GIS-BASED SEARCH THEORY APPLICATION FOR SEARCH AND RESCUE PLANNING

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ABSTRACT

GIS-BASED SEARCH THEORY APPLICATION FOR SEARCH AND RESCUE PLANNING

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Search and Rescue (SAR) operations aim at finding missing objects with minimum time in a determined area. There are fundamentally two problems in these operations. The first problem is assessing highly reliable probability distribution maps, and the second is determining the search pattern that sweeps the area from the air as fast as possible.

In this study, geographic information systems (GIS) and multi criteria decision analysis (MCDA) are integrated and a new model is developed based upon Search Theory in order to find the position of the missing object as quickly as possible with optimum resource allocation. Developed model is coded as a search planning tool for the use of search and rescue planners. Inputs of the model are last known position of the missing object and related clues about its probable position.

In the developed model, firstly related layers are arranged according to their priorities based on subjective expert opinion. Then a multi criteria decision method is selected and each data layer is multiplied by a weight corresponding to search expert's rank. Then a probability map is established according to the result of MCDA methods. In the second phase, the most suitable search patterns used in literature are applied based on established probability map. The developed model is a new approach to shortening the time in SAR operations and finding the suitable search pattern for the data of different crashes.

Keywords: Search and Rescue, Multi-Criteria Decision Analysis, GIS, Search Theory, Kütahya

ÖZ

CBS - DESTEKLİ ARAMA TEORİSİ UYGULAMSI VE ARAMA KURTARMA PLANLAMASI

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Arama kurtarma operasyonları, kayıp nesneleri belirli bir alanda en kısa sürede ve en uygun kaynak kullanarak bulmayı hedefler. Bu operasyonlarda temelde iki sorun ile karşılaşılır. Birincisi, güvenilirliği yüksek bir olasılık haritası elde etmek; ikincisi ise, üretilen olasılık dağılımına göre belirlenen bölgeyi, en kısa sürede havadan taramada kullanılabilecek arama desenini belirlemektir. Yüksek güvenilirliğe sahip olasılık haritaları üretmek, taranacak alanın küçültülmesi ve tarama süresinin azalması için gereklidir.

Bu çalışmada, kayıp nesnelerin en kısa sürede bulunması ve en uygun kaynak kullanımına altlık sağlayacak Coğrafi Bilgi Sistemleri (CBS) tabanlı Çok Ölçütlü Karar Verme Analizi (ÇÖKVA) ile bütünleştirilmiş arama teorisine dayalı bir model geliştirilmiştir. Geliştirilen model, arama kurtarma uzmanlarının CBS ortamında kullanabileceği bir arama kurtarma planlama yazılımı olarak kodlanmıştır. Model girdisi olarak kaybolan nesnenin en son görülme koordinatları ve ilintili diğer bilgiler kullanılmaktadır.

Modelde öncelikle ilgili katmanlar uzman görüşüne göre öznel olarak önceliklerine göre sıralanır. Ardından uygun olan ÇÖKVA metodu seçilir ve her katman uzmanın verdiği ağırlığa göre sıralanır. Olasılık haritası ÇÖKVA metodunun çıktılarına göre belirlenir. İkinci basamakta ise oluşturulan olasılık haritası temel alınarak literatürde kullanılan arama teorisine dayalı metotlar kullanılarak en uygun arama metodunun deseni belirlenir. Geliştirilen model ve yazılım arama kurtarma operasyonlarındaki arama süreçlerini kısaltması ve farklı kazaların verilerine göre en uygun arama desenini bulması bakımından alanda yeni bir yaklaşımdır.

Anahtar Kelimeler: Arama Kurtarma, Çok ölçütlü karar analizi, CBS, Arama Teorisi, Kütahya

To My Love

And

To My Family

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INTRODUCTION

Search and Rescue (SAR) is an operation to find and rescue the people in distress either in a difficult area, such as in mountains, deserts, forest or at sea (Stone, 1975). SAR operations have several distinct stages. In the first stage, the most likely location of the missing object is determined. This information is then processed with other considerations to decide the initial importance and scale of the operation (Frost, 1999).

The next stage is the search stage, in which a search is mounted by appropriate search tools like searching the area from air or land. When a search mission is required, there are four factors which should be considered immediately:

1) An adequate description of the search target,
2) The search area condition, including weather and any possible risks and dangers,
3) The best search pattern, sweeps the area optimally,
4) The appropriate track spacing, according to the terrain conditions (Haley and Stone, 1979).

Then the third stage is the Rescue stage, at this stage support is rendered to the object where it is found, to allow it to be safely transported to a place, where more intensive aid can be provided.

Finding the people in distress as quickly as possible requires well designed SAR planning and better use of technology (Zeid and Frost, 2004). For either complex or simple search operations, a search plan should always be developed by the control of the search expert, as many lives may depend on the care with which the search is planned and conducted (NSAR, 1998).

SAR planning operations differ from each other according to the search location. These are; inland search and rescue planning, maritime search and rescue planning, and aeronautical search and rescue planning. The latter is the subject of this study.

Aeronautical Search and Rescue (ASAR) term defines operations that are carried out by aircrafts which are the most satisfactory units for searching large areas quickly (IMCO, 1980). An ASAR planning operation characteristically involves three main parts, and requires several layers of information about probable position of the target (IAMSAR, 2001). The first and second steps in aeronautical search planning are to search along the track visually and electronically and determine the limits of the area containing all possible survivor locations, respectively (NSAR, 1998). This is usually done by determining the planned route of the missing airplane. Currently, search planners are mainly using the New Two-Area Method (NTAM) which sweeps the either side of track the search area along the route of the plane; commonly a search performed in an area of 10 nautical miles either side of track, the method was developed by the Canadian Department of National Defense's Directorate of Air Operational Research (Zeid and Frost, 2004). This method is based on research of 76 missing aircraft missions conducted in Canada from 1981 to 1986 (NSAR, 1998). The usage of this method requires search planners to have the last known position (LKP) of the missing aircraft and the intended route of the missing aircraft, and the intended destination of the missing aircraft. From this information the search area is defined for prioritizing the search.

The last stage in ASAR planning is computation of a probability area by using navigational tolerance, LKP and signals from the area. Hence, SAR planners have to know the LKP, route, and destination as discussed, but there are other mitigating factors that often allow planners to focus the search efforts. These include a known flight plan, signals from the area, radar, witnesses, or known Emergency Locator Transmitters (ELT) signals or distress calls in the area of possibility of the search.

1.1. Search Theory in SAR

The theory of how to search for missing objects has been a subject of serious scientific research for more than 50 years. It is a branch of the broader applied science known as operations research (Frost, 1999). In more recent years, the principles of operations research have been applied to a wide variety of problems that involve making good decisions in the face of uncertainty about many of the variables involved (Champagne et al., 1999).

Search theory is defined by Cadre and Soiris (2000) as a discipline that treats the problem of how a missing object can be searched optimally, when the amount of searching time is limited and only probabilities of the possible position of the missing object are given. The development of search theory and its search application and rescue consist of three main parts. These are scientific research and subsequent developments, developments of search planning doctrine with SAR manuals and development of computer based search planning decision support tools (Stone, 1989).

The first part is mainly developments in a scientific research side. Search theory was first established by Koopman during World War II using the new techniques of operations research. First applications of search theory were made on military operations (Stone, 1975). Koopman (1980) stated that the principles of search theory could be applied effectively to any situation where the objective is to find a person or object contained in some restricted geographic area. After military applications it was applied to different problems such as; surveillance, explorations, medicine, industry and search and rescue operations (Haley and Stone, 1979). The aim of searching in the context of ASAR is to find the missing aircraft effectively and as quickly as possible with the available resources (Stone 1989). In search theory framework, effectively means minimizing the time required to find the search object while maximizing the chances for finding the object.

Koopman (1956) defined Search theory in three reports. The first one is Kinematics-based, which includes the analytical description of equations of a target and observer movement, description of equations of probability value of connecting an observer and a target and equation describing the randomly distributed targets. The second report was about target detection that consisted of analytical description of instantaneous probability for target location, analytical description of horizontal distance distribution and the analytical description for a common case of a random search. The last report investigated the problem of optimum distribution of search efforts.

The second part of developments in search theory involves establishment of search planning doctrine. In 1957 the U.S coast guard first articulated its search planning doctrine in the form of search and rescue manual and showed how the basic principles of search theory were applied to the SAR planning process. (Stone, 1989)

The third part is development of computer based search planning decision support tools. According to Stone (1989) in the early 1970s Richardson (1972) developed the computer assisted search planning (CASP) system for dynamic planning of search for ships and people lost in the sea. Then, CASP systems were developed to assist U.S navy in planning submarine searches.

The first computer based systems mostly used for marine SAR operations (Stone 1975). In order to reach a target in minimum time with limited resources, it is important to use CASP systems to increase the speed of the search. With the development of search theory CASP systems have been used since 1970s.

CASP systems were first introduced by United States Coast Guard in 1974s (Champagne et al., 1999). It was based on Monte Carlo simulation and applied in naval SAR operations. CASP generates an initial probability distribution taking in to account current wind and environmental information. Richardson and Corvin (1980) used CASP systems in marine SAR operations. They have stated three types of SAR scenarios to construct initial probability map. These are referred as position, area and track line scenarios for distress objects. Position Type initial target probability distribution is modeled as bell shaped distribution because it considers that the missing object is not stationary. In the area type scenario the search area is bounded and the probability in the area is thought to be as uniform for distress object. The third scenario is the track line scenario. It is used if a reported track of the object is assumed to be true.

CASP systems were limited in terms of spatial data (Cooper et al., 1999). Therefore, in order to put up limitations about spatial data, it is important to integrate GIS into CASP systems used in ASAR operations. Use of GIS is highly increased in SAR operations. Hence, GIS permits to analyze the relationships between different data layers easily and effectively.

Cooper et al., (1999) have focused inland search and planning techniques. They developed a methodology for land search planning and developed computer based search planning decision support tool for land SAR. Champagne et al., (1999) tested three of the search patterns used only for naval search and rescue operations. They examined with respect to number of U boats sighted by aircrafts as a measure of search efficiency. Their studies conclude that search patterns have impacts on search efficiency in naval SAR operations.

Wollan (2004) investigated creation of search patterns in ASAR operations. Besides generic search patterns in use; Wollan tested heuristic algorithms in the mean of minimizing the time. In the study of Wollan (2004) added GIS into a developed search management implementation. Also Wollan offered to modify search patterns individually to accommodate the area that needs to be searched instead of using generic search pattern.

Zeid and Frost (2004) have developed a decision support systematic for Canadian search and rescue operations in the case of lost air craft. They developed an optimization module based on search theory, on gradient search methods. They compared their system with current Canadian manual SAR system.

1.2. Problem Definition and Aim

Search and rescue operations are spatial activities (Haley and Stone, 1979). Search planners must combine information on where the missing object was last seen, likely routes, and maps of the areas already searched, time last searched, and available resources to effectively mount a search area (Burrough and Frank, 1995). The main problem is to produce the reliable probability maps, which accounts for these clues (Stone, 1975).

The majority of the SAR planning is made through the ease of methods described in the United States National Search and Rescue Manual (NSM) and Canadian National Search and Rescue Manual (NSAR). However, these documents are adequate for describing search planning doctrine and providing practical guidance for planning searches with only traditional tools like pencil, paper, nautical charts etc. They are inadequate as a guide to search theory or to the practical application of the currently available considerable computing power to the search planning problem (Frost, 1999).

While preparing probability maps of the suspicious distress area, integrated spatial technologies such as geographic information systems (GIS) would be an ideal solution for aeronautical search and rescue operations (USADT, 2001). The dynamic relation between maps and the spaces represented in SAR operations is common to geographic information systems. Therefore, GIS presents itself as the most useful tool in making effective SAR operations.

Moreover, for more accurate probability maps it is important to include more inputs about the location of the missing object (USR, 1991). In order to enrich the information about the area and getting more reliable probability maps about its distribution on the area, GIS could be used as a tool (Armstrong and Cook, 1979). In the absence of inputs on the contrary, it may be assumed that the most probable area within which a missing aircraft will be found is along the intended track from LKP to intended destination and within a reasonable distance either side of track (NSAR, 1998).

Each SAR mission has different characteristics (Stone, 1983). Zeid and Frost (2004) stated that, parameters related with the missing plane, such as intended route, is an important role of the SAR planning. However, if the route of the plane is not known like air combat maneuvering, achieving this step cannot be possible to sweep the route of the plane. In this kind of search operations it is impossible to sweep the either side of track, in the search area along the route of the plane. It can be faced with many crashes, such as dog fight flights which is a common flight type used to describe close-range aerial combat between military aircrafts (Web 1). In this type of flights route information of the missing plane cannot be determined to include into SAR mission planning. SAR planners can cope with this problem by calculating maximum distance the survivors could have traveled between the time of their LKP and the known or assumed time of the distress incident and drawing a circle of that radius around the LKP. Knowing the extreme limits of possible locations allows the search planner to determine where to seek further information related to the missing airplane. However, systematic search of such a large area is normally not practical. Therefore, the next step is shrinking the search area as possible.

Besides the problem of decreasing size of the search area, an aeronautical search and rescue operation requires access to information from many different sources in order to properly respond to an emergency or incident. An incident must be understood within the context of the environment that it has occurred (Robe and Frost, 2002). Generally search environment is very dynamic and SAR operations need to include all of the dynamic factors. Therefore this process can be summarized as location of an incident and how to access that location. The most logical way of organizing such data could be geospatial monitoring and analysis.

Missing aircraft search methods are very intensive and tie up many resources that could be used elsewhere (Stone, 1975). SAR planning procedures plans basically where, when and how to search. Therefore, determining the optimal search area is the main problem. The subject of search theory is constructing a probability distribution for the location of the missing object in order for optimal resource allocation (Cadre and Soiris, 2000).

The use of GIS in SAR operations is growing very rapidly. SAR operations benefit greatly from the GIS technology in recent years. In recent studies (Liu et al., 2006; Wollan, 2004; Zeid and Frost, 2004) lots of applications were developed to help solving SAR problems. Many early systems like computer aided search planning systems (CASP) were developed to solve relatively narrow, specific kinds of problems. The past twenty years have seen an explosion in the technological base for these systems, particularly in the areas of spatial data processing in GIS technologies. Zeid and Frost (2004) tested how their GIS integrated tools could be applied in SAR operations in Canada. Wollan (2004) used GIS for defining the search area, generating the search patterns and viewing the current status of search effort. (Web 2) presented examples of how the development of GIS increases capabilities in a natural disaster management in the example of SAR operations in India.

According to above mentioned state of the art, the following problems related to SAR operations can be listed:

1) The problem of producing highly reliable probability map from the limited available information to conduct a SAR operation,
2) Highly subjective decisions by SAR expert while distributing resources to the area,
3) Dividing the area into sub sectors before considering the probability map,
4) The problem of having no information about intended route, and intended destination of the missing aircraft.

In the present context, due to scientific advances it has become easier to carry out SAR operations efficiently with the use of GIS, which help to identify areas that are probable location of missing objects, searching them according to probability distribution maps, and simulating search operation according to those maps. Moreover, GIS is useful even in managing SAR planning as it provides instant access to information and analyzing efficiently required for search management decisions (Web 3).

In this study it is aimed to develop a new systematic integrated methodology which could reduce the time it takes to find survivors of plane crashes, and thus save lives. The proposed methodology with the desired characteristics integrates Search Theory, for constructing reliable probability distribution maps with GIS; for acquiring, integrating and analyzing data coming from different heterogeneous sources and Multi Criteria Decision Analysis (MCDA) methods for constructing probability maps.

Particularly, this study focuses on incorporating the spatial data and clues from variety of sources to create a meaningful, accurate and comprehensive representation for aeronautical search and rescue planning. After preparing reliable and accurate probability map, search pattern efficiency is tested. In order to do this properly, the criteria necessary for the preparing of the probability map is reviewed.

