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Dynamic Ambulance Deployment to Reduce Ambulance Response Times using Geographic Information Systems: A Case Study of Odunpazari District of Eskisehir Province, Turkey

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Abstract

Background and Objective: 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 objective of the study was to find optimal stations to deploy ambulances so as to reduce ambulance response times and increase patient survival chances as a result.

Data and Methods: To reduce ambulance response times for Odunpazari district, the study employed system status management technique and maximal coverage location problem optimization model, to deploy ambulances according to ambulance demand and ensure maximum ambulance demand coverage is realized with a small ambulance fleet size, respectively. ArcGIS network analyst location allocation tool was used to find optimal ambulance stations from where ambulance demand areas can be reached within 5 minutes of drive time. Four different ambulance deployment plans were modeled for periods ranging from 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. The study used a total of 20,260 ambulance demand calls' data for Odunpazari district collected from January 1st to December 31st 2014.

Results: The Odunpazari district fleet of 17 ambulances was deployed differently for every six hours; 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 to match ambulance demand and as a result, 77.6% of ambulance demand areas were located within 5 minutes of drive time from the nearest ambulance station.

Conclusion: The study found out that moving ambulances closer to ambulance demand areas reduces ambulance response times and dynamic ambulance deployment is by far a more effective ambulance deployment strategy than static ambulance deployment.

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Keywords: Ambulance response times; dynamic ambulance deployment; maximal coverage location problem

1. Introduction

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 response time is a key criterion for evaluating the effectiveness of an emergency medical services (EMS) system. One of the important components of healthcare service provision is pre-hospital care provided by EMS. The mission of EMS is to coordinate the delivery of timely and appropriate first aid services to patients under emergency conditions to prevent disability, and increase patient survival chances1. The main aim of the study was to model ambulance deployment plans for Odunpazari district using geographic information systems (GIS) technology that would ensure the reduction of ambulance response times without expanding the Odunpazari district ambulance fleet.

1.1. Ambulance response time

Ambulance response time is the period between when 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[10]. Ambulance response time is an integral part of out-of-hospital healthcare provision. Apart from the relation to clinical outcomes, EMS response time is also an important public expectation and quality of service benchmark. Because resources are often constrained and EMS providers cannot continuously expand their ambulance fleet, 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 response time and increase patient survival chances as a result[9].

The survival of individuals with serious medical cases of stroke, myocardial infarction, pulmonary embolism, and cardiac arrest is largely dependent on ambulance response time. The shorter the ambulance response time, the greater the possibilities of survival. 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 a patient to survive[14]. The ‘chain-of-survival’ concept, states that survival in case of a cardiac related medical condition, can be improved with early access, early cardiopulmonary resuscitation, early defibrillation, and early advanced care[6, 12, 17]. A study carried out in Texas which was tasked to come up with an efficient ambulance deployment strategy that ensured reduction in average ambulance response time, improved prehospital medical care, equity improvements, and capital and operation costs savings was a success with the introduction of dynamic ambulance deployment strategy[5]. The placement or deployment of ambulances, which has been a subject of thorough investigations, has been found to have an effect on the time ambulance services reach patients[1, 2, 8]. Various studies undertaken to investigate dynamic ambulance deployment have all registered steady reduction in ambulance response time making use of dynamic ambulance deployment basing on system status management (SSM) implemented by GIS technology[11,12]. Emergency medical systems could become more effective if a dynamic, load-responsive ambulance deployment plan is adapted[13].

1.2. Study area

Odunpazari district of Eskisehir province is located between latitude 39°45’32’ N, and longitude 30°31’33’E. The district is found in Eskisehir province in the Northwestern part of the Central Anatolian region of Turkey as shown in Fig. 1a. Odunpazari district is located on an altitude of 788 m (2.585 ft.) and has a population of 376,650 people according to Turkish Bureau of Statistics 2014. Odunpazari district is made up of 85 parishes.

