. D., & Tager, I. B. (2011). Crime, neighborhood deprivation, and asthma: a GIS approach to define and assess neighborhoods. *Spatial and spatio-temporal epidemiology, 2*(2), 59-67.

Gendreau, M., Laporte, G., & Semet, F. (1997). Solving an ambulance location model by tabu search. *Location science, 5*(2), 75-88.

Gendreau, M., Laporte, G., & Semet, F. (2001). A dynamic model and parallel tabu search heuristic for real-time ambulance relocation. *Parallel computing, 27*(12), 1641-1653.

Gottfried, K. (2003). *Geoinformation, Remote Sensing, Photogrammetry and Geographic Information Systems*: Taylor and Francis.

Grubesic, T. H., & Mack, E. A. (2008). Spatio-temporal interaction of urban crime. *Journal of Quantitative Criminology, 24*(3), 285-306.

Gu, W., Foster, K., & Shang, J. (2016). Enhancing market service and enterprise operations through a large-scale GIS-based distribution system. *Expert Systems with Applications, 55*, 157-171.

Higgs, G., & Gould, M. (2001). Is there a role for GIS in the 'new NHS'? *Health & Place, 7*(3), 247-259.

Hogan, K., & ReVelle, C. (1986). Concepts and applications of backup coverage. *Management Science, 32*(11), 1434-1444.

Hough, T. (1986). A view from the street. System status management. *JEMS: a journal of emergency medical services, 11*(12), 48-50.

Iskander, W. H. (1989). Simulation modeling for emergency medical service systems*. Paper presented at the Proceedings of the 21st conference on Winter simulation*.

Korte, G. (2001). *The GIS book*: Cengage Learning.

Lam, S. S. W., Ng, Y. S., Lakshmanan, M. R., Ng, Y. Y., & Ong, M. E. H. (2016). Ambulance Deployment under Demand Uncertainty. *Journal of Advanced Management Science Vol, 4*(3).

Lam, S. S. W., Zhang, J., Zhang, Z. C., Oh, H. C., Overton, J., Ng, Y. Y., & Ong, M. E. H. (2014). Dynamic ambulance reallocation for the reduction of ambulance response times using system status management. *The American journal of emergency medicine*.

Lam, S. S. W., Zhang, J., Zhang, Z. C., Oh, H. C., Overton, J., Ng, Y. Y., & Ong, M. E. H. (2015). Dynamic ambulance reallocation for the reduction of ambulance response times using system status management. *The American journal of emergency medicine, 33*(2), 159-166.

Li, X., Zhao, Z., Zhu, X., & Wyatt, T. (2011). Covering models and optimization techniques for emergency response facility location and planning: a review. *Mathematical Methods of Operations Research, 74*(3), 281-310.

Lim, C. S., Mamat, R., & Bräunl, T. (2011). Impact of ambulance dispatch policies on performance of emergency medical services. *Intelligent Transportation Systems, IEEE Transactions on, 12*(2), 624-632.

Lloyd, C. (2010). *Spatial data analysis: an introduction for GIS users*: Oxford university press.

Maleki, M., Majlesinasab, N., & Sepehri, M. M. (2014). Two new models for redeployment of ambulances. *Computers & Industrial Engineering, 78*, 271-284.

Martin, D. (1996). *Geographic information systems: socioeconomic applications*: Psychology Press.

Meade, M. S. (2010). *Medical geography*: Wiley Online Library.

Misra, R. P. (2007). *Geography of health: A Treatise on Geography of Life and Death in India*: Concept Publishing Company.

Mokgalaka, H., Mans, G., Smit, J., & McKelly, D. (2013). GIS-based accessibility analysis-a mixed method approach to determine public primary health care demand in South Africa.

Nayak, S., & Zlatanova, S. (2008). *Remote sensing and GIS technologies for monitoring and prediction of disasters*: Springer.

Ong, M. E., Ng, F. S., Overton, J., Yap, S., Andresen, D., Yong, D. K., . . . Anantharaman, V. (2009). Geographic-time distribution of ambulance calls in Singapore: utility of geographic information system in ambulance deployment (CARE 3). *Annals Academy of Medicine Singapore, 38*(3), 184.