The integration of GIS and MCDA provide a powerful tool to generate probability maps of the search area, since GIS provides efficient manipulation and presentation of the spatial data and MCDA supplies consistent ranking of the spatial layers and clues from the area based on a variety of criteria.

The proposed methodology is coded as computer software (METUSAR), which allows SAR planners to observe how the conditions and clues affect the probability maps and SAR planning process. It creates a condition for SAR planners for ranking and rating the environmental and geographical data. In computer program three goals are met. Firstly, the system is designed in a manner that allows for ease of understanding for the search experts. Secondly, the system involves all the steps of preparing probability map for SAR operations rather than separate parts of functions. Thirdly, the system contains spatial and geographical data, in order to get more accurate probability map. These characteristics are combined in geographic information systems, based on multi-criteria decision analysis tool for SAR operations.

The developed methodology and the coded Software are implemented on the case of Plane Crash in Kutahya in 2004. The search time of this crash was one of the most excessive ones in the Turkish ASAR (Gerede, 2007), as the plane was in a dog fight. The case is used for performance testing of the methodology and the software.

The main innovation of this study is integration of search theory and MCDA within GIS framework and providing a single integrated system for ASAR operations. The proposed methodology provides easy retrieval of spatial and non spatial information, analysis of this information in the light of Search Theory concepts and estimating consequences of proposed SAR plans.

1.3. Organization of the Thesis

Outline of the thesis is as follows;

First chapter starts with a brief summary of SAR planning and problem definitions as well as aim of the thesis.

In the second chapter, the historical and theoretical framework of Search Theory is presented. The terminology is defined briefly.

In the third chapter, developed methodology of the thesis is explained. Also, preparing the probability map with using MCDA is described. Moreover, the steps of methodology which are classification of probability maps and search pattern comparison are discussed.

In the fourth chapter, the software design and development is mentioned, module-by-module.

In the fifth chapter, implementation of application on the case study area is discussed. The data related to the incident is presented and the status of the incident area is set accordingly. Geographical settings of the study area and all layers used are given. Different search patterns are compared.

In the Conclusion chapter, an evaluation is made, regarding the aim, objective of the study and analysis for these objectives. Finally, recommendations and conclusion of the study were discussed and some ideas are given about the future studies.

CHAPTER 2

SEARCH THEORY AND SAR

2.1. Principles of Search Theory

One of the goals of search theory is to provide optimal solutions in the Search and Rescue (SAR) context. A search plan would be optimal if it provides maximum probability of success (POS), which is the probability of finding the object (Zeid and Frost, 2004). Two concepts are also important: the probability of area (POA) which is the probability that the search object is contained within the boundaries of a region, segment, or other geographic area and the probability of detection (POD) which is probability of detecting the search object in the determined area. The relation between POD, POA and POS is given in Equation 2.1

$$POS = POD \times POA \tag{2.1}$$

The POD of a search is determined by the coverage, as shown in Figure 2-1. Coverage (C) is the ratio of the search effort (Z) to the area searched (A) and is equal to Z/A. For parallel sweep searches where the searcher tracks are perfectly straight, parallel, and equally spaced, it may be computed as the ratio of effective sweep width (W) to track spacing (S) or C = W/S. "A" (area searched) and "Z" (search effort) must be described in the same units of area. W (effective sweep width) and "S" (track spacing) must be expressed in the same units of length. Coverage may be thought of as a measure of thoroughness (NSAR, 1998). The POD may be derived from the POD vs. Coverage graph (Figure 2-1).

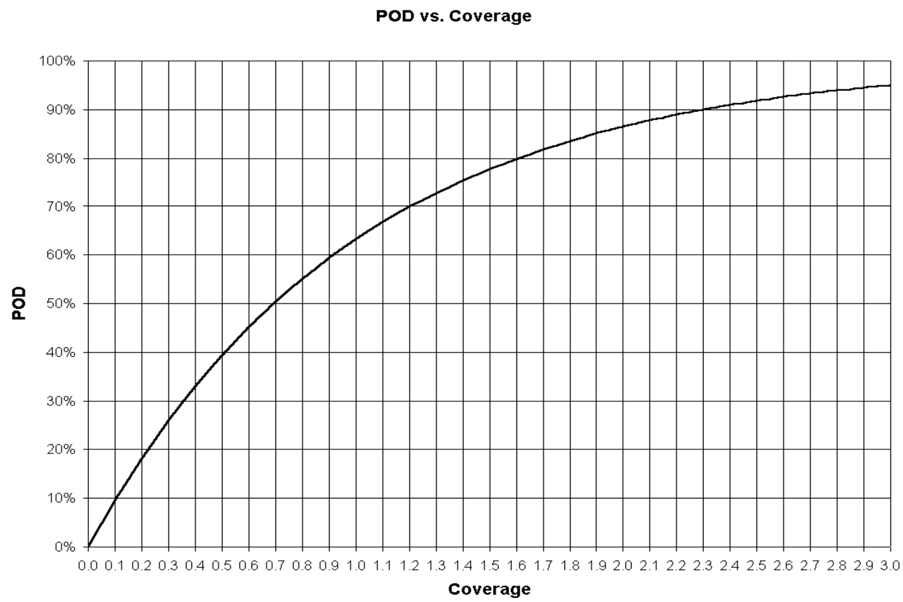


Figure 2-1 Coverage vs. POD

Effective sweep width is a measure of detectability. Effective sweep width depends on the search object, the sensor, and the environmental conditions existing at the time and place of the search. Real effective sweep width values must be measured via exact scientific experiments, but rationally accurate estimates may be made from tables of effective sweep widths (Tables A-1, A-2, A-3 and A-4) that have been experimentally determined for various search situations. A less accurate method of estimation for visual search is to assume the effective sweep width equals to the visual distance.

The effective sweep width may be thought of as the width of a swath centered on the sensor's track such that the probability of failing to detect an object within that width equals to the probability of detecting the same object if it lies outside that width, assuming the object is equally likely to be anywhere (Frost, 1999).

Another, equivalent, definition is: If a searcher passes through a swarm of identical stationary objects uniformly distributed over a large area, then the effective search width, W, is defined by the Equation 2.2,

$$W = \frac{N_1}{N_2 \times V_s} \tag{2.2}$$

Where V_s is searcher speed, N_1 is Number of objects detected per unit time and N_2 is Number of objects detected per unit area. All values in Equation 2.2 are averages over a statistically significant sampling period. Generally, a significant increase in search speed will decrease the effective sweep width. W is needed to compute the search effort (Z), and Z is needed to compute the C based on the amount of search effort expended in the segment relative to the segment's physical area.

The effective sweep width (W) times search speed (V) times hours spent in the search area (T) equals to the search effort (Equation 2.3) for one searcher or one resource.

$$Z = W \times V \times T \tag{2.3}$$

Alternately, Z = W x D, where D is the linear distance traveled. The unit of measure for search effort is described in area. If multiple searchers simultaneously follow independent paths when searching and together achieve approximately uniform coverage of the segment, then the total search effort is given by Equation 2.4

$$Z = n \times (W \times V \times T) \tag{2.4}$$

Where n is the number of searchers.

2.2. Search Sequence

Generally five steps for search and rescue operations are adequate. These steps are as follows: (NSAR, 1998)

1. Estimating the Last Known Position (LKP)
2. Determining the size of the search area
3. Selecting appropriate search patterns
4. Determining the desired area coverage
5. Developing an optimal search plan

2.2.1. Estimating the Last Known Position (LKP)

The term Last Known Position (LKP) expresses the last witnessed, reported, or computed position of a lost object. Estimating the LKP is essential for determining the probable position of the target in ASAR cases (IMCO, 1980; IAMSAR, 2001). According to Thomas and Hulme (1997) as randomization of the initial position of a stationary target is equally likely to be at any point in the area, besides LKP, every clue about target should be considered before preparing probability maps.

Estimating the LKP of the target is the first step of an efficient search planning process (Champagne et al., 1999). Therefore, getting clues about the target, determining where it was last seen, and defining the approximate size and location of the area, where the subject could be are all important preliminary steps for any kind of search problem.

2.2.2. Definition of the search area

The second step of the SAR planning is highly related with LKP and probability map. According to NSAR (1998) the search area is the section that bounded by the target's limit of endurance in all possible directions from the LKP of the search object. It approximates a circle centered on the LKP with the radius being expressed in terms of distance.

After the search area has been determined, the next step is to assign a probability map location of the search object, which is called POA. According to NSAR (1998), estimated location for a stationary object is based on one of the following three distributions: point datum, line datum or area datum. The point datum is a bivariate normal distribution centered on the LKP with no correlation between x and y variables. The standard deviations for these variables assumed to be equal. This standard deviation represents the error in the estimation of the last known position. Position error may also be expressed as the total probable error of position, E. This quantity represents the radius of the circle around the LKP that contains 50 % cumulative probability that the search object located with in the circle. The line datum is used when both LKP and destination are known. It corresponds to a uniform distribution along the flight path. The area datum is uniform distribution that is appropriate when very little is known about flight plan of the search object.

Normally, it is impractical to search wide area; hence, searching the whole area is not optimal. In the absence of information, it may be assumed that the most probable area that missing aircraft is found is that along the intended track from the last known position to intended destination.

2.2.3. Selecting Appropriate Search Pattern

There are mainly six search patterns according to the National Search and Rescue Manual for visual searches from the air:

1. Track crawl search pattern
2. Parallel track search pattern
3. Creeping line search pattern
4. Expanding square search pattern
5. Sector search pattern
6. Contour search pattern

Track Crawl Search Pattern:

The Track crawl pattern is usually used as the initial search action, and is based on the assumption that the search object's route is known. Track crawl pattern (Figure 2-2) can be used on electronic or visual searches if the route of the target is known before the crash time.

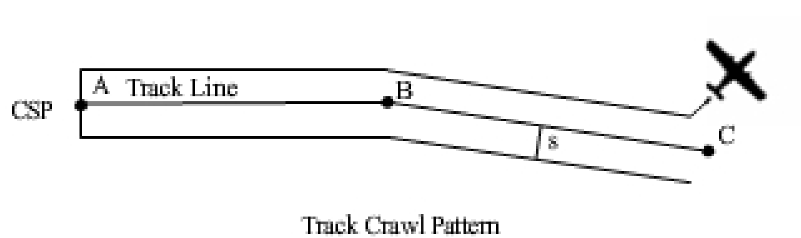


Figure 2-2 Track Crawl Search Pattern (NSAR, 1998)

Parallel track search pattern:

Parallel Track search pattern (Figure 2-3) which is employed to provide uniform coverage over the search area is used for the successive search legs advancing across a search area.

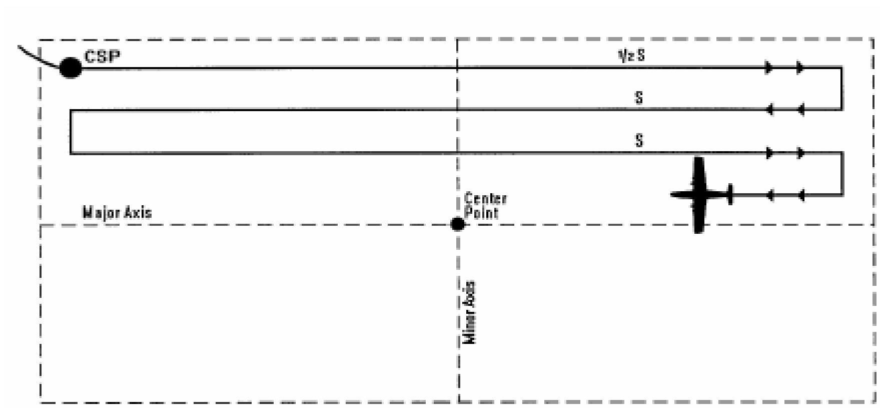


Figure 2-3 Parallel Track Search Pattern (NSAR, 1998)

Creeping Line Search Pattern

Creeping Line Search Pattern (Figure 2-4) like Parallel Track pattern is employed to provide uniform coverage over areas where only the approximate position of the target can be estimated. The difference between parallel track and Creeping line search pattern is if legs are parallel to the shortest side of the search area it is called Creeping line search pattern.

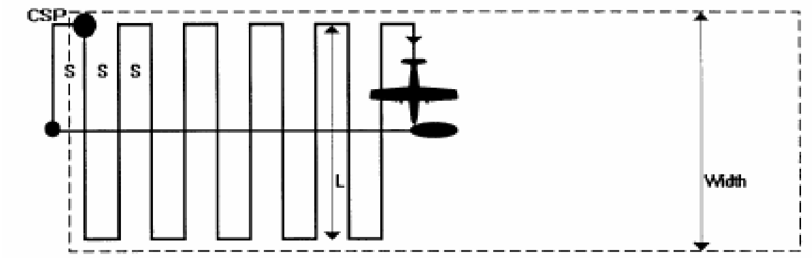


Figure 2-4 Creeping Line Search Pattern (NSAR, 1998)

Expanding Square Search Pattern:

The Expanding Square Search Pattern (Figure 2-5) is used when the location of the stationary search object is known with reasonable accuracy. If first coverage of an area is not adequate, the tracks should be angled at 45 degrees to the first coverage for the second coverage.

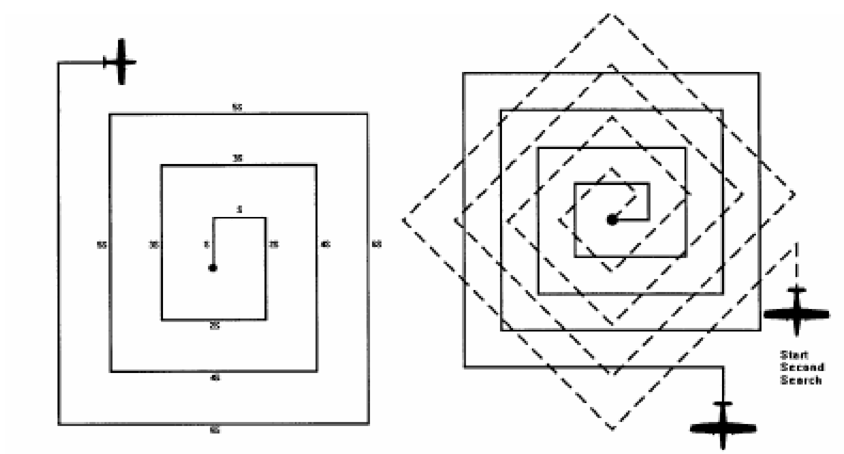


Figure 2-5 Expanding Square Search Pattern (NSAR, 1998)

Sector Search Pattern:

The Sector Search Pattern (Figure 2-6) is used when probability map is established with a high degree of confidence, the search area is not extensive and the search object is difficult to detect. The main advantage of a sector search is that track spacing at the centre of the search is very small, resulting in a greater probability of detection in the area of greatest probability of whereabouts (NSAR, 1998).

According to (NSAR, 1998) sector search patterns should not have a radius greater than 18 Kilometers for air searches.

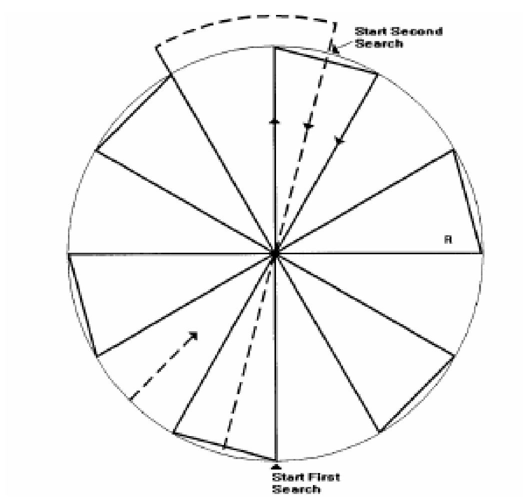


Figure 2-6 Sector Search Pattern (NSAR, 1998)

Contour Search Pattern:

The Contour Search Pattern (Figure 2-7) is used for the terrain searches however it can be hazardous search procedure, and can only be done when the aircraft used must be suitable for the conditions, highly maneuverable and low speed and small turning radius with adequate power reserve. The restriction of this pattern is that only one aircraft can search the area.