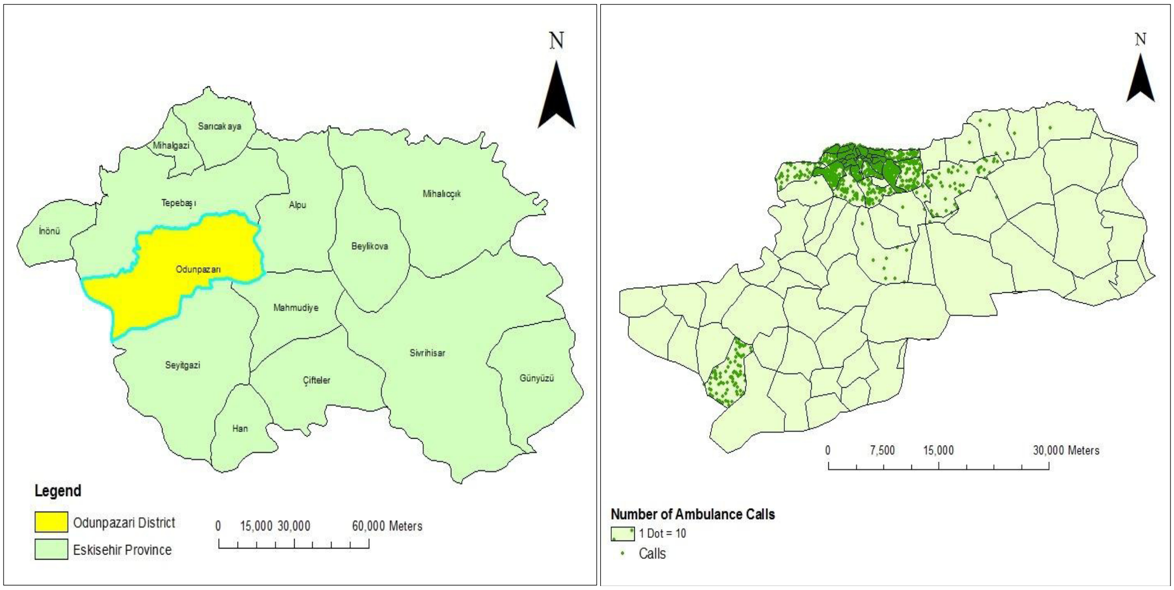

Figure 1a: A map of Eskisehir province showing Odunpazari district's location (left) and Figure 1b: a spot map of Odunpazari district showing the origin of ambulance demand calls (right) respectively.

2. Data and methods

2.1. EMS system of Odunpazari district

An EMS is 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[16]. The EMS of Odunpazari district is managed by the Turkish ministry of health under the health directorate of Eskisehir province, which operates the national '112' emergency telephone service. The system is supported by a centralized dispatching unit that uses computer-aided medical dispatch protocols, global positioning satellite-based automatic vehicle locating systems, and road traffic monitoring systems. The system has a fleet of 17 ambulances that 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.

According to ambulance demand calls (registered from January 1st to December 31st 2014), the average response time of Odunpazari district EMS was 10 minutes and an ambulance demand call originating from Karapinar parish received an ambulance after 24 minutes of waiting. The ambulance deployment plan used by the EMS management of Eskisehir province is static; thus, each permanent station has one ambulance for 24 hours a day to serve ambulance demand calls. Odunpazari district EMS has 17 ambulances in 17 different permanent 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 response times observed. A large number of the Odunpazari district ambulance fleet should be deployed in high ambulance demand areas in this case in the northern part of Odunpazari district where most ambulance demand calls originate from as shown in Fig. 1b. Logically, ambulances after delivering patients to hospitals should be moved to parishes where higher call volumes are anticipated rather than returning to their base stations.

2.2. Data

The study was carried out using a total of 20,260-ambulance demand call data recorded from January 1st to December 31st 2014. Ambulance demand call data was collected from the Eskisehir province directorate of health and had enough patient details to enable analysis to be carried out. Data that did not have addresses, call time, ambulance arrival time, geographic location, and did not require ambulance dispatch was not included in the study. Road network shape file data, on which network analysis was carried out, was obtained from the Eskisehir province directorate of geographic information systems. Road speed limit data was obtained from the directorate for roads of the Republic of Turkey.

2.3. Geospatial-time distribution of emergency ambulance calls

Geospatial-time distribution of ambulance demand calls has been successfully used as a basis for optimal ambulance deployment to reduce ambulance response times. A study was conducted which implemented six time based deployment plans for ambulances and concluded that, geospatial-time based ambulance deployment has implications for maximizing the effectiveness of ambulance deployment[11]. In this study, ambulances were moved every after six hours thus 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. The major reason as to why four ambulance deployment plans were proposed according to time was to cater for high call demand areas since call demand locations change according to different times of the day. Therefore, the study proposed that more ambulances should be placed near residential areas at night than work places and more ambulances should be deployed near workplaces during day times than at night.

