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DETERMINATION OF FIRE CREWS LOCATIONS USING OPERATIONS RESEARCH AND GEOGRAPHICAL INFORMATION SYSTEMS: İZMİR CASE

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ABSTRACT

Spatial information systems and technologies such as Geographical Information Systems (GIS), Global Positioning Systems (GPS), and Remote Sensing (RS), provide resource managers with tools to use in analyzing and understanding a forest. As the forest planning process becomes increasingly complicated, there is a need for assisting forest planners with operative tools. The combined use of GIS and Operations Research (OR) gives forest managers the chance to visualize solutions proposed by OR. Fire fighting planning is an important component of forest management and optimizing the numbers of fire crews is very essential in fire fighting planning. In this study current locations of fire crews are examined for İzmir Forest Administration Chief Office and these fire crews are represented on a digital map. Then new locations for fire crews are proposed by using Location Set Covering Problem (LSCP) and GIS.

Keywords: Forest management, Geographical information systems, Location set covering problem, Spatial information systems.

1. INTRODUCTION

Geographical Information Systems (GIS) are computer-based systems and assist forest managers to store, update, manipulate and analyze spatial and nonspatial forestry data effectively.

Consideration of alternative uses of forests and their products always raises the question of 'What is the best way to make the most effective use of them?'. However, because of the large number of alternatives, the complexity of product interactions, and the conflicting desires of the public, it is almost impossible to find an optimal answer to that question. In these cases, Operations Research (OR) helps forest managers. The combined use of GIS and OR techniques gives forest managers the chance to visualize solutions proposed by OR and to gain a better understanding of the real problem they confront.

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Location is an important factor for forestry to conduct certain activities. Hogg (1968), used a set-covering technique, which minimizes the total number of fire appliance journey times to fires for any given number of fire stations. Toregas et al. (1971) and Toregas and ReVelle (1973) introduced Location Set Covering Problem (LSCP) to deal with minimizing number of facilities and sites. Plane and Hendrick (1977), used the maximum covering distance concept in developing a hierarchical objective function for the set covering formulation of the fire station location problem. ReVelle (1989) reviewed emergency service siting models.

Location problems have also been studied extensively in GIS. Estochen et al. (1988) used GIS to determine the location/allocation of emergency response vehicles in the state of Iowa. Because GIS is very important in location planning problems (Miller, 1996), GIS and LSCP integration was discussed in this study. As stated by Martell et all., (1998) that spatial relationships have always been important in forest management planning. Church (2002) provided a functional review of GIS in relation to location modeling and discussed one of the analytical functions of GIS, buffering. As suggested by O'Sullivan and Unwin (2003), GIS has changed how spatial analysis in general is approached. Dimopoulou and Giannikos (2004) developed an integrated system that consists of GIS module, mathematical programming module and simulation module for forest fire control.

This study aims to integrate neighborhood relation analysis of OR, which is known as LSCP, with neighborhood relation (proximity) analysis of GIS, which is known as buffering so as to propose new fire crew locations for the south region of the study area, İzmir Forest Administration Chief Office (İFACO).

Fire crews were not represented on a digital map and coordinates of these fire crews were only in the form of attribute information for İFACO. For this reason, current locations of fire crews were examined and the representation of these fire crews was done on a digital map for the study area. Given that there was no fire crew in the south region of the İFACO, the optimum numbers of fire crews that must be assigned to this region and their locations were proposed by using LSCP and GIS.

1.1 Spatial Information Systems

Information systems are classified as spatial information systems and nonspatial information systems, depending on the nature of the data they process. Spatial information systems are computer-based tools for working with data about phenomena that is on, above or below the earth's surface (Laurini and Thompson, 1992). Nonspatial information systems are designed for processing data that are not referenced to any position in geographic space, such as student information system and library information system (Lo and Yeung, 2002).

GIS is a special type of information systems in which the data source is the database of spatially distributed features, and by these information systems, procedures such as storing, retrieving, analyzing and displaying are used for geographic data. GIS technology offers combined power of both geography and the information systems and provides ideal solutions for effective natural resource management (Shamsi, 2005). GIS can be used to answer questions about locations, patterns, trends and conditions, such as, where features are found, where changes occur over time, what geographic patterns exist. GIS presents a simplified model of the real world problems (Gilfoyle and Thorpe, 2004).

Buffer zone generation, which is one of the analytical functions of GIS, is a type of proximity analysis. A buffer is an area that is created around a spatial feature. It is a zone with a specified width surrounding a spatial feature. Such feature can be a point, a line or a polygon. Buffering is the process of creating areas of calculated distance from a point, line or polygon, and it is used to identify a zone around an entity, or a set of entities. The resulting buffer is a new polygon, which can be used in queries to determine which entities occur either within or outside the defined buffer zone (Birkin et al., 1996; DeMers, 1997; Heywood et al., 2002; Lo and Yeung, 2002).

1.2 Forest Management

Forestry involves the management of a wide range of natural resources. In addition to timber, forests provide various resources like land for livestock to graze, recreation areas and water supply resources. In this context, forest management includes management of harvesting and recreational areas and protection of endangered species and archeological sites. Management of forest resources is a complex task due to multi-functional nature of these resources. Therefore, the problems of forest management and planning shifted from wood production objective to multiple objectives such as water conservation, prevention of soil erosion, landscape conservation and recreation (Aronoff, 1995; Kazana et al., 2003; Mohren, 2003).

The amount of data, information and knowledge involved in the forest management process is often overwhelming. Integrated decision support systems help managers to make consistently good decisions about forest ecosystem management (Potter et al., 2000). Compared to previous forest management approaches, new forest management strategies require integration of spatial information technologies, such as GIS, remote sensing, and decision support systems (Franklin, 2001).

The designing of the forest database is crucial in a comprehensive forest management plan. Data should be accurate, properly organized, detailed and it should be obtained easily and economically. The gathering of spatial and nonspatial data and analyzing them determine the quality of forest management plans.