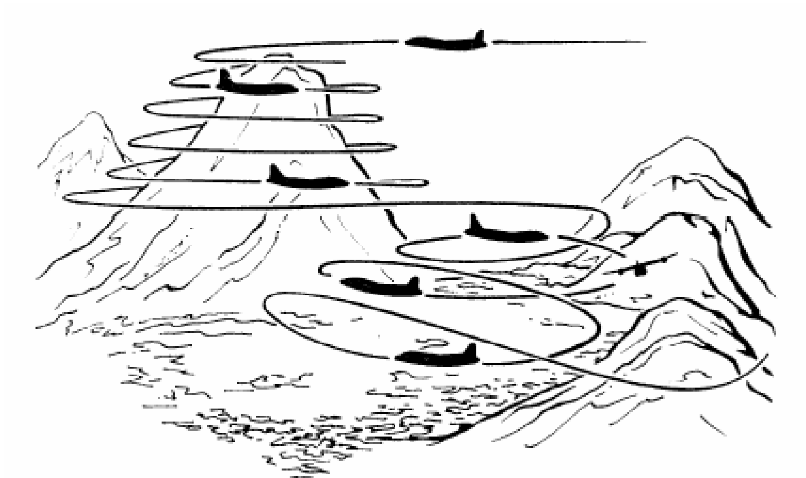


Figure 2-7 Contour Search Pattern (NSAR, 1998)

2.2.4. Determining the Desired Area Coverage

The coverage factor is a measure of how systematically an area was swept. It is the ratio of the area effectively swept divided by the physical size of the area. These steps include consideration of the factors that affects sweep width, track spacing and number of sweeps. To make optimum use of probability of detection (POD), sweep width terminology has been developed (NSAR 1998). Sweep width (W) is a mathematically expressed measure of detection capability based on target characteristics, weather and other variables (Figure 2-8). W is obtained by choosing a value less than the maximum detection range so that scattered targets that may be detected beyond W are equal in number to those which may be missed within W (Zeid and Frost 2004).

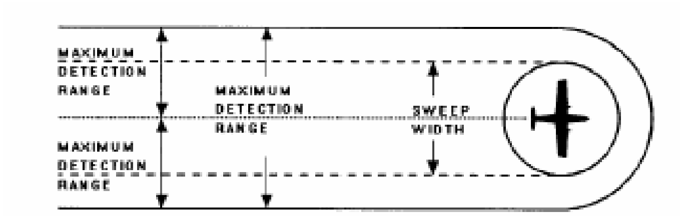


Figure 2-8 Sweep Width (NSAR, 1998)

In general two types of inland search are conducted: initial coverage and intensive coverage. For initial coverage, track spacing (S) is usually dependent on terrain. For intensive coverage, S is less than 3,2 km with 1,6 km being the norm depending on terrain (IMCO, 1980).

Mostly, the coverage factor is based on the subjective judgment of the search expert and the search planner (Frost, 1999). This value can then be used to assess the effectiveness of the initial coverage and the requirement of repeated searches of an area.

2.2.5. Developing an Optimum Search Plan

The optimal search problem is made of three basic elements: the probability distribution for the target's location or motion, the detection function and the constraint on the search effects. The target's position is uncertain usually, but there is some information about its location. For search theory, it is assumed that the information has been quantified in the form of a probability distribution function called the target distribution (Liu et al., 2006).

According to Stone (1975) the detection function relates the amount of search efforts utilized in searching an area to the probability of detecting the target given that it is located in the area. Usually, the searcher has a limited amount of search resources available to carry out the search. For each allocation of total search effort to the various regions of search space, the probability of detecting the target with that allocation can be computed given the probability distribution function. Therefore the optimal search problem is to find an allocation of resources which can maximize the probability of detection, or to minimize the expected consumption of resources for detecting the target.

2.3. Probability Density Distribution and Probability Maps

Quantifying all the available information about the target's most probable locations and establishing the probability density distributions is called a probability map (Frost, 1999).

Dividing the search area in to the smaller searchable units is named as segmentation. According to Champagne et al., (1999) segmentation is generally determined by logistical and operational constraints unrelated to the probability density distribution on search object location.

Finding probability distribution for a target's location relies on a subjective judgment and experience of the search planner. Constructing target location distribution is strictly related with the last known position of the target and this is a critical step in preparing a search plan (Stone and Wagner, 1977). According to Frost (1999) in order to determine starting point, it requires a careful and attentive assessment of all the available information from all the possible sources.

2.4. Determining a search area

In order to solve a search problem, creating or assuming a probability density distribution, which represents where the search object is more likely and less likely, is essential (Koopman, 1980). Therefore, determining the border of the search area is a crucial step in search and rescue operations. When the rough search area is determined it is necessary to define it to detailed search units. Then total area is needed to be divided in sub-areas (NSAR, 1998).

CHAPTER 3

FRAMEWORK OF DEVELOPED METHODOLOGY

The proposed methodology, integrates principles of Search theory through Geographic Information Systems (GIS) supported with Multi Criteria Decision Analysis (MCDA) methods. GIS provides a suitable framework for SAR applications for capturing, storing, retrieving, editing or displaying spatial SAR data. MCDA provides GIS with the means of performing complex analysis on multiple and often conflicting objectives, while taking multiple criteria and expert knowledge into account.

In this study GIS and MCDA analyses are integrated with the ultimate aim of selecting the most appropriate search pattern, producing probability maps and segmenting the area according to probability map. In Figure 3.1, the steps of this methodology are shown..

The methodology has a number of steps (Figure 3-1). The first step is to prepare the data for generating probability map. In order to do this, digital elevation model of the area, last known position of the target, location of settlements near the LKP and roads in the area are used in order to prepare probability maps based on MCDA methods. Then the probability map is classified. Later different search patterns are selected and finally the appropriate search pattern is obtained based on minimum search effort.

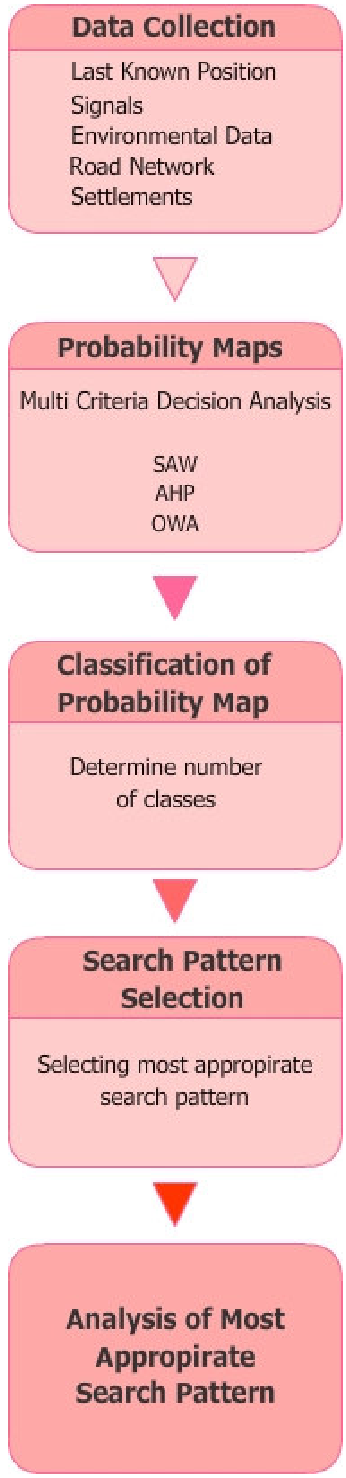


Figure 3-1 Stages of Developed Methodology

3.1. Data collection

Data collection part of Aeronautical Search and Rescue (ASAR) operations consist of two main parts. Generally, in ASAR cases the most important part is to know clues about the probable last location of the missing object. The ultimate clue about the target is last known coordinates (LKP) or its probable route. Altitude and velocity of the plane before the crash is also important to determine the limits of the search area (Figure 3-2). The second part is environmental information that effects construction of probability map and search operation. Vegetation, weather conditions, size of object, composition of the surface composition of the object (color, reflective ability), visibility of area from the ground.

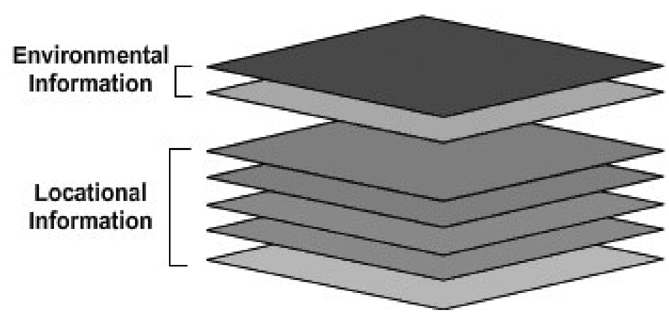


Figure 3-2 Layer structure

3.2. Probability Maps

An optimal search plan should include the following procedures; the dimension and the location of the search area and sub search areas, the assignment of the available search and rescue units to the corresponding area, along with the track spaces and altitudes (Cooper et al., 1999).

In SAR planning determining the probability of success (POS) is an important part. POS helps to find the minimum amount of search effort required to achieve the search process.

POS is determined by probability of area (POA), which is the chance that the missing object is located within the limits of the determined area. Probability of detection (POD) is related with the used detection tool, which is the probability of detecting the target in the given area (Koopman, 1956). Robe and Frost (2002) described the effective sweep width as a basic measure of how easy or hard it will be for a searcher to detect the search object under the environmental conditions that exist at the scene of the search.

The method for estimating effective sweep width is based on concept of a lateral range curve (Figure 3-3), which refers to the perpendicular distance an object to the left or right of the searcher's track where the track passes the object. (Robe and Frost, 2002) Therefore the distance from the searcher to the object at the closest point of interaction indicates how narrowly the searcher approaches to the target.

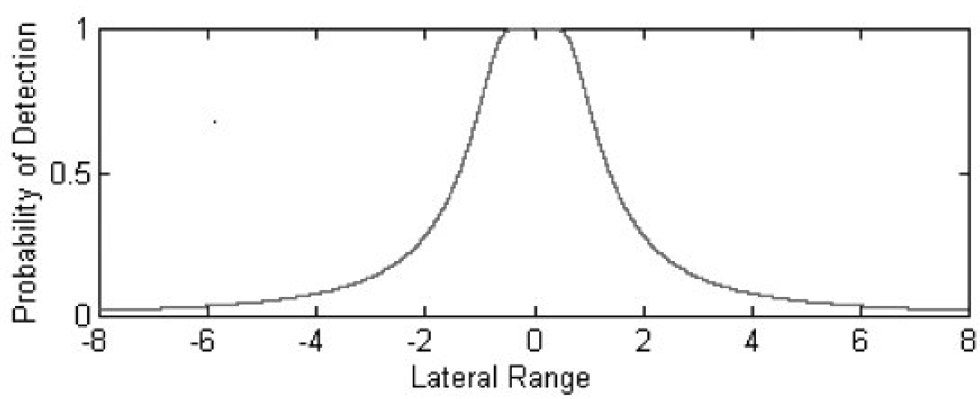


Figure 3-3 Lateral Range Curve (IMCO, 1980)

Probability maps consist of regular grids which are geometrically identical square cells. Each cell is labeled with its POA value. However, the data obtained from different sources about the possible location of the missing object could be disordered. Therefore, producing probability maps of the case could be more difficult. In this case it is important to decide which information is more or less important. Moreover, different types of information should be combined in obtaining probability maps. Multi-criteria decision analysis (MCDA) tools provide a solution to this problem. In this thesis, MCDA methods are used for obtaining probability maps.

MCDA is a set of procedures to analyze complex decision problems. Main objective is dividing the problem into small interpretable parts, and then analyzing every part and integrating them in a logical manner to produce a meaningful solution for the decision problems (Malczewski, 1999). The types of decision problems that interface SAR planners typically involve a large set of feasible alternatives and multiple conflicting evaluation criteria. (Stone, 1989) In order to solve this kind of problems an appropriate decision rule should be used for overall assessment (Malczewski, 1999). Since, choosing an appropriate decision rule according to their performance with respect to evaluation criteria is a main part of MCDA, results of this process is important for the accuracy of the study.

According to Malczewski (1999) the goal of the MCDA is to choose better alternatives, to sort alternatives and rank them according to preference. There are numerous decision rules that can be used for tackling the MCDA problems. Additive decision rules are the best known and most widely used methods in GIS-based decision making. The most often used three decision rules: simple additive weighting (SAW), analytic hierarchy process (AHP) and ordered weighting averaging (OWA) are discussed below.

3.2.1. Simple Additive Weighting (SAW)

Simple additive weighting (SAW) which is also known as scoring methods is a simple multi attribute decision technique (Malczewski, 1999). SAW method is based on the weighted average concept which is a direct weight assessment method. Decision maker assigns importance weights according to his/her assessments to the variables and makes a numerical scaling of them (Kenneth 1973). An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria. The simple additive weighting method evaluates each alternative, Ai, by Equation 3.1:

$$A_i = \sum w_i \times x_{ji} \tag{3.1}$$

Where x_{ij} is the score of the i_{th} alternative with respect to the j_{th} attribute, and w_j is the normalized weight, so that $\sum w_i = 1$. The weights represent the relative importance of the attributes (Malczewski, 1999).

The GIS-based SAW methods can be implemented by using GIS having overlay capabilities. The order of this operation is first defining the set of evaluation criteria (i.e. GIS layers). Second standardizing each criterion map layer and third defining the criterion weights according to expert's choices. After standardizing the map layers, they are translated to the weighted standardized map layers. GIS helps generation of the overall score for each alternative using the overlay operation and ranking of the alternatives according to the overall performance score (Malczewski, 1999).

The main advantage of SAW method is that it is a proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal.

3.2.2. Analytical Hierarchical Process (AHP)

The Analytical Hierarchical Process is a technique, developed by Thomas Saaty in 1980 to solve multi-criteria decision problems. It is based on three principles; decomposition, comparative judgment and synthesis of priorities (Malczewski, 1999).

In AHP process, a decision-maker firstly decomposes the decision problem into the hierarchical structure typically consisting of three levels. The goal of the decision is at the top level, the second level consists of the criteria and alternatives are located in the third level. Then, a simple pair wise comparison is made to develop the overall weights of criteria for decision making. Finally, the priority of alternatives is ranked according to the overall scores, which can be synthesized by considering the weights and values of criteria for each alternative.

In AHP the first step is decomposition, which is called design of hierarchies; in this stage a complex decision problem is decomposed into a hierarchy with each level consisting of a few manageable elements by group discussion and group judgment. In the second step which is weight derivation, relative weights of decision elements are derived at each level by carrying out pair wise comparisons for all the elements in each level. The final stage is synthesis level. The overall priorities are ranked for each alternative according to the scores synthesized by weights and values of criteria. A final decision can be made based on the ranks made for each alternative.

When the matrix A shown in Figure 3-4 is normalized, the consistency of the judgment matrix can be determined which is called the consistency ratio (CR) defined as:

$$CR = \frac{CI}{RI} \tag{3.2}$$

where CI symbolizes the consistency index and RI the random index. CI is defined as:

$$CI = \frac{(\lambda \max - n)}{(n-1)} \tag{3.3}$$

n	1	2	3	…	m
1	1			Reciprocal values	
2		1			
3			1		
…				1	
m	Judgements values				1

Figure 3-4 Matrix A

Where n is the number of items being compared, λmax the average of the values in matrix. RI is the consistency index of a randomly generated reciprocal matrix from the 9-point scale, with forced reciprocals (Bottero and Pelia 2005). Saaty (1990) provided average consistencies (RI values) of randomly generated matrices (up to 11 × 11 size) for a sample size of 500. In general, a consistency ratio of 10 % or less is considered acceptable. If the value is higher, the judgments are not reliable and have to be formed again.