2.4. System status management

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[12]. SSM is a computer-based system where historical call data are used to deploy the ambulance fleet for optimal ambulance response time and to predict where the next cluster of calls is likely to occur[15]. SSM has become the most widely accepted strategy for managing EMS resources and has been used to improve ambulance response time performance without the need to deploy more ambulances and to set up new ambulance base locations. Since its adoption, SSM has changed EMS for the better. Using SSM ambulances were moved from areas where no or less ambulance demand was anticipated to areas where higher ambulance demand was anticipated so as to bring ambulances closer to where they might be needed

2.5. Maximal coverage location problem

Maximal Coverage Location Problem (MCLP) is a location optimization model which seeks the maximum population that can be served within a stated service distance or time given a limited number of facilities[3]. MCLP based ambulance deployment strategy results into maximization of coverage of demand areas with a limited number of ambulance resources. MCLP optimization model does not involve additional costs of ambulance fleet expansion since it ensures maximum demand is covered with a small ambulance fleet. MCLP also seeks to minimize the population that is left uncovered within the maximal service time or distance. The study adopted MCLP optimization model to find optimal stations where 17 ambulances of Odunpazari district can be deployed in order to reach ambulance demand areas within 5 minutes of drive time.

2.6. ArcGIS network analyst location allocation tool

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[7]. Using a GIS-based network analysis strategy, a study was successfully carried out 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[4]. This study used the ArcGIS Network Analyst location allocation tool to 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.

2.7. Data analysis

Data analysis was performed using Microsoft excel and Microsoft Access (Microsoft 2013 Redmond, Washington). Locations of optimal ambulance stations were determined and ambulance stations were mapped using ArcMap (ArcGIS10.3, ESRI Redlands, California).

3. Results and discussions

3.1. Results

Between 00:00 to 06:00 hrs, a total of 2,614 ambulance demand calls originated from Odunpazari district accounting for 13% of the total ambulance demand calls registered in the year 2014 (20,260). Akarbasi, Alanonu, Camlica, Cankaya, Emek, Gokmeydan, Gundogdu, Ihlamurkent, Kirmiztoprak, Kurtulus, Sumer, Visnelik, Yenidogan, 71 Evler and 75 Yil parishes of Odunpazari district had one ambulance allocated to each one of them as shown in Fig. 2a and Table 1. Two ambulances were deployed in Buyukdere parish as shown in Fig. 2a and Table 1. The two ambulances that were allocated to Buyukdere parish were placed at different locations within the parish in order to maximize ambulance demand coverage. The Odunpazari district ambulance fleet of 17 ambulances was shared among only 16 parishes of the district between 00:00 to 06:00 hrs.