Forest management constists of several subsystems and fire management system is one of these systems. Fire fighting planning is an important component of fire management system. This paper discusses fire fighting planning in terms of determination of numbers and locations of new fire crews.

1.3 Location Set Covering Problem

Questions of how many and which vehicles are going to be moved towards fire area and especially the assignment of fire crews to proper locations are very essential in fire fighting planning. In question such as "how many facilities (fire crew, reservoir or pool) are required to meet fire zone (fire sensitive area) demand?" the concept of covering is important. LSCP seeks to assign facilities in such a way that all of the spatially distributed demand points are covered within a specified distance and the number of facilities is minimized. In other words, this problem finds the smallest number of needed facilities and their locations in a way that each demand point is covered at least once (Revelle et al., 1996; Church and Gerrard, 2003). Mathematical model of the problem is given in equations 1, 2 and 3. (Church and Gerrard, 2003):

$$\text{Minimize } Z = \sum_{j=1}^{n} x_j \tag{1}$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \geq 1 \qquad \text{for each demand point i= 1, 2, ……,m} \tag{2}$$

$$x_j = 0,1 \qquad \text{for each site j= 1, 2, ……,n} \tag{3}$$

where

$$a_{ij} = \begin{cases} 1, & \text{if site j can cover demand i} \\ 0, & \text{if not} \end{cases}$$

$$x_j = \begin{cases} 1, & \text{if site j is selected for a facility} \\ 0, & \text{if not} \end{cases}$$

The objective is to find the minimum number of needed facilities and their locations in equation 1, 2 and 3. The first constraint requires that each demand i is covered at least at once. The second constraints are for integrality (Church and Gerrard, 2003).

2. MATERIALS AND METHODS

Forest management was discussed from fire management perspective in this paper. This study represents only small portion of the doctorate thesis and aims to determine optimum numbers and locations of new fire crews by using LSCP and GIS for İFACO. İFACO is subordinate to İzmir Directorate of Forest Administration. İzmir Directorate of Forest Administration has 11 forest administration chiefs, and our study area, İFACO, is one of them. The general area is 39270 ha and 50.88 per cent of this area is forested land. The total forest area is 19983.5 ha, of which 11494.5 ha is productive and 8489 ha is unproductive.

Most of the forest administration chief offices of İzmir Directorate of Forest Administration, also our study area, have paper maps and do not regulary maintain and update a forestry database. In contemporary forest management a forest database must be designed regularly, and all maps must be in digital form. It is important to handle forestry problems by using spatial information systems. GIS provides not only organization and management of data but also integrates different optimization models into the problem solving environment. GIS is a valuable tool in transition from conventional forest management to contemporary forest management.

This study is performed to initiate contemporary forest management planning in study area. Several interviews were made with the directorates of the Forest Protection and Fire Combating Department of the İFACO in every phase of the study and all data were obtained from them. The first phase of the study was data collection and transformation of all maps, obtained from study area, to MapInfo compatible format. Then database was designed. GIS was used for positioning current fire crews and water resources on a digital map.

Figure 1 shows compartment map of İFACO.

Figure 1. Compartment Map of İFACO

3. RESULTS

Figure 2 shows database that is constituted for our study area, İFACO, to manage forest and fire effectively.

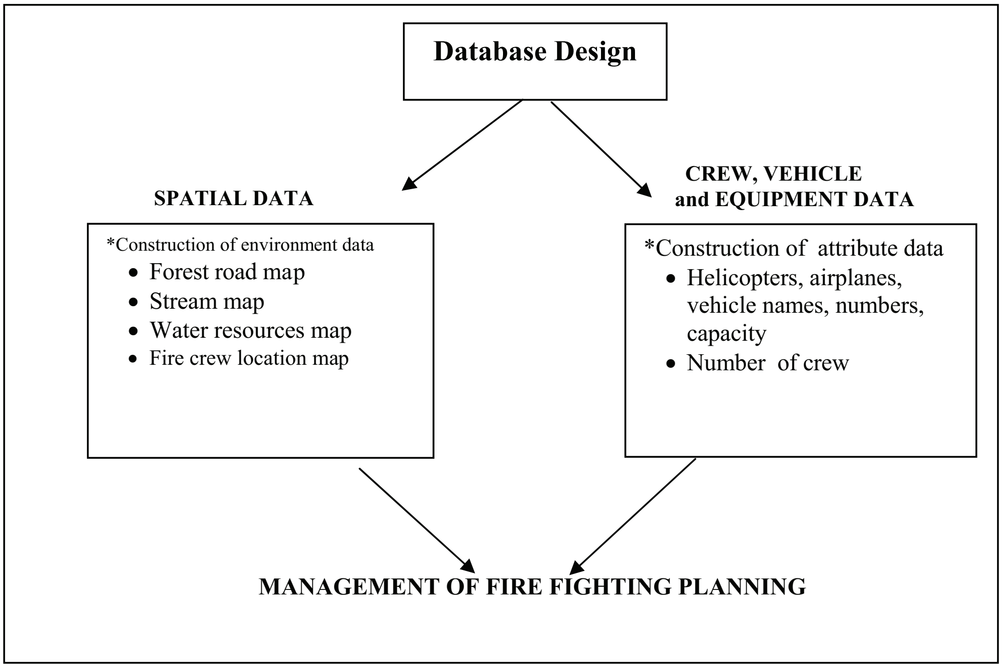

Figure 2. Development of a Database to Manage Fire Fighting Planning

Water resources and fire crew locations were only available as attribute data with coordinate information. In order to display these points on a digital map, firstly, coordinates of all water resources and fire crews were converted to decimal degrees and then to meters. East longitude and north latitude coordinates of water resources are, 27˚ 19′ 06″ and 38˚ 22′ 15″ for Kaynaklar, 27˚ 14′ 29″ and 38˚ 20′ 54″ for Buca Gölet, 27˚ 10′ 48″and 38˚ 16′ 53″ for Sarnıç Gölet, 27˚ 12′ 52″ and 38˚ 20′ 02″ for BP-Olduruk. Longitude and latitude coordinates of fire crews are, 27˚ 06′ 47″ and 38˚ 27′ 13″ for Karşıyaka, 27˚ 18′ 05″ and 38˚ 27′ 02″ for Belkahve, 27˚ 11′ 40″ and 38˚ 22′ 30″ for Buca. Then database of water resources and fire crews were designed.