Two features of the AHP differ from the other decision-making approaches. One is its ability to handle both tangible and intangible attributes. The other is its ability to test the consistency according to results of decision maker's preferences (Roper-lowe and Sharp, 1990).

It is a quantitative comparison method used to select the optimal alternative by comparing project alternatives based on their relative performance on the criteria of interest after accounting for the decision-maker's relative preference or weighting of these criteria. AHP wholly aggregates various facets of the decision problem into a single objective function. The goal is to select the alternative that results in the greatest value of the objective function. AHP is a compensatory optimization approach (Saaty, 1990).

AHP uses a quantitative comparison method that is based on pair-wise comparisons of decision criteria, rather than utility and weighting functions. Accordingly, it compares the decision elements as to the dominance of one element over another for each of n elements with respect to an element on the next higher level using a 1-9 scale (Table 3-1) (Pomerol, 2000).

Table 3-1 Saaty's fundamental scale

Value	Definition	Explanation
1	Equally important	Two decision elements equally influence the parent decision element
3	Moderately more important	One decision element is moderately more influential than the other
5	Much more important	One decision element has more influence than the other
7	Very much more important	One decision element has significantly more influence over the other
9	Extremely more important	The difference between influences of the two decision elements is extremely significant
2, 4, 6, 8	Intermediate judgment values	Judgment values between equally, moderately, much, very much and extremely

All individual criteria must be paired against all others and the results compiled in matrix form. If the first criterion is strongly more important compared to the second criterion (i.e. a value of 4), then the second criterion has a value of 1/4 compared to the first criterion. Thus for each comparative score provided, the shared score is awarded to the opposite relationship. The normalized weight is calculated for each criterion using the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria. The AHP technique thus relies on the assumption that humans are more capable of making relative judgments than absolute judgments.

3.2.3. Ordered Weighted Averaging (OWA)

Ordered Weighted Averaging (OWA) method was first introduced by Yager (1988). The main difference of this method is to provide a method for aggregating multiple inputs that lie between the max and min operators. As the term "ordered" implies, the OWA operator pursues a nonlinear aggregation of objects considered. In the short time since the first appearance, the OWA method has been used in an amazingly wide range of applications in lots of operational fields. (Byeong, 2006)

OWA decision rule is illustrated by a set of order weights in addition to the importance weights. With the help of OWA method, the standardized criterion values a_{ij} are multiplied with the corresponding importance weights w_j Thus,

$$b_{ik} = w_j \times a_{ij} \tag{3.4}$$

Which denote the weighted criterion values for alternative *i*, but they are re-ordered so that $b_{i1} > \ldots > b_{in}$. Result evaluation scores are calculated as the sum of the re-ordered standardized criterion values with an additional weighting of the positions. The score of alternative *i* is

$$s_i = \sum v_k \times b_{ik} \tag{3.5}$$

Where v_k is the order weight for the k-th position in the re-ordered of sequence weighted criterion values (Malczewski 1999). The order weights are used to emphasize the better or the poorer properties of each decision alternative. The set of order weights is a parameter that determines an instance of the OWA operator. On the one hand, order weights (1, 0, …, 0) will give full weight to the best criterion outcome of each alternative, independent of how poorly an alternative may perform in some other criteria. Alternatives with a single outstanding property will be ranked highest. This is called an optimistic decision strategy. On the other hand, order weights (0, …, 0, 1) will give full weight to the poorest criterion outcome, independent of how well an alternative performs otherwise. Alternatives with the "least poor" properties will rank highest under this pessimistic decision strategy. Between these two extremes there is a variety of intermediate strategies, the most important of which is the neutral strategy that does not emphasize any position in the re-ordered criterion values. The neutral strategy is achieved by using order weights yields scores that are proportional to those resulting from simple additive weighting.

$$v_k = \frac{1}{n} \text{ for every k from 1 to n} \qquad (3.6)$$

Where v_k is the order weight for the k-th position in the re-ordered of sequence weighted criterion values. Order weights could be defined manually by the user of an application. Yager (1988) suggests a way of calculating the order weights based on a parameter α, which corresponds to the decision strategy defines a set of valid order weights for a given number n of criteria.

$$v_k = (\frac{k}{n})^a - (\frac{(k-1)}{n})^a \qquad (3.7)$$

The α parameter allows a mapping of labels on a qualitative scale to order weights. As it was discussed, MCDA is a quantitative approach for evaluating decision problems that involve multiple criteria. The choice of the MCDA decision rule is very crucial step since it has a significant effect on the final probability distribution map. MCDA characteristics and properties should be compatible with the specific nature of the decision problem (Malczewski, 1999).

In order to get appropriate layers, the first step is the standardization of layers. It is important to get comparable units. The next step is weighting criteria incorporation of expert preferences, this step is typically carried out by means of relative importance weights. The last step is aggregating layers according to a specific function. According to a given decision rule, weighted criterion layers are combined. (Figure 3-5)

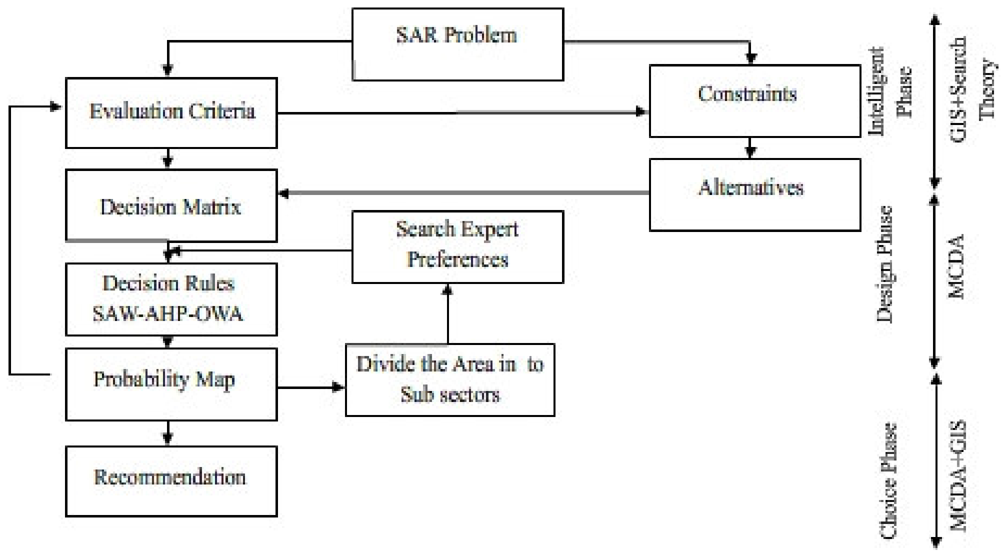


Figure 3-5 Decision flowchart for MCDA of Malczewski (1999) adapted for SAR operations

At the end, scores for all input objects in these three MCDA methods were set up to indicate probability map. The higher MCDA values therefore indicate areas of higher probability. This map could then be used to divide the search area into sub sectors. This step should be done by a search expert.

3.3. Classification of probability map

Two striking features of the MCDA analysis results are remarkable: the output probability maps for every decision rule are numerically and spatially continuous, which means that it has to be classified subjectively in order to help decision making. Classification of the resultant probability map provides for search expert easy understanding of outcomes.

In this step, it is also important to determine the number of classes. Less number of classes generates non interpretable results hence differentiating the probability map into sub sectors is difficult, on the other hand higher number of classes creates continual results that are not interpretable. Resulting probability maps contain many details. Therefore it is important to reclassify these results to more understandable formats. The suitable number of classes is tested for each MCDA decision methods.

3.4. Determining a suitable Search Pattern

The details of five search patterns are explained in Section (1). For each of the five patterns sweep width is determined from the NSAR manual. After deciding the search area, search patterns are tested on the base grid drawn by SAR tool. Parallel Track, Creeping Line and Expanding Square searches are used grid searching. Grid searching for the target via aircraft is the primary technique in aeronautical Search and rescue operations (O'Conor, 2004). On the other hand Sector Search Pattern handles the area as a circle. It calculates the radius of the determined search area.

CHAPTER 4

SOFTWARE DESIGN AND DEVELOPMENT

4.1. Introduction

The basic aim of this computer program is to integrate Search theory with GIS through MCDA to be used in Aeronautical Search and Rescue (ASAR) planning process. In order to do this, the program must provide to the ASAR Planners interpretable information, but not make the decision for them.

In order to meet described purpose above, the computer program had to be designed as a tool that would allow SAR planners to prioritize different criteria and view the results. Furthermore, it had to have the ability to separate the search area into the sectors by the classification module, which would let SAR planners to compare and discuss dissimilar results according to the different classification decisions. This tool also let the SAR planners to compare different search patterns with their efficiency considering their SAR time.

One of the objectives of this study is testing the search pattern efficiency in aeronautical search and rescue cases. In order to test search pattern efficiency, previous steps of the search planning process should be assessed correctly to coordinate various aspects of the search operation. As a result, developed implementation has to perform some basic objectives of the search planning steps.

4.2. Requirements

The GIS based system is compulsory for Aeronautical SAR planning process to handle both vector and raster grid based data well. It should have an easy user interface; one that allows the designer free control on what functions and tools the user has access too. The system should also function well on a personal computer and not require a large amount of disk space or computing power.

A concluding requirement of the system is that it must be easily modifiable and updateable. This is important since the SAR planning process is racing against the time.

4.3. Development Environment

ESRI's product ARCGIS which is the most popular GIS program, provides extending the capability of program by using computer programming languages like Visual Basic (Web 4). ArcGIS Desktop products give the ability to the user to develop their own tools. In this thesis a GIS based tool is coded in the form of Dynamic Link Library (DLL) with ArcGIS 9.1, Visual Basic 6.0 and ArcObjects.

ArcObjects is a desktop GIS application which represents user friendly interfaces and components to work with GIS functionality. The use of ArcObjects provides a comprehensive set of components to embed GIS functionality for the SAR applications. ARC Objects Interfaces are used in the implementation. The implementation of the software part is divided into three parts:

- MCDA based Probability mapping module
- POA segment module
- Search pattern comparison module

4.4. MCDA-based Probability mapping

Determining the area to be searched and where to start a search operation is the basic question of the search operations. Starting a search from the high probability areas, which the subject is in, decreases the search time. Probability maps are determined based on a number of features, to perform the reliable probability mapping. This tool provides the search expert to test three different multi criteria decision analysis methods described in Chapter 2. With the help of this tool, search expert determines the search area according to base probability distribution on the map. Figure 4-1 and Figure 4-2 represent the results of this process.

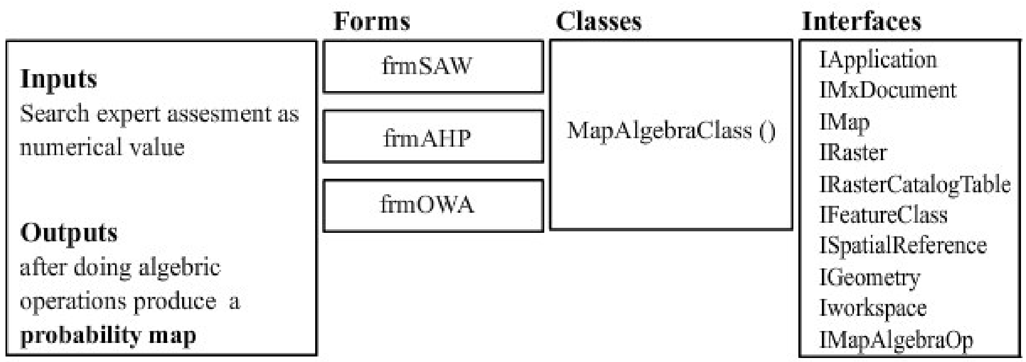


Figure 4-1 MCDA based probability mapping module

MCDA based Probability mapping (Figure 4-1) module uses raster, geometry and map algebra interfaces. *MapAlgebraClass* calculates inputs from the search expert and produce a probability map. MapAlgebraClass uses IRaster interface to prepare raster layers for the necessary algebraic calculations.

For each of MCDA methods, program compares search expert assessment on the layer-based and produce probability map. Detailed documentation is given in Appendix B.2.

4.5. Probability of Area (POA) based segmenting

Once the probability map of the area has been defined by the software based on the MCDA methods considering the individual judgments of the search expert, the next step is to divide the area into segments in order to determine where the search starts. The tool makes this operation by classifying the probability map with the help of GIS. The tool also gives the ability to search expert to determine the number of classes according to the case. It gives the ability to search planner POA based segmenting the area. Search expert can divide area to sub search areas (Figure 4-2).

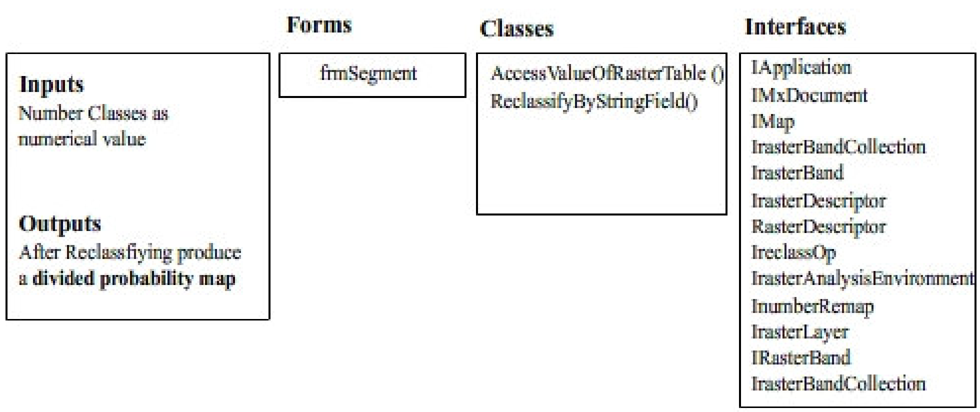


Figure 4-2 POA segment module

POA segment module (Figure 4-2) uses *AccessValueOfRasterTable()* and *ReclassifyByStringField()* classes in order to divide produced probability map into sub areas visually. *AccessValueOfRasterTable* reaches pixel value of raster layers. *ReclassifyByStringField()* remaps old pixel value of raster layer to user defined values. Search expert determines the number classes to produce sub sectors from the probability map. Detailed documentation is given in Appendix B.3.

4.6. Search pattern comparison

One of the objectives of this thesis is to test the performance of the search patterns, and offer the most suitable search pattern for air search and rescue cases. After dividing area to the segments according to their probabilities, with the help of ARCGIS's rectangle tool, the area to be scanned by the aircraft is chosen. The next step is determining the sweep width by considering the search factor. A search factor is a variable that is changing according to the features of the terrain. Finally, the tool compares search patterns according their speed and how quick to sweep the search area.