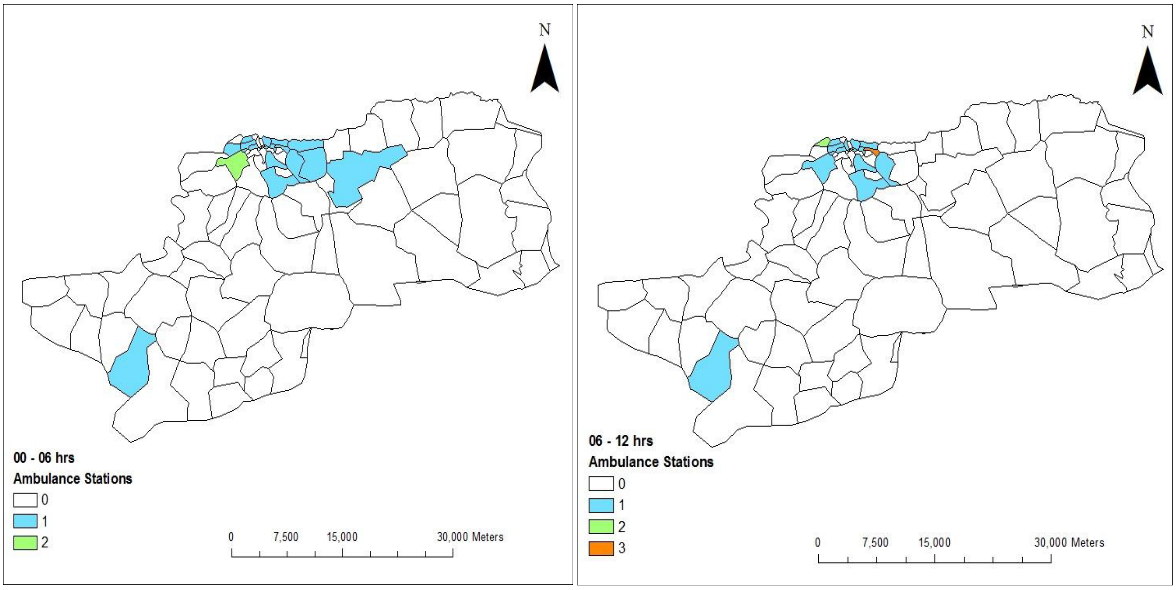

Figure 2a: A map of Odunpazari district showing ambulance deployment plan between 00:00 to 06:00 hrs (left) and Figure 2b: A map of Odunpazari district showing ambulance deployment plan between 06:00 to 12:00 hrs (right) respectively.

Twelve parishes of Odunpazari district namely; Akarbasi, Alanonu, Arifiye, Buyukdere, Camlica, Cankaya, Emek, Gokmeydan, Ihlamurkent, Kirmiztoprak, Kurtulus and Visnelik recorded a total of 4,980 ambulance demand calls between 06:00 to 12:00 hrs accounting for 25% of the total number of ambulance demand calls recorded in the year 2014 (20,260). These twelve parishes had 12 ambulances deployed in each one of them as shown in Fig. 2b and

Table 1. Osmangazi parish had two ambulances allocated to it and Yenidogan parish was allocated three ambulances as shown in Fig. 2b and Table 1. The two ambulances allocated to Osmangazi parish were stationed at two different locations within the parish and the three ambulances allocated to Yenidogan parish were stationed at three different locations within the parish to provide proper coverage of expected ambulance demand calls. Between 06:00 to 12:00 hrs, the fleet of 17 ambulances was allocated to only 14 parishes of Odunpazari district.

Table 1. The proposed ambulance fleet deployment plan for Odunpazari district EMS with rows indicating different parishes and columns showing the number of ambulances to be deployed per parish in different time sections.

Parishes	00-06 hrs	06-12 hrs	12-18 hrs	18-24 hrs
Akarbasi	1	1	1	1
Alanonu	1	1	0	1
Arifiye	0	1	1	1
Buyukdere	2	1	2	2
Camlica	1	1	1	1
Cankaya	1	1	0	0
Deliklitas	0	0	1	0
Emek	1	1	1	1
Gokmeydan	1	1	1	1
Gundogdu	1	0	0	0
Ihlamurkent	1	1	1	1
Istiklal	0	0	1	1
Kirmiztoprak	1	1	1	1
Kurtulus	1	1	1	1
Osmangazi	0	2	0	1
Sultandere	0	0	0	1
Sumer	1	0	0	0
Visnelik	1	1	1	1
Yenidogan	1	3	3	1
71 Evler	1	0	1	1
75 Yil	1	0	0	0

A total of 6,960 ambulance demand calls originated from Odunpazari district between 12:00 to 18:00 hrs accounting for 34% of the total ambulance demand calls registered in the year 2014 (20,260). Parishes Akarbasi, Arifiye, Camlica, Deliklitas, Emek, Gokmeydan, Ihlamurkent, Istiklal, Kirmiztoprak, Kurtulus, Visnelik and 71 Evler were allocated one ambulance each one as shown in Fig.3a and Table 1. Two ambulances were allocated to Buyukdere parish and three to Yenidogan parish as shown in Fig. 3a and Table 1. The two ambulances that were allocated to Buyukdere parish were deployed at different locations within the parish, as was the case with the three ambulances allocated to Yenidogan parish in order to maximize ambulance demand coverage. In total, only 14 parishes of Odunpazari district shared the fleet of 17 ambulances among them between 12:00 to 18:00 hrs.

Odunpazari district received a total of 5,706 ambulance demand calls between 18:00 to 24:00 hrs which accounted for 28% of the total ambulance demand calls recorded in the year 2014 (20,260). One ambulance was deployed in each one of Akarbasi, Alanonu, Arifiye, Camlica, Emek, Gokmeydan, Ihlamurkent, Istiklal, Kirmiztoprak, Kurtulus, Osmangazi, Sultandere, Visnelik, Yenidogan and 71 Evler parishes of Odunpazari district between 18:00 to 24:00 hrs as shown in Fig 3b and Table 1. While Buyukdere parish had 2 ambulances stationed there as shown in Fig. 3b and Table 1. The two ambulances allocated to Buyukdere parish were posted at two different locations within the parish to maximize ambulance demand coverage. Between 18:00 to 24:00 hrs, only 16 parishes of Odunpazari district shared the Odunpazari fleet of 17 ambulances between them.