Locations of water resources and fire crews and related attribute data were shown in Figure 3. As interviewed with directorates of the Forest Protection and Fire Combating Department, the south region of the study area was deprived of the fire crews. Then by taking into account the requests of directorates, new locations and optimum numbers of fire crews were proposed by using LSCP and GIS for the south region of the study area. MapInfo software package was used for GIS side of the problem and WINQSB software package was used for OR side of the problem.

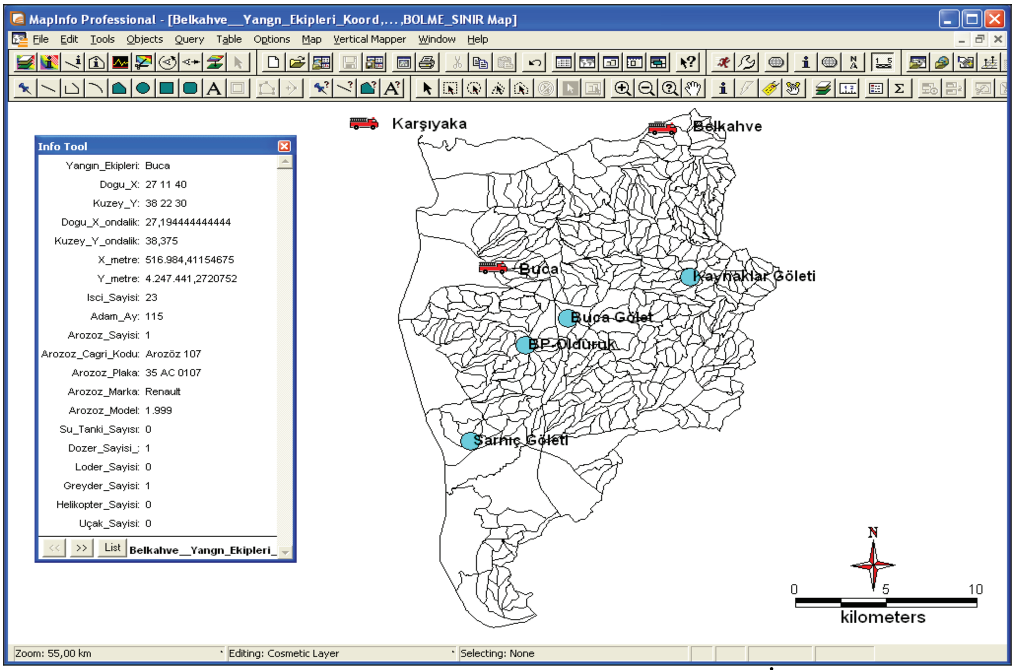

Figure 3. Locations of Fire Crews and Water Resources of İFACO

In order to determine optimum numbers of new fire crews by LSCP, compartment map of the study area was used. In this study fire crews were named with the compartment number they were assigned. For instance fire crew 368 means that this fire crew is assigned to the compartment 368 according to results of LSCP. In Figure 4 south region of the study area and the locations of current fire crews were displayed together.

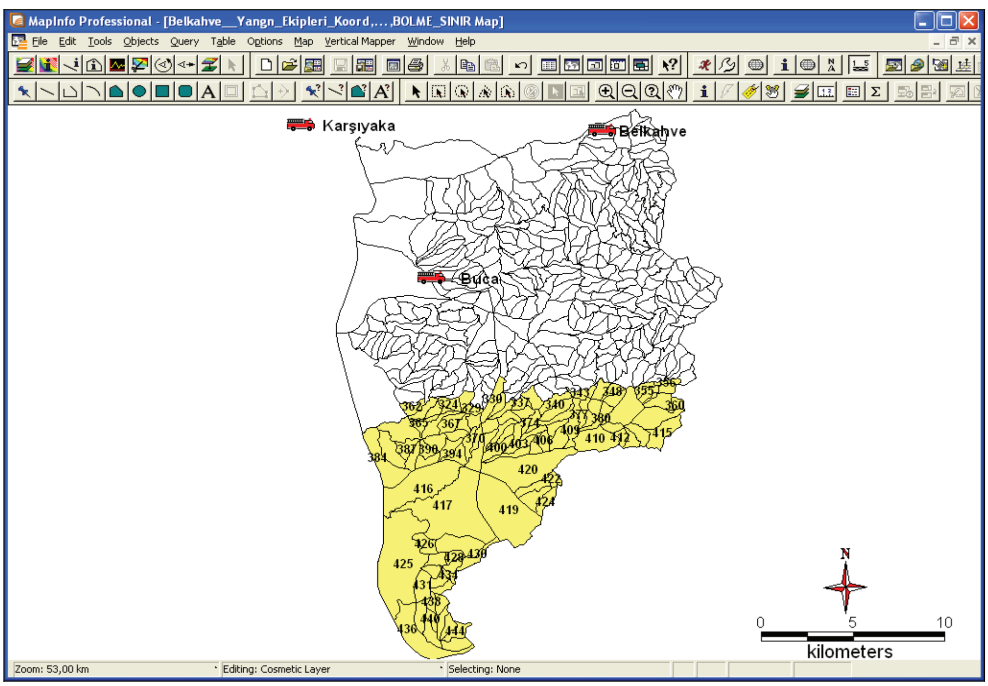

Figure 4. South Region of the Study Area and Locations of Current Fire Crews

The south region of the study area consists of 102 compartments. LSCP formulation consists of 132 decision variables and 102 constraints. Constraints are constituted according to the compartment neighborhood relations. An objective function of LSCP is shown in equation 4. Because of the size of the problem, constitutions of only some of the constraints are exemplified in Table 1. This table shows neighborhood relations between compartments, as ‘1’ shows there is neighborhood and ‘0’ shows there is no neighborhood between compartments. The rest of the constraints were constituted in the same logic.