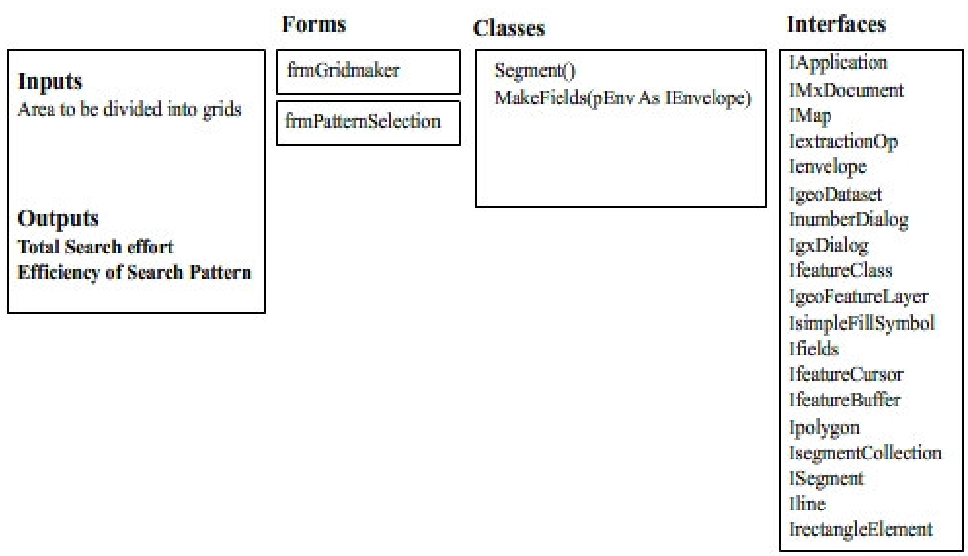
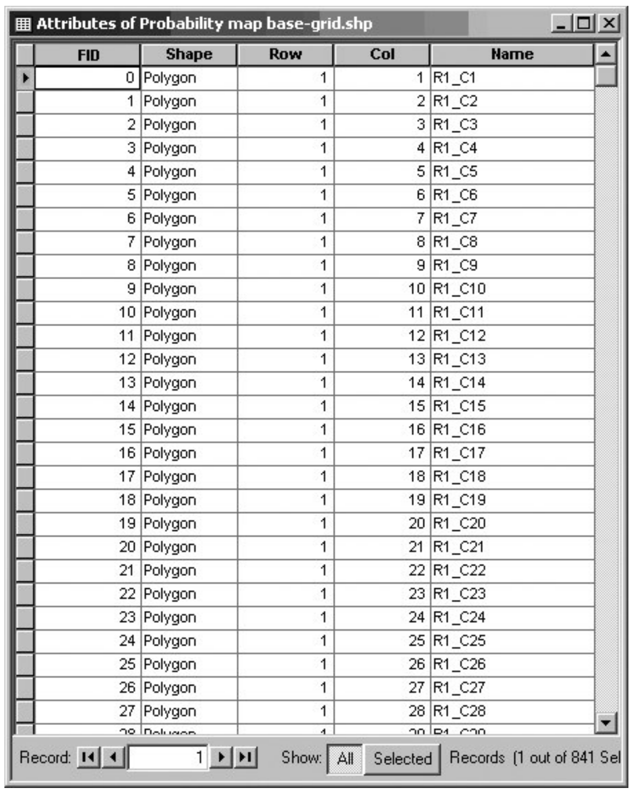


Figure 4-3 Search pattern comparison module

Search pattern comparison module has two different functions. First function uses *Segment()* classes in order to divide the area into grids. frmGridmaker form get sweep width and a search factor as input to generate a grid. *frmPAtternSelection* form read output of the *frmGridmaker* form to evaluate the value of search effort for each Search Pattern. Detailed documentation of used functions is given in Appendix B.4

Figure 4-4 shows the attribute table of the resulted grid shape file. Dimension of the grid is determined by the search expert considering the sweep width and search factor.



FID	Shape	Row	Col	Name
0	Polygon	1	1	R1_C1
1	Polygon	1	2	R1_C2
2	Polygon	1	3	R1_C3
3	Polygon	1	4	R1_C4
4	Polygon	1	5	R1_C5
5	Polygon	1	6	R1_C6
6	Polygon	1	7	R1_C7
7	Polygon	1	8	R1_C8
8	Polygon	1	9	R1_C9
9	Polygon	1	10	R1_C10
10	Polygon	1	11	R1_C11
11	Polygon	1	12	R1_C12
12	Polygon	1	13	R1_C13
13	Polygon	1	14	R1_C14
14	Polygon	1	15	R1_C15
15	Polygon	1	16	R1_C16
16	Polygon	1	17	R1_C17
17	Polygon	1	18	R1_C18
18	Polygon	1	19	R1_C19
19	Polygon	1	20	R1_C20
20	Polygon	1	21	R1_C21
21	Polygon	1	22	R1_C22
22	Polygon	1	23	R1_C23
23	Polygon	1	24	R1_C24
24	Polygon	1	25	R1_C25
25	Polygon	1	26	R1_C26
26	Polygon	1	27	R1_C27
27	Polygon	1	28	R1_C28

Figure 4-4 Attribute table of Probability map grid

Search expert can select a specific cell from the produced grid (Figure 4-5). Also, tool provides two distinct grid shapes in two different shape file formats (Figure 4-6).

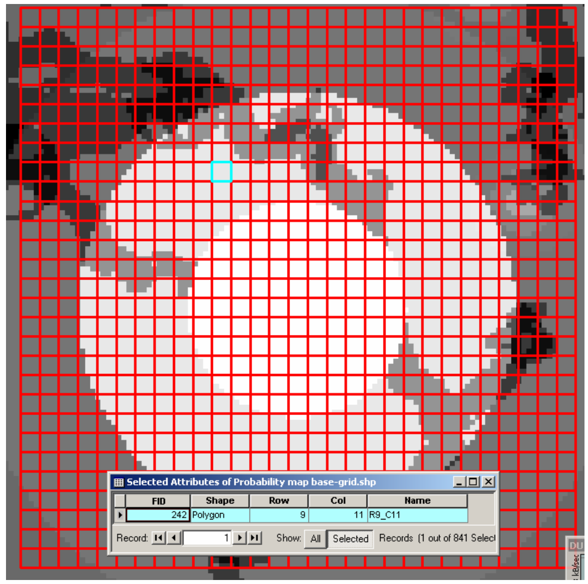


Figure 4-5 Relation between selected cell and whole probability map

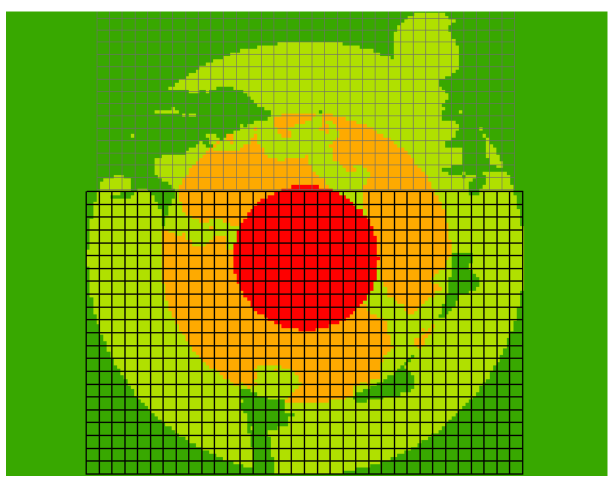


Figure 4-6 According to POA search area can be divided into sub sectors.

4.7. User Interface

The most critical factor in the user interface is its ease of use and simplicity. For ease of use, the focus of the user interface becomes to develop a new Graphical User Interface (GUI). A GUI is a class of windows that interface between the user and the underlying program (Burke 2003). The user interface is developed through Visual Basic 6.0. Main menu is shown in Figure 4-7, with three main modules, namely MCDA methods, Classify area and select search pattern.

Figure 4-7 Main menu of the METUSAR Tool.

Each GUI have unique pull down menus, pop up menus, buttons and a toolbar. In ArcGIS, each of the basic system classes (Views, tables, layouts) has their own GUI. The development of a new GUI allowed the user to leave the complete ArcGIS capability with the original GUIs (Web 4).

4.8. Modules of the tool

The tool contains three main modules. First module is a MCDA module (Figure 4-8), which gives the chance to the SAR planner applying three MCDA methods which are Simple Additive Weight (SAW), Ordered Weighted Analysis (OWA) and Analytical Hierarchical Process (AHP) method.

Figure 4-8 MCDA menu view

The second module is Classification module (Figure 4-9) which divides the search area to the small sectors.

Figure 4-9 Classification menu

The last module (Figure 4-10), which is a Search pattern selection module, gives ability to the SAR planners by dividing user-defined search area to the grids and calculating the search time and search effort for the entire search area. This module also gives the chance to compare the different search methods with different inputs.

Figure 4-10 Pattern selection menu

4.8.1. The MCDA Module

The MCDA module, as mentioned before, is opened by selecting the new ranking and rating command under the MCDA methods menu of the Tool (Figure 4-8). This command opens up the three MCDA methods. The MCDA gives the ability to SAR planners to analyze different type of multi criteria decision analysis methods like SAW method, OWA method and AHP method.

The MCDA module components firstly list the data layers in the most upper part of the layers section of the ArcGIS program. It views and collects the entire layer available there and places them in its list.

4.8.1.1 Simple Additive Weighted

The SAW method which is one of the sub menu of the MCDA menu, (Figure 4-11) queries the user to enter data layer ranking and prioritize them. The program correctly cancels to script it, when the user fails to enter at least one data layer and presses the cancel button.

The SAW module next calculates the weights that are to be assigned to each data layer. It does this by first counting the number of data layers selected and calculating the distance that each weight must have from the next weight of a base of one. Finally the weights are normalized so that they add up to one by taking each weight as a percentage of the sum of all the weights.

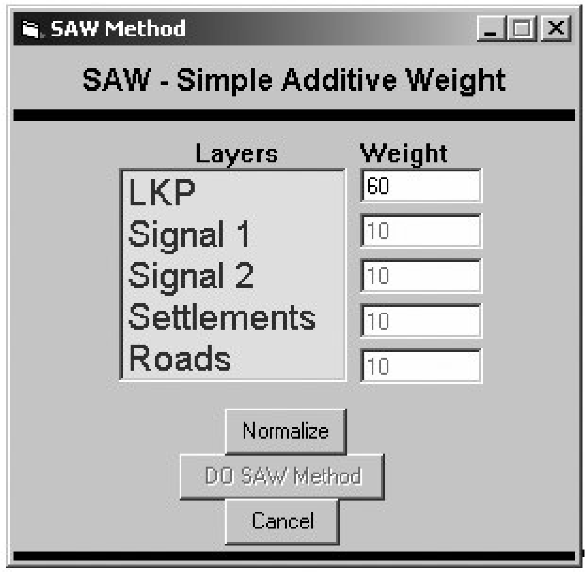


Figure 4-11 Layer available in open application

4.8.1.2 Analytical Hierarchical Process

The MCDA module performs additive overlay process as it is outlined in Chapter 2. Each layer is multiplied by its weight given by the expert of the SAR planning and then all the data layers are added together. This result in a grid has values ranging from zero to hundred and that is the representative of the user's ranking priorities. The program then adds this grid theme to the view with the name of "Grid #". The number of this name will change each time when a new grid is created since the program keeps track of an identity number to differentiate between the output grids.

Firstly program prompts the expert to enter the hierarchy of criteria. Secondly, it asks the decision maker with pairs of criteria from the hierarchy to judge their relative importance for them. It works from the bottom of the hierarchy to upwards rather than from the top down. Hence, expert wants to know how criterion sub-divides before judging it. This process helps to clarify the criterion meaning. After pair wise comparison process is completed, the program controls the consistency ratio of the judgment. If it is under 10 %, it prompts the user and does not give permission to the next step (Figure 4-12).

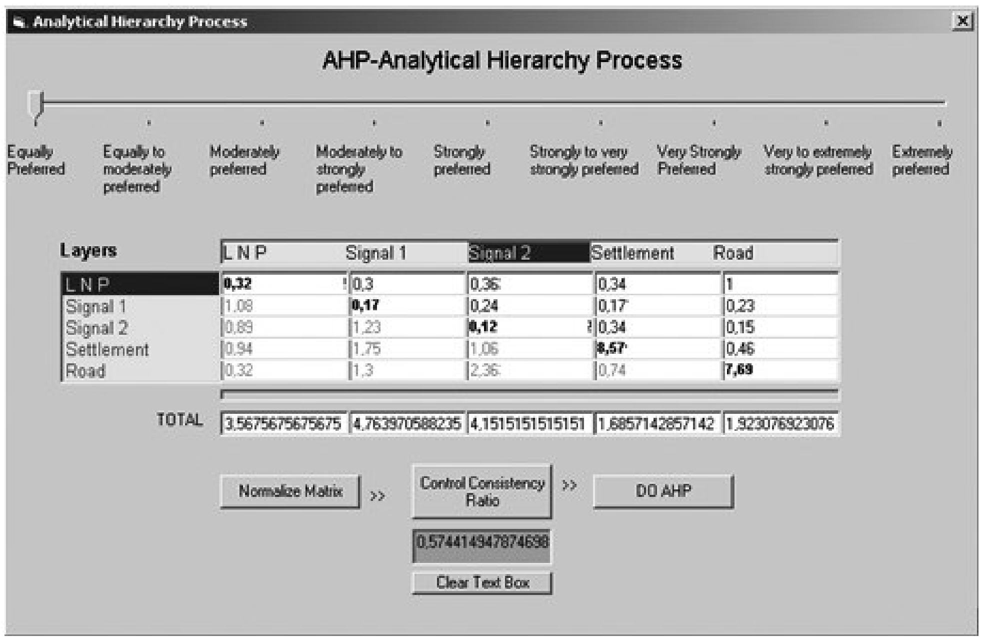


Figure 4-12 AHP form

4.8.1.3 Ordered Weighted Averaging

The last MCDA module, OWA, uses a fuzzy model. Firstly, program needs to rank the layer from the most important to the least important one. Secondly, it prompts the expert to determine the decision strategy: optimistic, moderately optimistic, neutral, moderately pessimistic or pessimistic.

After choosing strategy, the program controls number of layers and it calculates the ratio according to layer numbers (Figure 4-13). Each layer is multiplied by its weight given by the OWA decision rule and then all the data layers are added together.

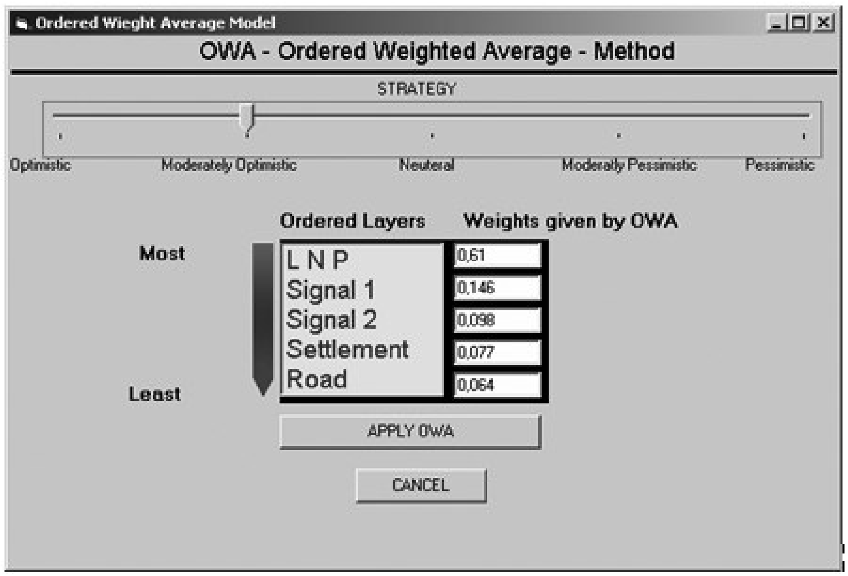


Figure 4-13 OWA form

4.8.2. The Classification Module

The Classification Module is executed by the Classification menu item under the classify area to the sector menu in the tool. This command opens Classification Form which was listed in Appendix B. Like the MCDA module, section the first issue is that the classification module does is to check to see if the top most layer is raster layer or not. If this criterion is not met, then buttons would not be in active mode (Figure 4-14).