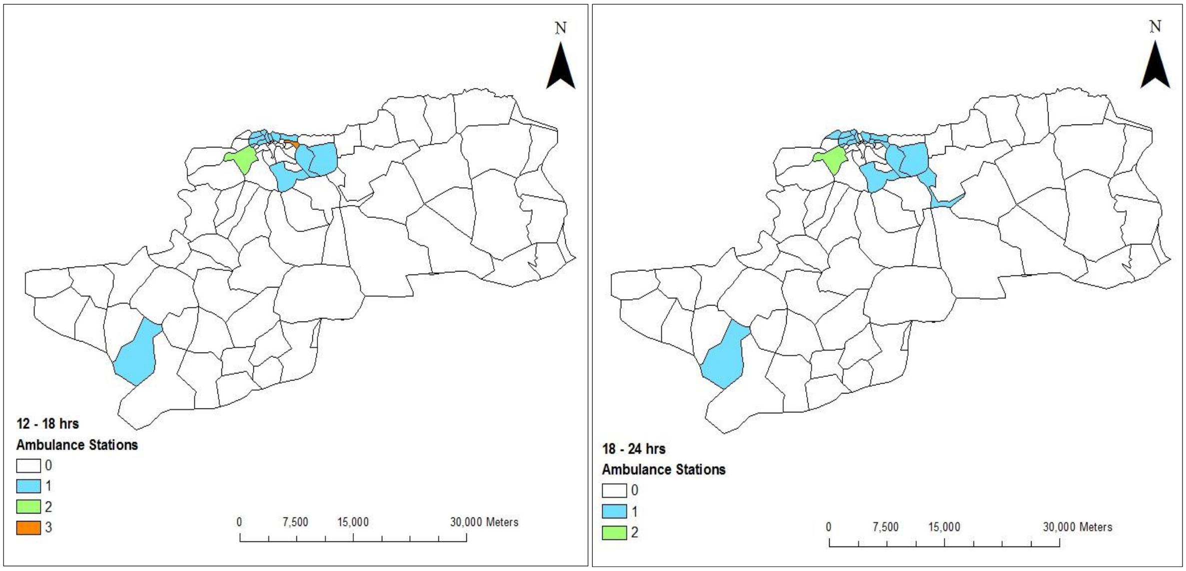

Figure 3a: A map of Odunpazari district showing ambulance deployment plan between 12:00 to 18:00 hrs (left) and Figure 3b: A map of Odunpazari district showing ambulance deployment plan between 18:00 to 24:00 hrs (right) respectively.

3.2. Discussions

Only 50 out of 85 parishes of Odunpazari district registered ambulance demand calls from January 1st to December 31st 2014. Thirty five of the 85 parishes of Odunpazari district did not register any ambulance demand call and therefore were not considered for ambulance deployment. A large number of ambulance demand calls originated from the northern part of Odunpazari district as shown in Fig. 1b, and this is the reason as to why the study in all the four cases proposed the deployment of 16 of the 17 ambulances in the northern part of Odunpazari district as shown in Fig. 2a, Fig. 2b, Fig. 3a, Fig. 3b and Table 1. Yenidogan, Buyukdere, and Osmangazi parishes registered the highest number of ambulance demand calls and had more ambulances allocated to them than other parishes which registered no or less ambulance demand calls. Kayacik, Karatepe, and Akkaya parishes had no single ambulance allocated to them since they registered no single ambulance demand call in the year 2014. Buyukdere parish which is a highy populated residential area was allocated the largest number of ambulances between 00:00 to 06:00 hrs and 18:00 to 24:00 hrs because in these periods much of the population is settled in residential areas. While Osmangazi and Yenidogan parishes which are largely occupied by workplaces were allocated the largest number of ambulances between 06:00 to 12:00 hrs and 12:00 to 18:00 hrs because during these periods much of the population is settled in workplaces.

4. Conclusion

The study modeled a demand and geospatial-time based dynamic ambulance deployment strategy to reduce ambulance responses time for Odunpazari district EMS. This ambulance deployment strategy if adopted by the Odunpazari district EMS, would ensure reduction of average ambulance response time from 10 to 5 minutes for 77.6% of ambulance demand areas. Deployment of ambulances closer to areas where higher ambulance demands are anticipated reduces ambulance response time which is a key basis in evaluating the performance of an EMS.

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