$$\text{Minimize } Z= \sum_{j=277}^{280} x_j + \sum_{j=308}^{312} x_j + \sum_{j=319}^{322} x_j + \sum_{J=323}^{344} x_j \sum_{j=346}^{349} x_j + \sum_{j=351}^{445} x_j \qquad (4)$$

Table 1. Neighborhood relations between compartments for only three constraints of the problem

	Compartment s															
Constraints	277	323	324	325	326	327	328	329	330	363	364	365	366	367	368	369
324	0	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0
325	1	1	1	1	1	1	0	1	0	0	0	0	1	1	0	0
329	0	0	0	1	0	1	1	1	1	0	0	0	1	1	1	1

According to LSCP solution obtained from WINQSB software package, the minimum numbers of fire crews was found as 17 for the south region of the study area. This number also indicated the minimum numbers of compartments that the fire crews must be assigned. Optimum solution was found as, $x_{324} = x_{338} = x_{356} = x_{368} = x_{371} = x_{376} = x_{379} = x_{383} = x_{386} = x_{389} = x_{400} = x_{412} = x_{419} = x_{420} = x_{427} = x_{435} = x_{441} =1$ and the rest equals to 0.

Figure 5 displays locations of current fire crews and proposed fire crews.

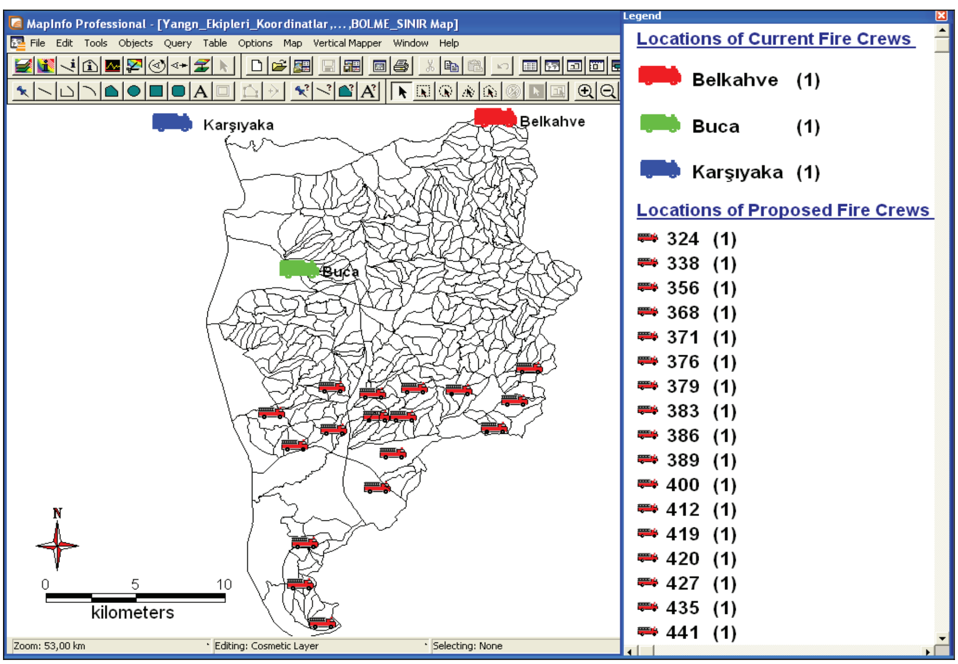

Figure 5. Locations of Current and Proposed Fire Crews

As interviewed with directorates, although 17 is the minimum number of fire crews found by LSCP it is difficult to assign 17 fire crews to the south region of the study area because of the budget constraints. So directorates demanded to locate three fire crews to the south region of the study area. Instead of trying all possible trio frew crew alternatives on 102 compartments, it is considered to optimize the problem firstly on the basis of neighborhood relation of compartments by using LSCP and then optimizing the LSCP results further by using buffering analysis. And finally it was aimed to reduce the number of fire crews to the three as demanded by directorates of the study area. Because the problem in this study is not Maximal Covering Location Problem (MCLP), coverage distance is not specified in LSCP. The only criterion is set in buffering analysis. This criterion is to assure coverage of all demand nodes (compartments) in buffering of three fire crews. That is, it is important to include all compartments in the south region of the study area to the buffering analysis.

Buffering process involved the creation of a circular polygon about each fire crew of radius equal to buffer distance. In this study fixed buffer distance (7 km) was used for all fire crews. This distance was determined by interviewing with the directorates of forest protection and fire combating department about accessibility criteria in the case of emergency (etc, forest fire in this study). Firstly buffering was done on a compartment map to see coverage of all compartments is ensured by selecting any of three fire crews. The aim was to find compartments that fall inside service area of each fire crew and to determine coverage areas of fire crews. Then same buffering was done on the road map to determine the intervention area of each fire crew and total length of roads that was usable by each fire crew in the buffered areas. Same distance, 7 km, was used for each fire crew in buffering. The term ‘usable road’ means that the roads that can be used by fire crews. For example, if there is a planned road or unstandardized road in the buffered area, these roads indicate unusable part of the total road.

Inside of each buffer indicated total length of usable roads and the intervention area of fire crew. Different alternatives were possible as to locations of these three fire crews. These trio sets were determined by trying buffering analysis on the results of LSCP. Among 17 fire crews all possible combination of trio fire crew sets were tried on the basis of fixed buffer distance (7 km) on a digital map, and coverage of all compartments in the south region was ensured.