Ong, M. E. H., Chiam, T. F., Ng, F. S. P., Sultana, P., Lim, S. H., Leong, B. S. H., . . . Tham, L. P. (2010). Reducing ambulance response times using geospatial–time analysis of ambulance deployment. *Academic Emergency Medicine, 17*(9), 951-957.

Ong, M. E. H., Ho, K. K., Tan, T. P., Koh, S. K., Almuthar, Z., Overton, J., & Lim, S. H. (2009). Using demand analysis and system status management for predicting ED attendances and rostering. *The American journal of emergency medicine, 27*(1), 16-22.

Organization, W. H. (2008). Emergency Medical Services Systems in the European Union: Report of an assessment project co-ordinated by the World Health Organization.

Pell, J. P., Sirel, J. M., Marsden, A. K., Ford, I., & Cobbe, S. M. (2001). Effect of reducing ambulance response times on deaths from out of hospital cardiac arrest: cohort study. *Bmj, 322*(7299), 1385-1388.

Pereira, M. A., Coelho, L. C., Lorena, L. A., & De Souza, L. C. (2015). A hybrid method for the Probabilistic Maximal Covering Location–Allocation Problem. *Computers & Operations Research, 57*, 51-59.

Pérez, J., Maldonado, S., & López-Ospina, H. (2016). A fleet management model for the Santiago Fire Department. *Fire Safety Journal, 82*, 1-11.

Peters, J., & Hall, G. B. (1999). Assessment of ambulance response performance using a geographic information system. *Social Science & Medicine, 49*(11), 1551-1566.

Pinto, L., Silva, P., & Young, T. (2015). A generic method to develop simulation models for ambulance systems. *Simulation Modelling Practice and Theory, 51*, 170-183.

Pons, P. T., & Markovchick, V. J. (2002). Eight minutes or less: does the ambulance response time guideline impact trauma patient outcome? *The Journal of emergency medicine, 23*(1), 43-48.

Rajagopalan, H. K. (2006). *Developing and validating realistic dynamic relocation models for emergency medical systems: a hybrid meta-heuristic approach*: ProQuest.

Reddy, M. A. (2008). *Textbook of remote sensing and geographical information systems*: BS publications Hyderabad.

Sarkar, A. (2007). GIS applications in logistics: a literature review. *School of Business, University of Redlands, 1200*.

Savas, E. (1969). Simulation and cost-effectiveness analysis of New York's emergency ambulance service. *Management Science, 15*(12), B-608-B-627.

Shi, W. (2009). *Principles of modeling uncertainties in spatial data and spatial analyses*: CRC Press.

Stout, J. (1989). System status management. The Fact Is, It's Everywhere. *Jems, 14*, 65-71.

Sund, B. (2010). Effect of response times on survival from out-of-hospital cardiac arrest: using geographic information systems.

Tomaszewski, B. (2014). *Geographic information systems (GIS) for disaster management*: CRC Press.

Toregas, C., Swain, R., ReVelle, C., & Bergman, L. (1971). The location of emergency service facilities. *Operations Research, 19*(6), 1363-1373.

Valenzuela, T. D., Roe, D. J., Cretin, S., Spaite, D. W., & Larsen, M. P. (1997). Estimating effectiveness of cardiac arrest interventions a logistic regression survival model. *Circulation, 96*(10), 3308-3313.

Valenzuela, T. D., Roe, D. J., Nichol, G., Clark, L. L., Spaite, D. W., & Hardman, R. G. (2000). Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos. *New England Journal of Medicine, 343*(17), 1206-1209.

Walz, B. (2010). *Foundations of EMS Systems*: Cengage Learning.

White, R. D., Asplin, B. R., Bugliosi, T. F., & Hankins, D. G. (1996). High discharge survival rate after out-of-hospital ventricular fibrillation with rapid defibrillation by police and paramedics. *Annals of emergency medicine, 28*(5), 480-485.

Zeiler, M. (1999). *Modeling our world: the ESRI guide to geodatabase design*: ESRI, Inc.

Zhen, L., Wang, K., Hu, H., & Chang, D. (2014). A simulation optimization framework for ambulance deployment and relocation problems. *Computers & Industrial Engineering, 72*, 12-23.