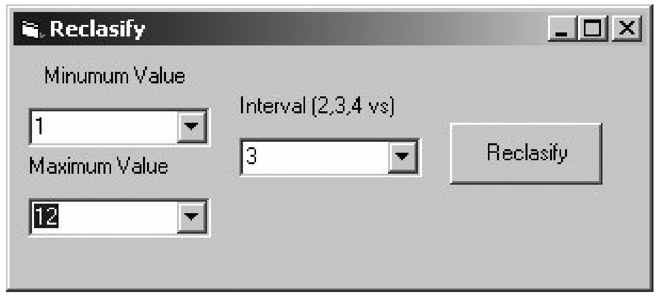


Figure 4-14 Reclassify form

The classification module gives the user the ability to make decision on how many classes of the data and their intervals and their starting and ending point are.

4.8.3. Pattern Comparison Module

This module has two sub menus; first one is grid button which helps to divide the area to the suitable number of grids and second one is pattern comparison tool that compares each of search patterns according to their effectiveness for the case. The effectiveness of a search pattern is determined by the search time of sweeping the area.

This command is under comparison module. After selecting the area by rectangle tool dividing grids, the program prompts the sweep width in kilometers and search factor (Figure 4-15). Then the program calculates number of rows and columns according to width and height of the area. Finally tool divides the area according to user defined grids. User can also change grid dimensions manually.

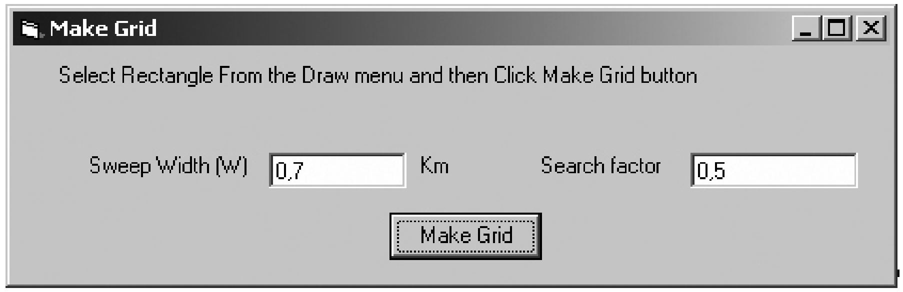


Figure 4-15 Grid making form

The Search Pattern comparison module is executed by the pattern comparison menu item under the Search Pattern menu on the tool. This command opens *FrmPatternComparision* which is listed in Appendix B. Search pattern module compare five different search patterns. The Search Pattern module (Figure 4-16) gives the user the ability to make decision on which pattern is best fit. It controls the effectiveness of the search.

Search speed, sweep width, search factor and height of plane affect the effectiveness of a search operation. These parameters are used as an input for pattern comparison form. Pattern comparison form (*frmPatternComparison*) automatically gets the sweep width from the *frmMakegrid*. Then *frmPatternComparison* form calculates total time for search and calculates effectiveness of the selected search pattern. Lastly with the help of *btnCompare* list the search effort for each search pattern. As it is known that found coordinates of the plane, this module can calculate the time to find the target for parallel track, creeping line and expanding square for this case.

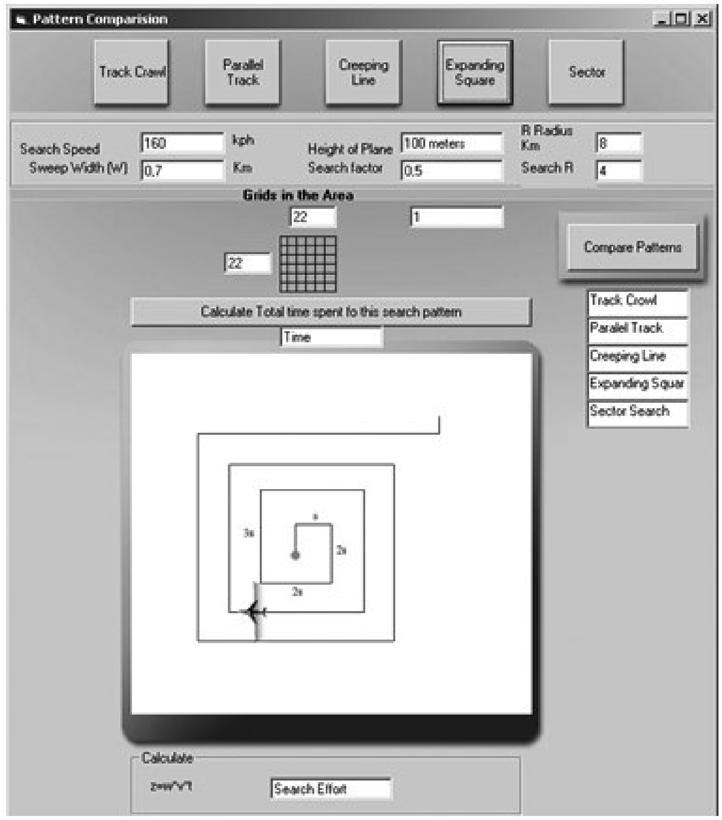


Figure 4-16 Pattern comparison form

In order to provide SAR experts a practical ASAR planning tool MCDA based GIS tool the "METUSAR" is developed, which integrated the GIS analysis and multi criteria evaluation model. The prototype of the program is tested on a real case study, producing conclusive performance assessment results for a particular F-16 plane crash case.

CHAPTER 5

IMPLIMANTATION

5.1. Case Study Area

An F-16 plane crash occurred twenty kilometers south of Kütahya city in Turkey in 16 January of 2004. Although lots of SAR team and civilian attended the search and rescue operation, the wreckage of the plane was found nearly after three days from the crash time which is one of the longest search periods in Turkey. Meteorological conditions were not suitable at that time. However, to test SAR tool, it is accepted that meteorological conditions were suitable for this case study. According to NSAR (1998), if winds are greater than 15 knots and /or visibility is less than 3 nautical miles (nm) but greater than 1 nm, a track spacing of 1 nm should be considered by day or night but reduced depending on the size of the search target.

The case study area is located at the northwest of Kütahya city in Central Anatolia (Figure 5-1). The area is covered by four 1:25.000 scale topographical map quadrangles of I23-d1, I23-d2, I23-d3 and I23-d4. The extents of the study area can be defined as 4405000N, 715000E in the northwest edge and 4337000N, 736000E in the southeast edge in the zone of 35 North of Universal Transverse 3 Mercator projections. The study area is nearly 603 km^2 with dimensions of 21.7 X 27.8 km.

Some parts of the region are mountainous with a number of high hills. Most of the area has dense forest and was covered by snow at the time of crash. The size of the possible search area, steep slopes and changing topography did not give chance for searching the area from the ground. Therefore, starting the search from the air was a solution for this case.

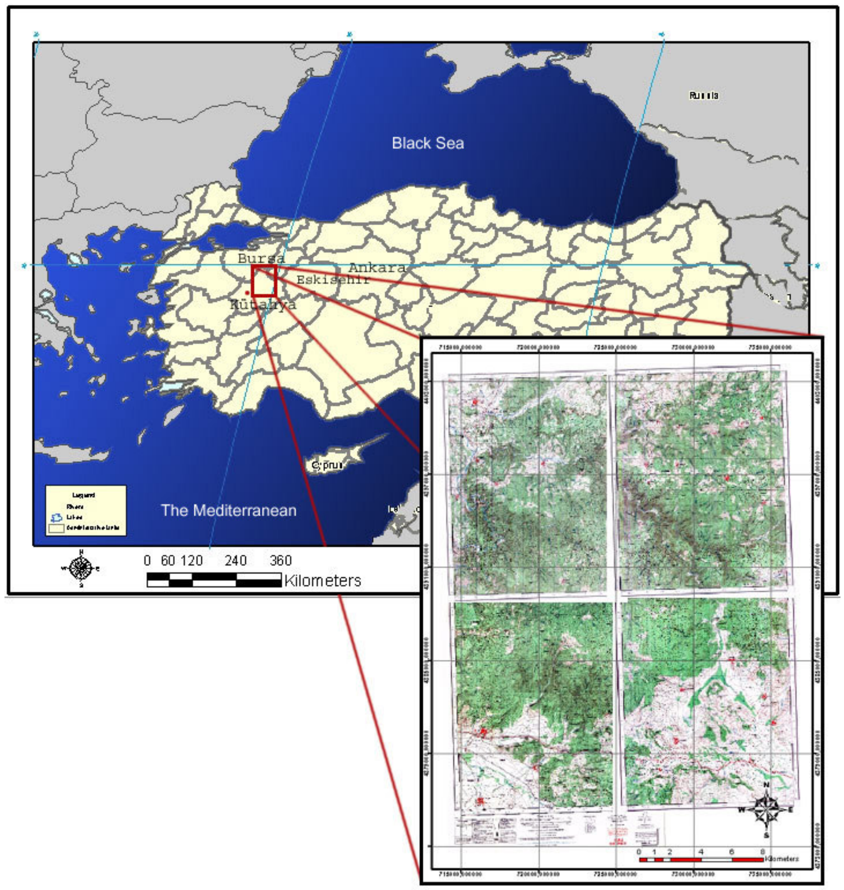


Figure 5-1 Geographical location of the study area

After digitizing the crash area and its near environment, DEM of the area (Figure 5-2) was created. DEM of the area is essential for the visibility analysis steps of the study.

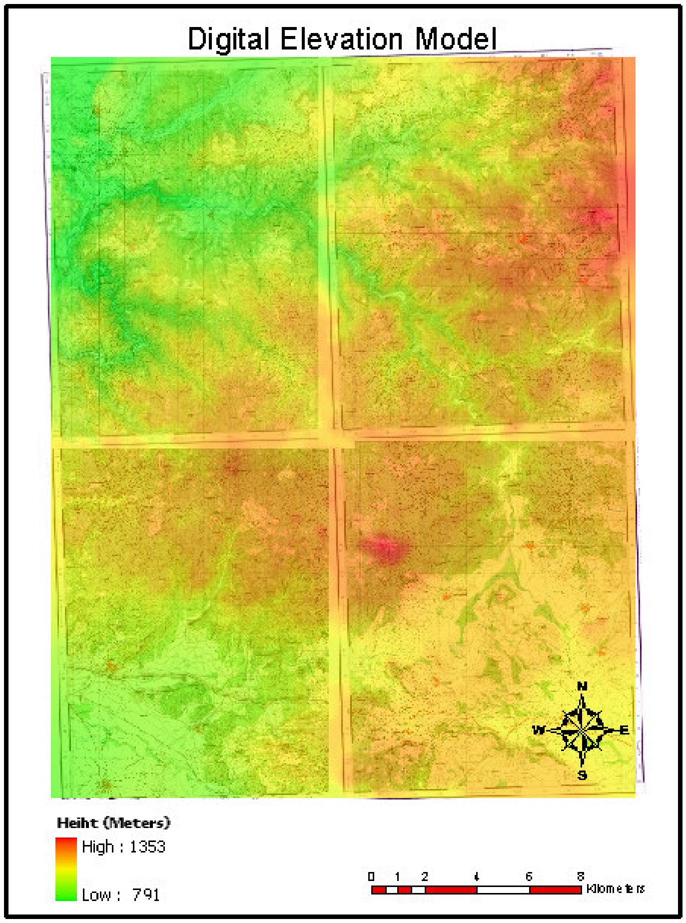


Figure 5-2 Digital elevation Model Layer and Map layer of the area

5.2. Data Collection and Preparing Data Layers

The most important information about the crash is LKP of the target. Also, clues from the reliable sources are important for the creation of a probability map. (Figure 5-3) Data layers used for this case study are described in detail in (Table 5-1). Graphical and non graphical data in Table 5-1 and 5-2 are obtained from the Turkish Air Forces (TAF). The dataset includes plane crash information in 2004 in Kütahya.

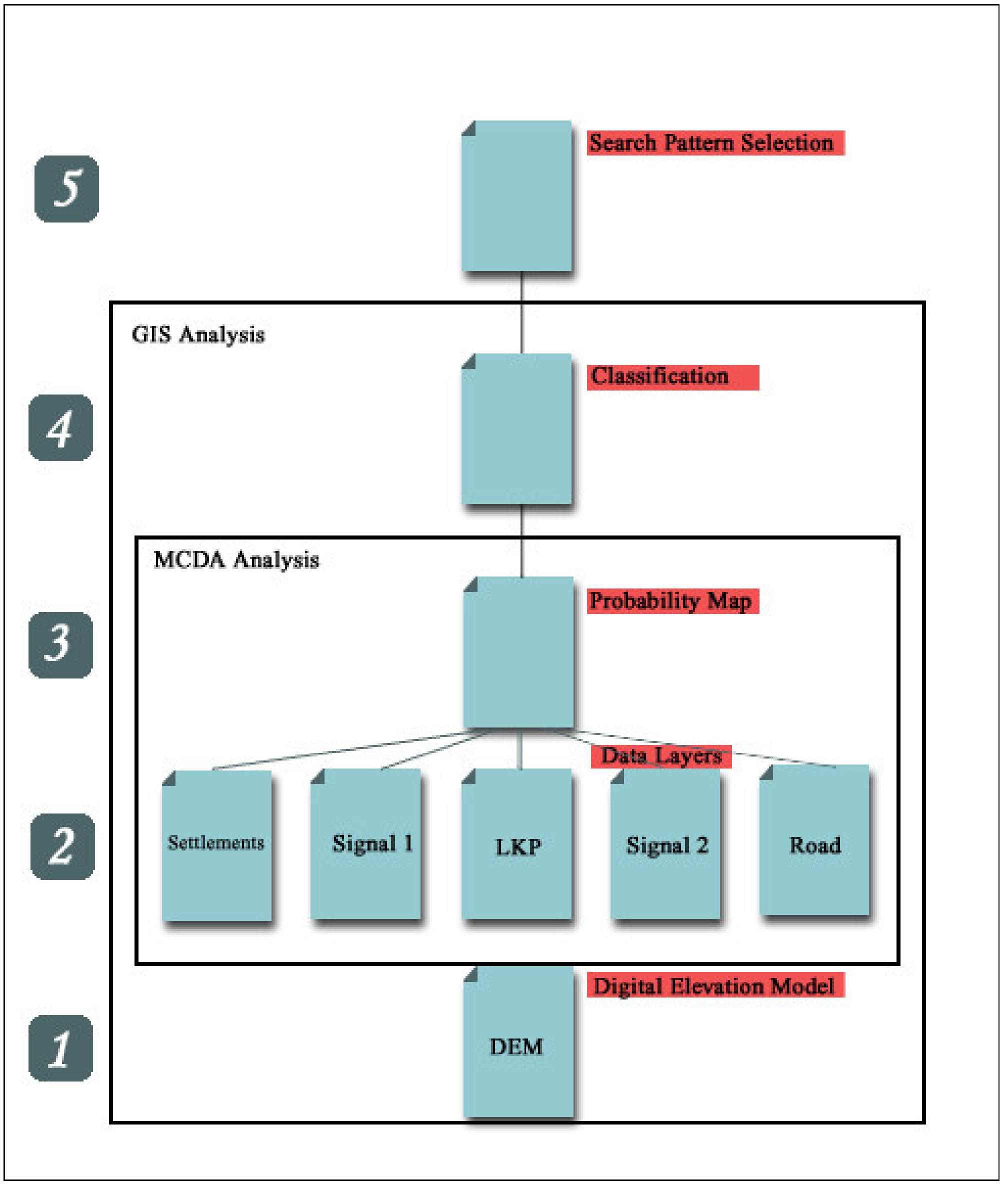


Figure 5-3 Framework of developed methodology

Table 5-1 shows the structure of graphical data layers. All data layers are 1/25.000 scale that enables accurate results to the SAR experts. Coordinates of each data layer are provided from TAF and put into a map.