One of these alternatives was assignment of fire crews to the compartments with the numbers of 356, 368, and 435. According to this assignment, if one fire crew is assigned to the compartment 368, the other two must be assigned to the compartment 356 and 435 (The same interpretation can be done as, if one fire crew is assigned to the compartment 356, the other two must be assigned to the compartment 368 and 435 or if one fire crew is assigned to the compartment 435, the other two must be assigned to the compartment 356 and 368). It is important to note that assignment must be done with this trio set. Total length of usable roads in buffered areas was found as 526 km with this assignment. In figure 6 intervention areas and total length of usable roads in buffered areas were shown for the fire crew 356, 368 and 435. Different trio sets were proposed as shown in figure 7, figure 8 and figure 9. The best assignment in terms of total length of usable roads was shown in figure 10.

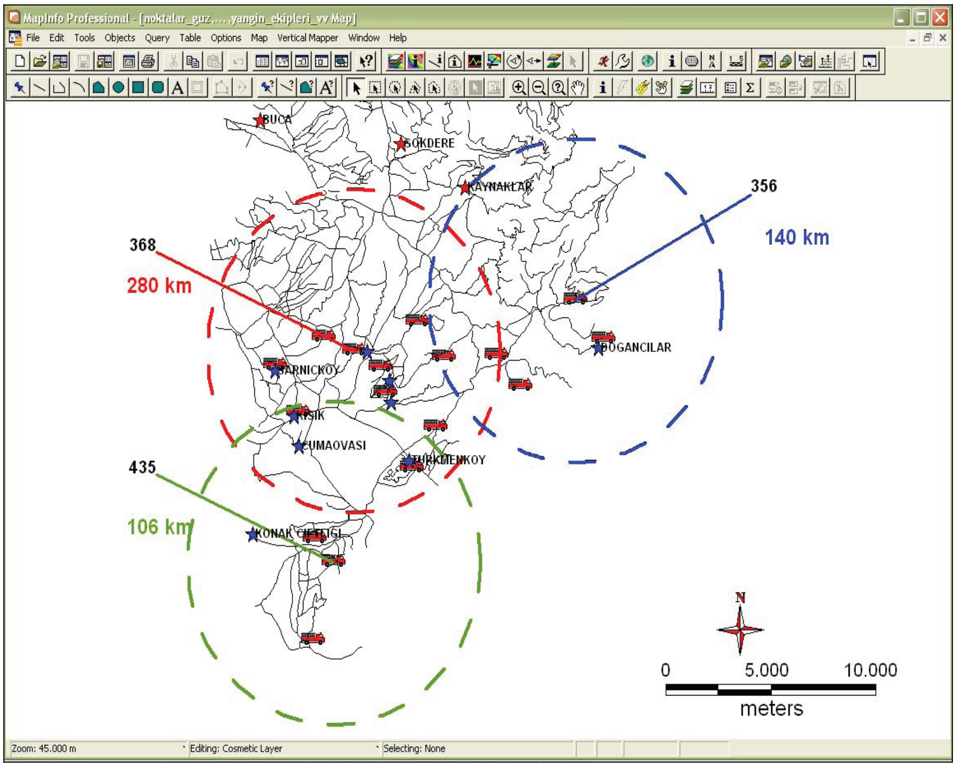

Figure 6. 7 km Buffers from Fire Crew 356, 368 and 435

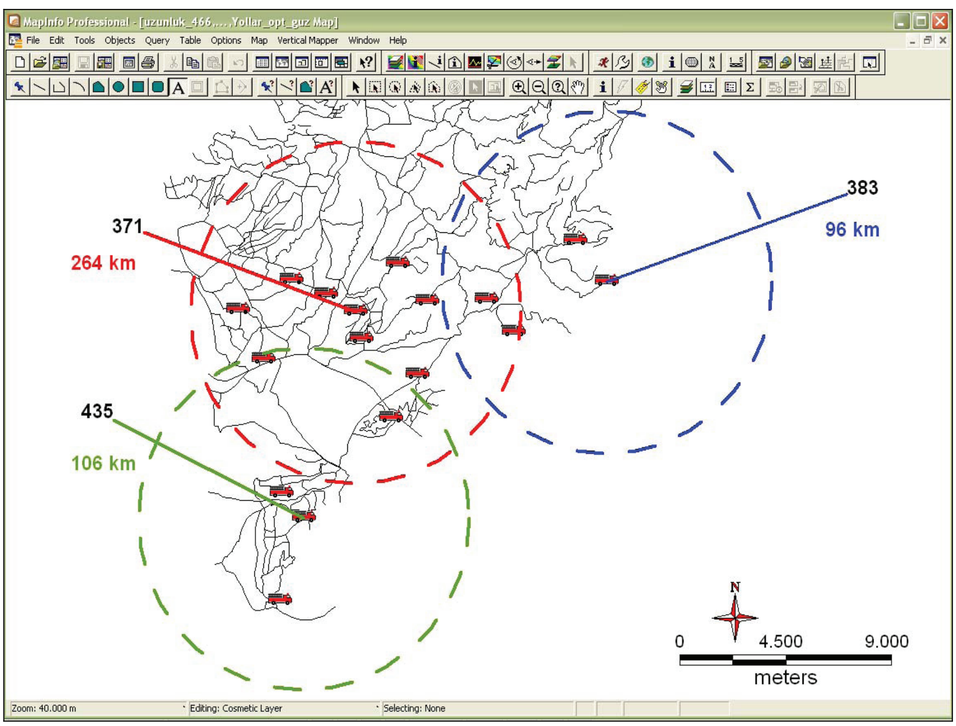

Figure 7. 7 km Buffers from Fire Crew 371, 383 and 435

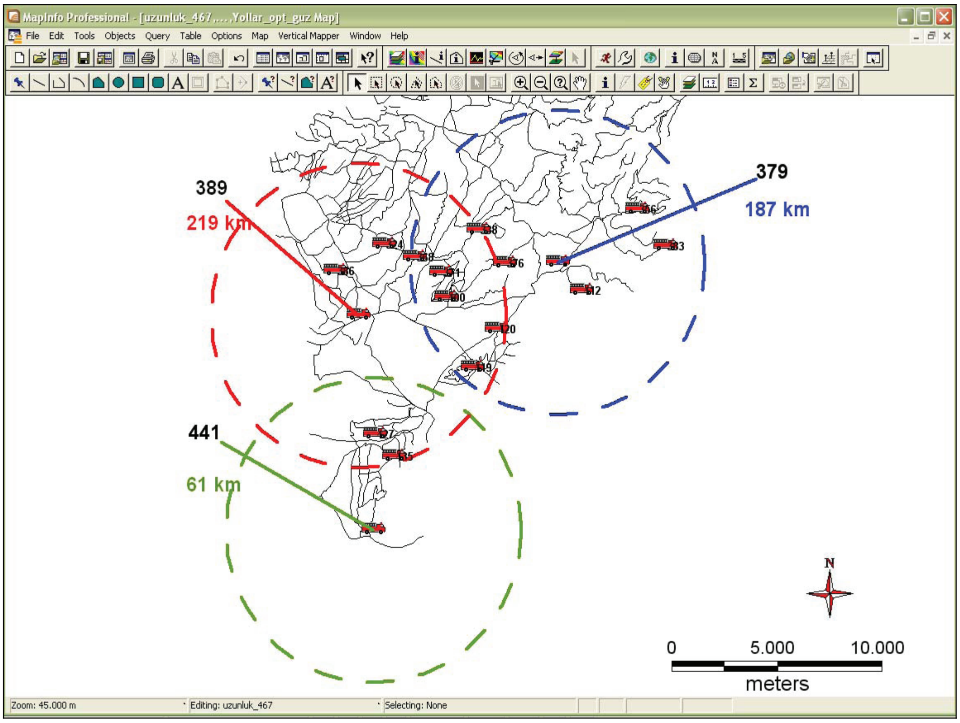

Figure 8. 7 km Buffers from Fire Crew 379, 389 and 441

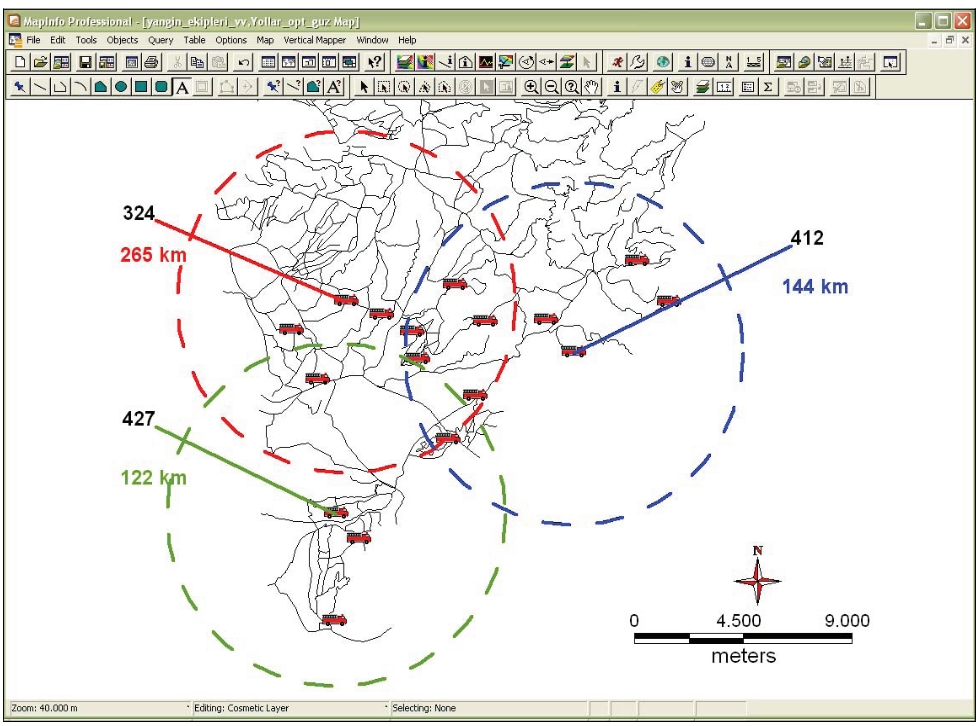

Figure 9. 7 km Buffers from Fire Crew 324, 412 and 427

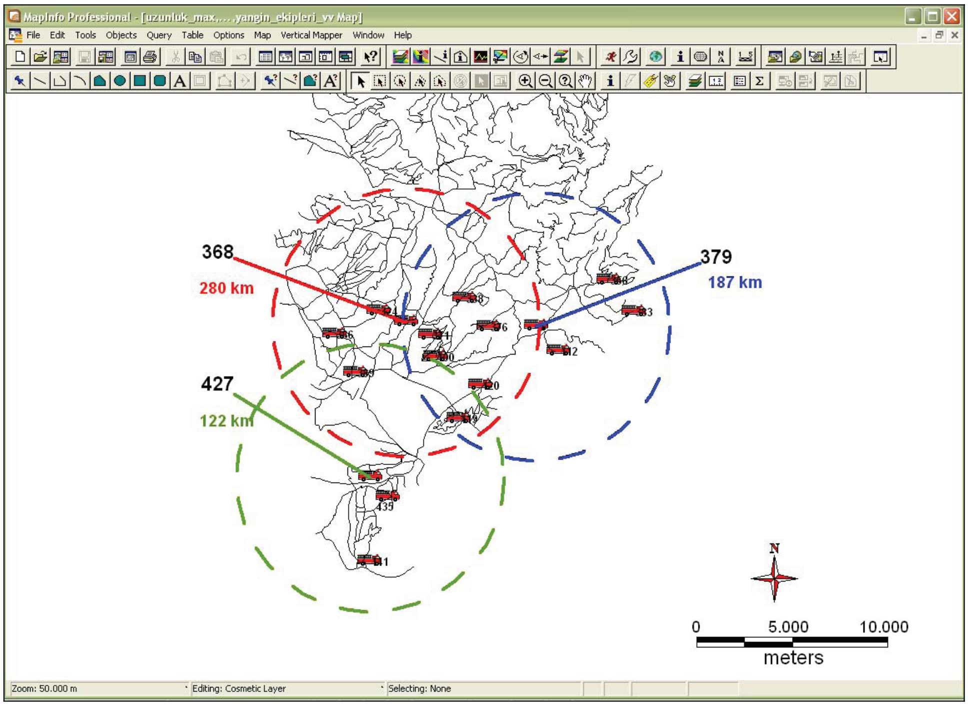

Figure 10. 7 km Buffers from Fire Crew 368, 379 and 427

Figures 11, 12 and 13 show types of the roads for buffering of fire crew 368, 379 and 427, respectively. The planned roads and unstandardized roads show unusable part of the total road.

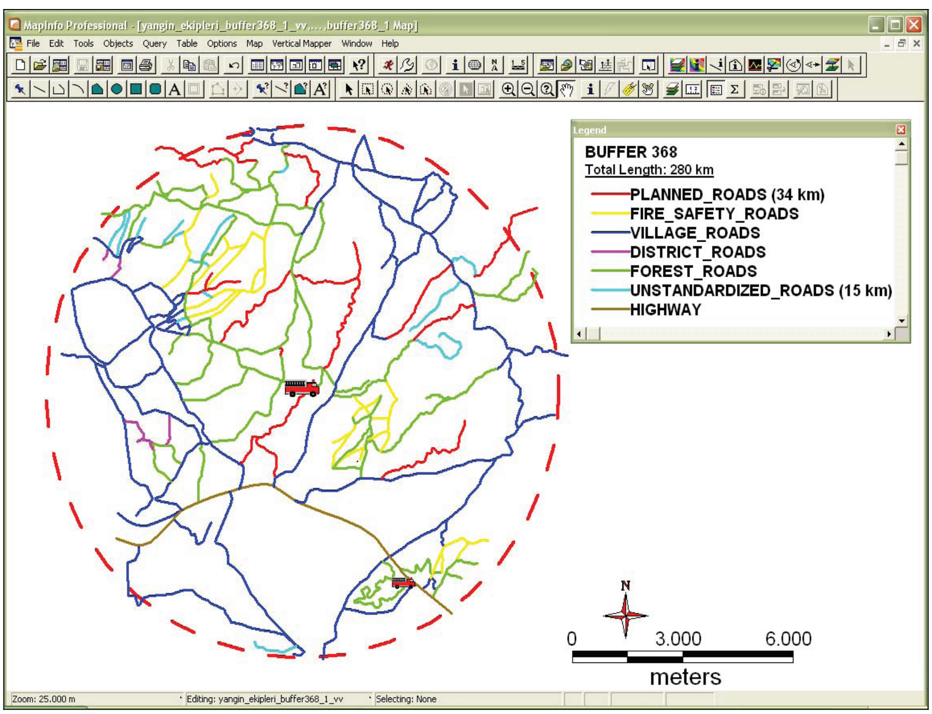

Figure 11. Road Types and Their Total Length for Buffering of Fire Crew 368

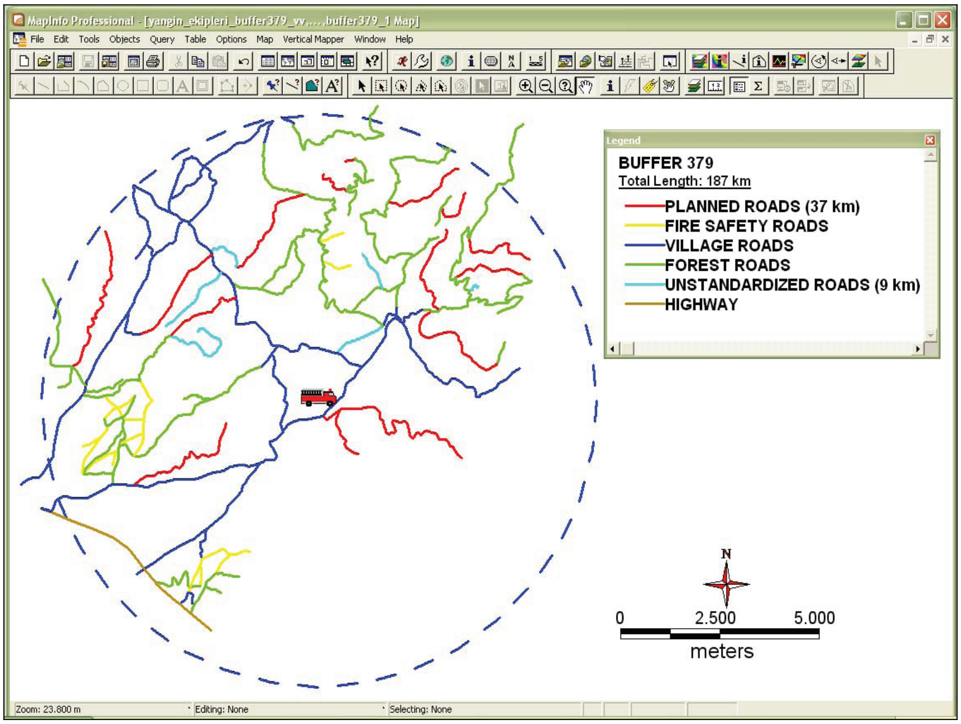

Figure 12. Road Types and Their Total Length for Buffering of Fire Crew 379

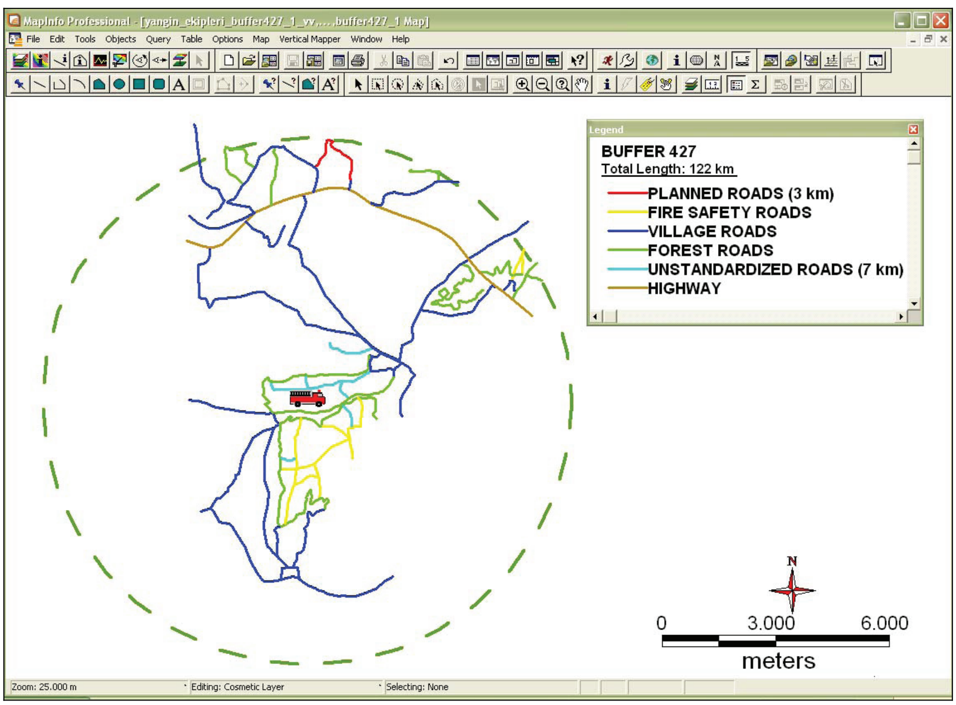

Figure 13. Road Types and Their Total Length for Buffering of Fire Crew 427

4. DISCUSSIONS AND CONCLUSIONS

In this study only small part of a very extensive appplication was presented. In order to optimize numbers and locations of fire crews LSCP and GIS integration was performed for the study area, İFACO. Firstly all water resources and fire crews of study area were displayed on a digital map by using coordinate information. Secondly database was designed in MapInfo. Attribute data consisted of water resources capacity, crew number per month, number, code, license plate and brand of sprinkler, water tank, grader, helicopter and airplane number. These attribute data were obtained from İFACO. Then current locations of fire crews were examined and assignment of new fire crews to the south region of the study area was investigated as demanded by directorates of forest protection and fire combating department. Optimum locations and numbers of fire crews were determined by LSCP and the results were visualized by GIS. Then because of the budget constraint of the proposed number of fire crew found by LSCP was minimized further by using GIS analytical function, buffering. In this study assignments were proposed in terms of total length of roads that was usable by fire crews. The assignment that gave the maximum road length was thought the best one because of the alternative roads it offered.

It was proposed that new fire crews must be assigned to the compartment 368, 379 and 427 as shown in figure 10. Because this assignment gave the highest result in terms of total length of usable road (589 km). The second alternative was proposed as the assignment of fire crews to the compartment 324, 412 and 427, as shown in figure 9. In this case total length of usable road was found as 531 km.