Table 5-1 Structure of graphical data layers

Layer Name	Data	Scale	Type	Format	Source
DEM	Digital elevation model	1/2500	Grid	Digitized from the map	Turkish Air Forces
LKP	Last Coordinate of the plane	1/25000	Point	Shape file (*.shp)	Map
Signal 1	Signal form the area	1/25000	Point	Shape file (*.shp)	Map
Signal 2	Signal From the area	1/25000	Point	Shape file (*.shp)	Map
Settlements	Villages	1/25000	Point	Shape file (*.shp)	Map
Roads	Primary and secondary roads	1/25000	Poly line	Shape file (*.shp)	Map

Table 5-2 Structure of non-graphical data layers

Data	Format	Source	Content
LKP	Coordinate data	Turkish Air Forces	Last known coordinates of the plane
Signal 1	Coordinate data	Turkish Air Forces	Signal got from the CN-235 plane from 243.00 MHZ
Signal 2	Coordinate data	Turkish Air Forces	Signal got from the CN-235 plane from 282.00 MHZ
Wreckage of Plane	Coordinate data	Turkish Air Forces	Coordinate of the wreckage of the plane after the crash
Height of Plane	Number	Turkish Air Forces	Probable height of the plane before the crash

The LKP coordinate information of the plane was reported as 39.39.652 N and 29.35.376 E, height of the plane before the crash was reported as nearly 3000 meter (Figure 5-4). According to NSAR (1998), the actual position of the target often has circular normal probability density distribution centered from the reported last known position. In the light of these information and free fall formula, the maximum reach of the plane wreckage was calculated as 6000 meters. (Equation 5.1)

$$Vy = (Vy0 + \frac{m}{k} g e^{-kt}) - \frac{m}{k} g$$

$$y = -\frac{m}{k}\left\{(Vy0 + \frac{m}{k} g)(e^{-kt} - 1) + gt\right\} + y_0 \tag{5.1}$$

$$V_{y0} = \frac{1}{2} g t^2$$

$$x = v_0 t$$

Where ;

Vy: Initial velocity of the plane on the y axis

Vy0: Initial altitude of the plane

g: Gravity acceleration

m: Mass of the object

t: Fall time

x: Range

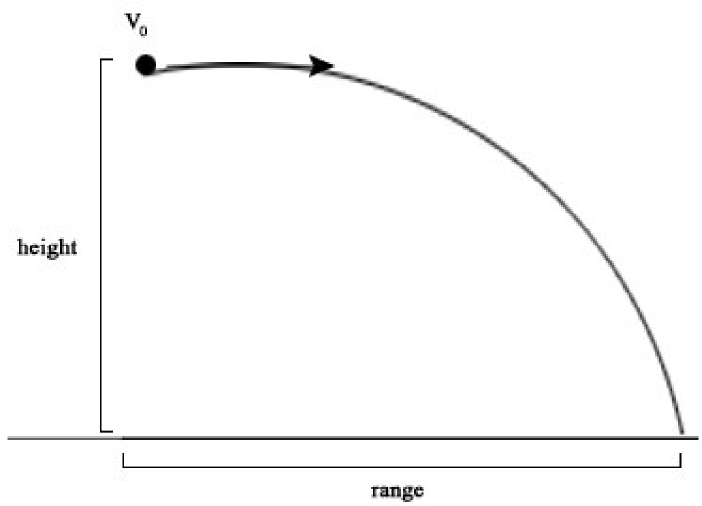


Figure 5-4 Range of the air plane

Statistically, the amount of probability of contained (POC) in a circle drawn from the last known position to reach the plane wreckages distribution is given in Equation 5.2 (Cooper et al., 2003).

$$POC = 1 - e^{R^2/2} \tag{5.2}$$

Where, e is the base for natural logarithm. The probability of containing one standard deviation of the mean is about 68 %, two standard deviation of the mean is 27 %, three standard deviation of the mean is 4 % and the remaining part of the area is accepted as 1 % (Figure 5-5).

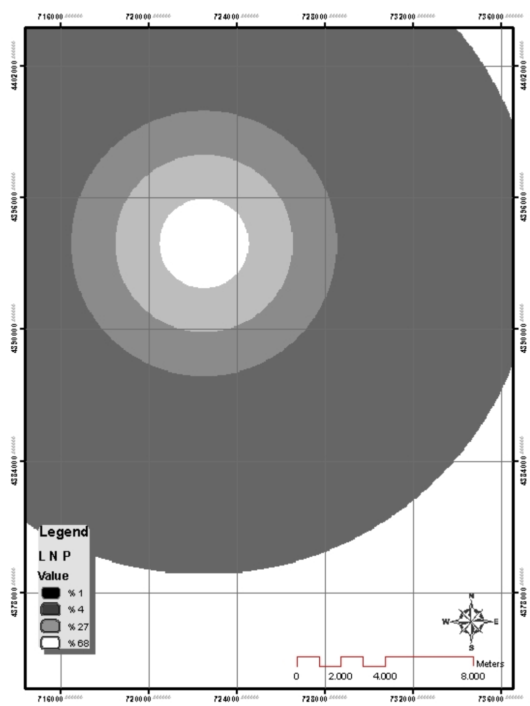


Figure 5-5 Areas with certain probabilities around last known position

5.2.1. Signal Points

After the crash and before finding the wreckage of the plane, some signals and words of witnesses were reported to the search planning center. One of the dense signals was reported from the CN-23 aircraft from 243 MHZ (39.43 N and 29.38 E) (Gerede, 2007).

The other point of signal was again reported from the CN-23 Aircraft from the channel 8 and 282.8 MHZ. Considering all the suggested safe distances in the NSAR (1998) and expert suggestion, minimum distances for the signal points are determined as 5 km from the centers. These distances are used to create buffer zones around signal points and included to the study area (Figure 5-6).

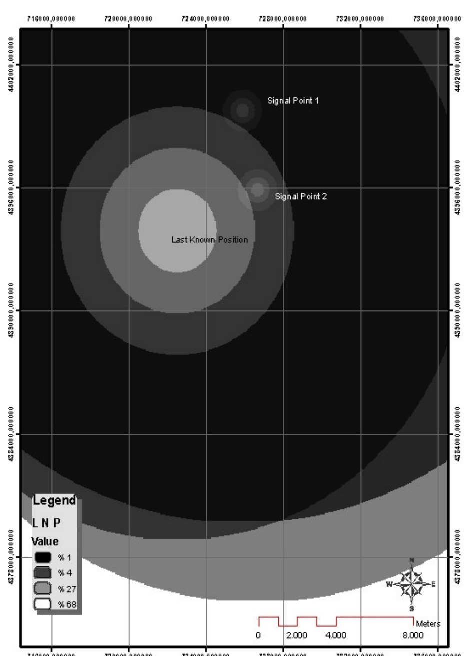


Figure 5-6 Location of signal points

5.2.2. Settlement Layer

After digitizing all the settlements in the area, visibility analysis was made from the center of the each settlement. Considering all the suggested safe distances in the NSAR (1998), minimum distances for the study area are determined as 5 km for settlements. These distances are used to create buffer zones around settlement areas and excluded from the study area.

The next step is intersecting the visibility of the sight of the settlements and buffers from their centers. It is assumed that, if the wreckage of the plane is in the buffer zones within 5 km radius from the center of settlements, it is already seen by the people living in the settlements over there. Therefore; black areas should not be searched by the search team shown in Figure 5-8. Also, height of the visibility is tested aside from formal human height. It gives much large areas effecting probability map. Therefore, formal human height is used for visibility map creation.

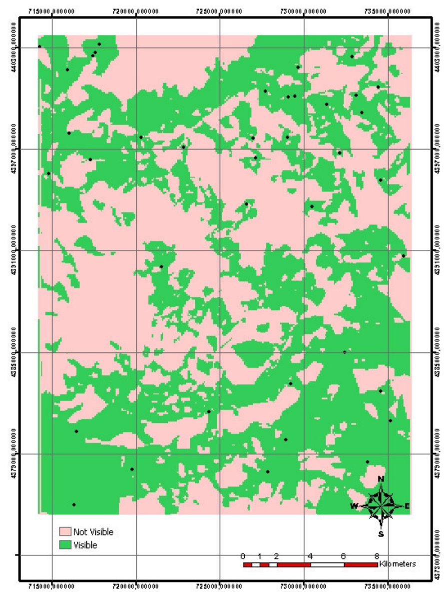


Figure 5-7 Visibility of Settlement layer of the study area

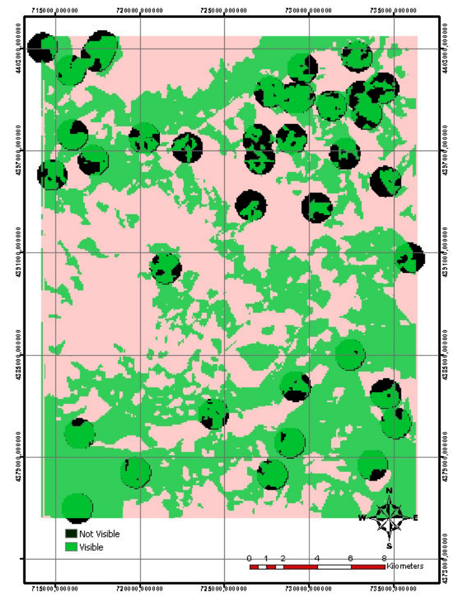


Figure 5-8 Intersection of visibility map and settlement buffers

5.2.3. Roads Layer

The same process is repeated for the road layer which is digitized from the 1:25.000 scaled topographical maps. As in the case of settlement areas, it is intersected with the visibility layer. The buffer zone from the roads is accepted as 100 meters, since it is accepted that if the wreckage of lost F-16 is in the buffer zone of the roads, it could be seen by the people passing over there. (Figure 5-9)

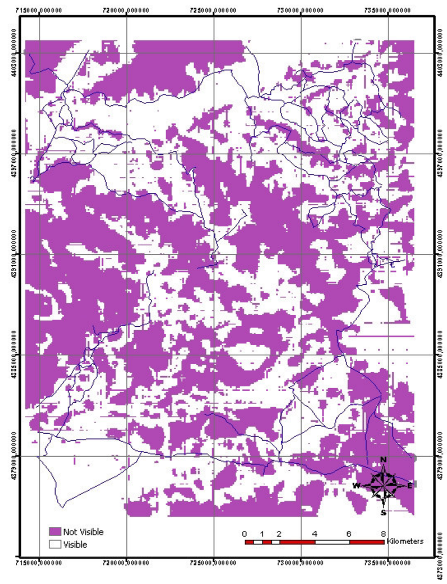


Figure 5-9 Visibility map from the view of roads

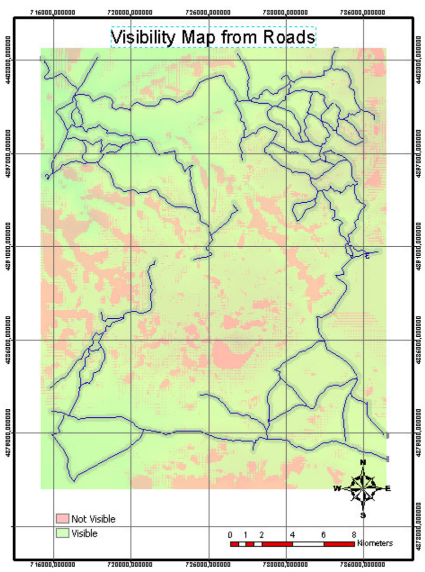


Figure 5-10 Intersection of visibility map and road buffers

5.3. Construction of Probability Maps based on MCDA

The most important part of this search operation is having a consistent probability map. Ranking the layers according to their importance and rating them was done by search expert from the Turkish Air Forces, Major Ali Gerede. Three different MCDA methods were tested while producing probability map.

5.3.1. Simple Additive Weight (SAW)

Weights given by the expert is showed in Table 5-3. The highest score is given to last known position of the plane.

Table 5-3 SAW ranking

Layers	Weights
Last Known Position	0.6
Signal 1	0.1
Signal 2	0.1
Visible range of roads	0.1
Visible range of villages	0.1

The tool normalizes the values given by experts and according to the values; the first probability map of the area is created (Figure 5-11). As expected center of the produced probability map according to SAW decision rule (Figure 5-11) contains higher probability area hence search expert gives 60 % of the weight to LKP. Also signal points are easily distinguished from the environment of them. The lowest probabilities are shown in the centers of settlement areas. Probabilities in the area are between 0.0019 and 0.0996. According to result of this decision rule the center of the area in white color and three outer circles contains 32 % of the total probability.

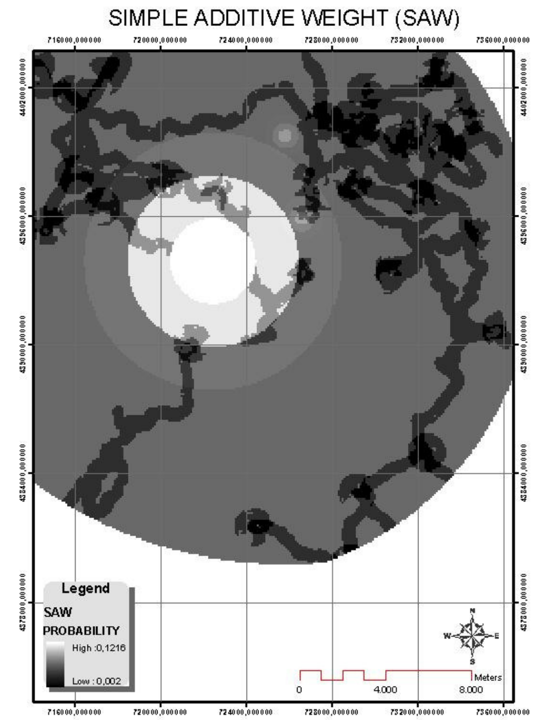


Figure 5-11 Probability map produced with SAW method

5.3.2. Analytic Hierarchy Process (AHP)

Difference of the AHP method is based on pair wise comparison. With the help of this tool every layer of the study can be seen in a matrix and the expert compared them for producing probability map (Table 5-4). Probability map according to the result of AHP decision rule is shown in Figure 5-12. Probabilities in the area are between 0.0017 and 0.106. According to the result of this decision rule, the center of the area in white color and three outer circles contain 36 % of the total probability.

Table 5-4 AHP method criteria

Preference	Value
Equally	1
Equally to moderately	2
Moderately	3
Moderately to strongly	4
Strongly to very strongly	5
Very strongly	6
Very extremely strongly	7
Extremely	8

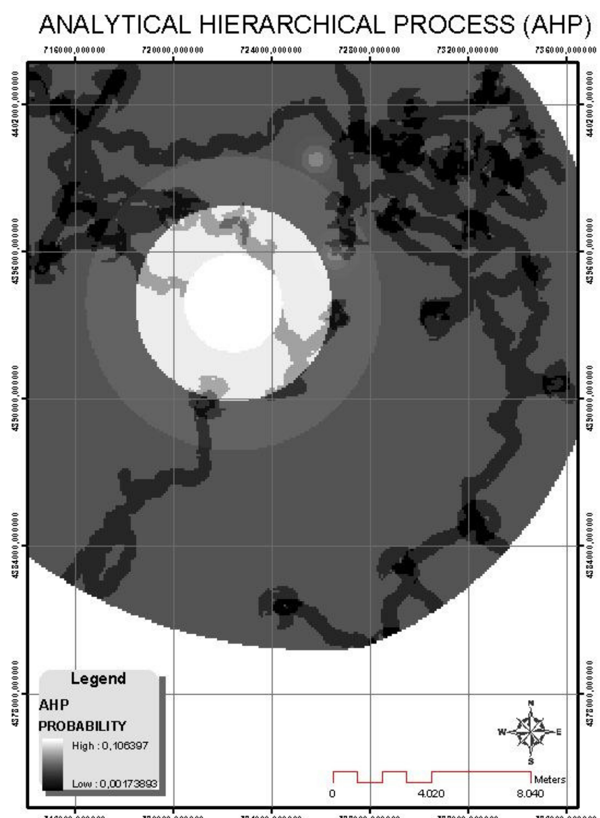


Figure 5-12 Probability map produced from the AHP method

According to values in Table 5-4 the tool produced the probability map in Figure 5-12

5.3.3. Ordered Weighted Averaging (OWA)

OWA decision rule determines weights according to list of layers and number of layers. Expert can make an order from the most preferable to a least preferable layer. The values of OWA are shown in Table 5-5:

Table 5-5 Preferences of Search Expert according to OWA method

Layers	Weights	Strategy	Order
LKP	0.61	Moderately Optimistic	1 Most Preferable
Signal 1	0.146		2 …
Signal 2	0.098		3
Visible range of roads	0.077		4
Visible range of villages	0.064		5 Least Preferable

According to values in Table 5-5 the tool produced the probability map as shown in Figure 5-13. Probabilities of founding wreckage of the plane in the area for one cell are between 0.0019 and 0.108. According to the result of this decision rule, the center of the area in white color and three outer circles contains 36 % of the total probability. The rest of the area contains 64 % of total the probability. On the other hand, road and settlements buffers in black contain lesser probabilities.