By using findings of this study, questions like, “what is the optimum number of fire crew?”, “where must fire crew be assigned?”, “which areas can be covered with this assignment?” can be answered easily.

Contributions of this study can be summarized as development of database related to digital map, that is establishing GIS, reperesentation of current water resources and fire crews locations on a digital map by using coordinate information, optimizing numbers and locations of fire crews for İFACO.

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YANGIN EKİPLERİNİN KONUMLARININ YÖNEYLEM ARAŞTIRMASI VE COĞRAFİ BİLGİ SİSTEMLERİ KULLANILARAK BELİRLENMESİ: İZMİR ÖRNEĞİ

ÖZET

Coğrafi Bilgi Sistemleri (CBS), Küresel Konumlandırma Sistemleri (KKS) ve Uzaktan Algılama (UA) gibi konumsal bilgi sistemleri ve teknolojileri, kaynak yöneticilerine ormanı anlamaları ve analiz etmeleri için araçlar sağlamaktadır. Orman planlama süreci giderek karmaşık bir hal aldığından, orman planlamacılarına yardımcı olacak operasyonel araçlara ihtiyaç vardır. CBS ve Yöneylem Araştırmasının (YA) bir arada kullanılması, orman yöneticilerine YA tarafından önerilen çözümleri görselleştirme şansı tanımaktadır. Yangınla mücadelenin planlanması orman yönetiminin önemli bir bileşenidir ve yangın ekiplerinin sayılarının optimize edilmesi de yangınla mücadelenin planlanmasında çok önemlidir. Bu çalışmada İzmir Orman İşletme Şefliği için yangın ekiplerinin mevcut konumları incelenmekte ve yangın ekipleri sayısal harita üzerinde gösterilmektedir. Daha sonra Konumsal Küme Kapsama Problemi (KKKP) ve CBS kullanılarak yangın ekipleri için yeni konumlar önerilmektedir.

Anahtar Kelimeler: Orman yönetimi, Coğrafi bilgi sistemleri, Konumsal küme kapsama problemi, Konumsal bilgi sistemleri.