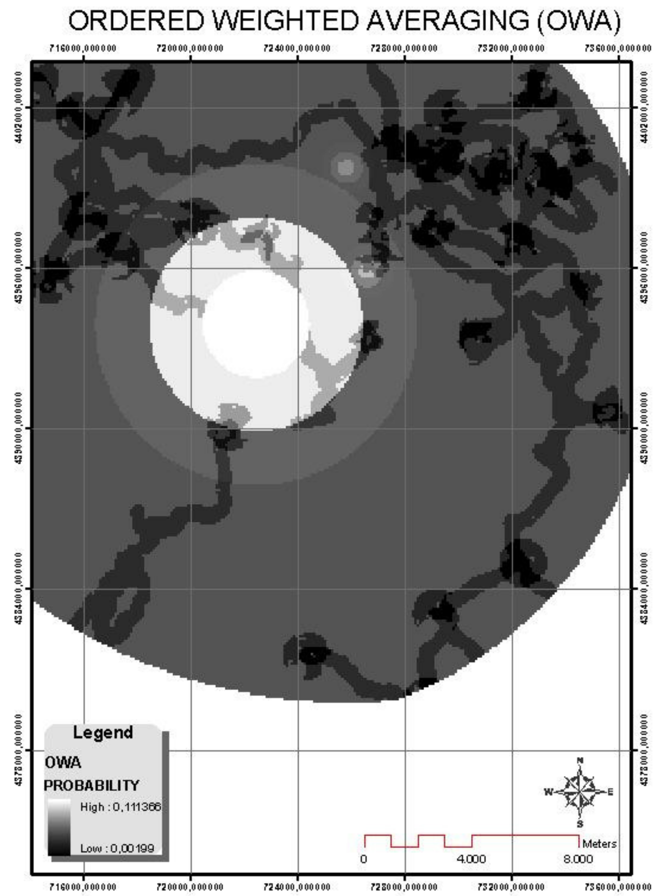


Figure 5-13 Probability map produced from the OWA method

Although the results of three methods gave visually the same pattern, there are some distinctions among them. The resultant probability maps according to three methods of MCDA show that the SAW method gives the maximum probability (between 0.1216 and 0.002) the second method OWA (between 0.11136 and 0.00199) and the third AHP method between (0.106397 and 0.001738). Total probability in the center of the circles of SAW method is higher, as search expert gave the maximum weight to LKP (60 %). Similarly, OWA method calculates the weight according to order and number of layers it gives the (61 %) weight to the LKP. Lastly, AHP method gives less weight according to these methods. After applying three different MCDA methods on the case, expert started classification each production with different classification intervals.

5.4. Reclassification of the Probability map

Reclassification of the area gives ability to divide the area according to classified segments. Expert examined different classification intervals for every probability maps produced from the MCDA methods. Firstly, the probability map was produced from the SAW method and was classified with different values.

The aim of this procedure is testing different classification intervals for probability maps. Resulted probability maps were classified into three, four, five, six, seven, eight and nine intervals. Used classification method is natural breaks, and then the last classes are widened manually to encompass the entire lower half of the ranked values. Also, the upper classes are restricted to the highest ranking value.

Effects of classification determining the sub search areas are a critical question. Taking into consideration each decision rule results, each decision rule is classified into 3, 4, 5, 6, 7, 8 and 9 plots intervals. Every decision rule gives different pattern and these patterns provide detailed and reliable information for the expert to divide the search area into search sectors.

5.4.1. Reclassification According to Result of SAW

Figure 5-14 shows the case when the area is classified into 3 classes which form a preference scale with three degrees of decreasing probability. The center of the circle colored by red has the maximum probability. Yellow areas have contained minimum probability. The weakness of this figure is the second maximum probability area covers almost the whole area (72 %). Therefore using Figure 5-14 would not give an optimal solution.

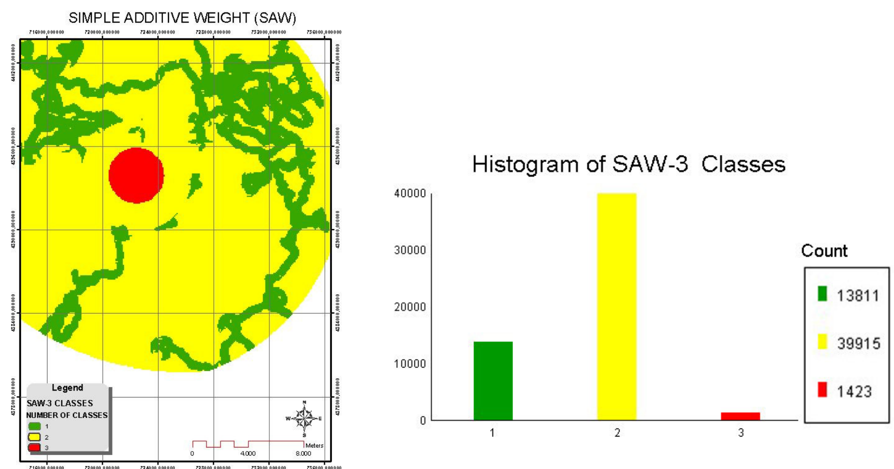


Figure 5-14 SAW classification with 3 classes

Figure 5-15 shows the case when the area is classified into 4 classes. It covers much more area in the center of the circle than Figure 5-13. Thus the effectiveness of this classification is better. Also, road weights decrease the probability of the center area in red color. However, signal points can not be discriminated from this classification. Since used classification method is natural breaks, the second plot in the histogram of Figure 5-15 resulted as 0.

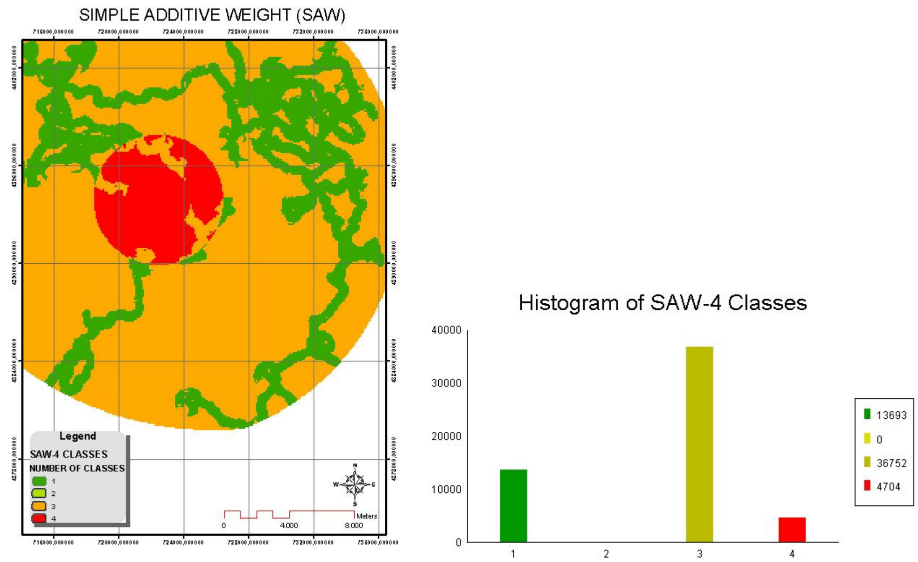


Figure 5-15 SAW classification with 4 classes

In Figure 5-15 Probability of Area (POA) is higher than 3 classes. Also a signal point is shown in this figure. Figure 5-16 gives a similar result with Figure 5-15. However, intersection of road and settlement buffers can be discriminated easily.

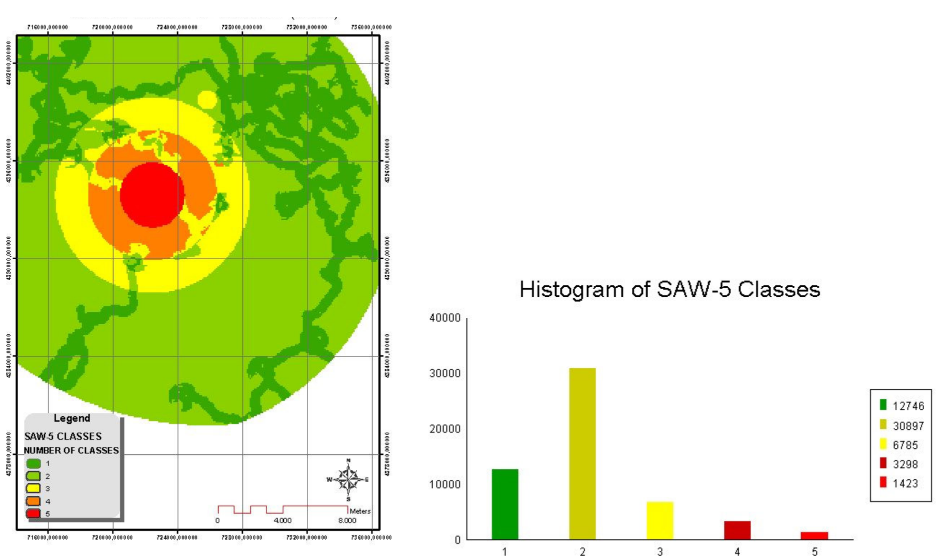


Figure 5-16 SAW classification with 5 classes

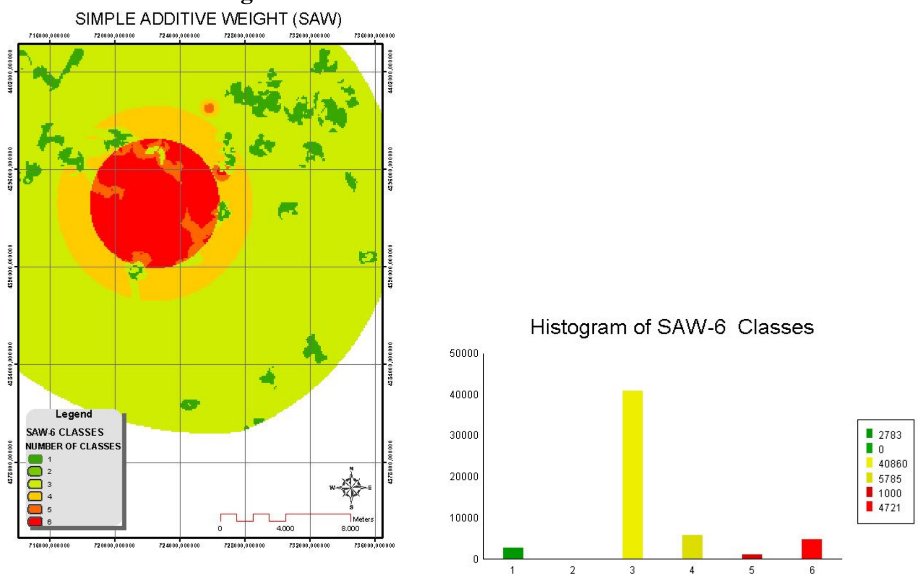


Figure 5-17 SAW classification with 6 classes

Hence, Figure 5-17, 5-18 and 5-19 have nearly equal areas and their effectiveness are nearly the same. However, signal points are not discriminated in Figure 5-18.

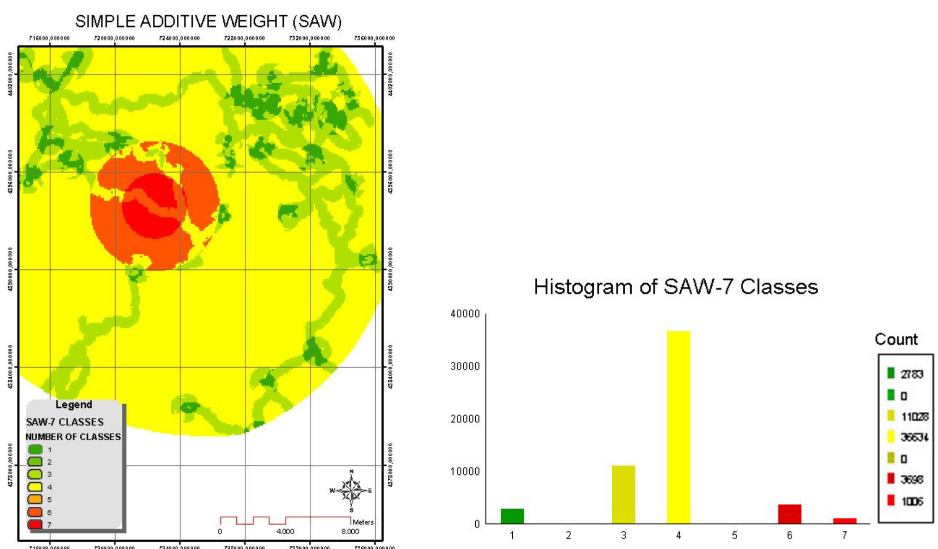


Figure 5-18 SAW classification with 7 classes

Figure 5-19 and Figure 5-20 differentiate the other reclassification figures hence signal points can be easily discriminated from the others.

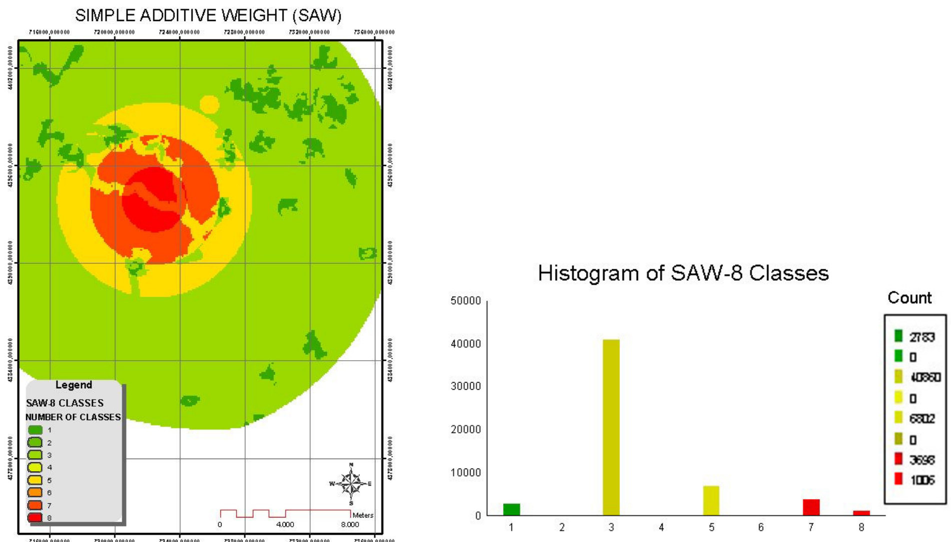


Figure 5-19 SAW classification with 8 classes

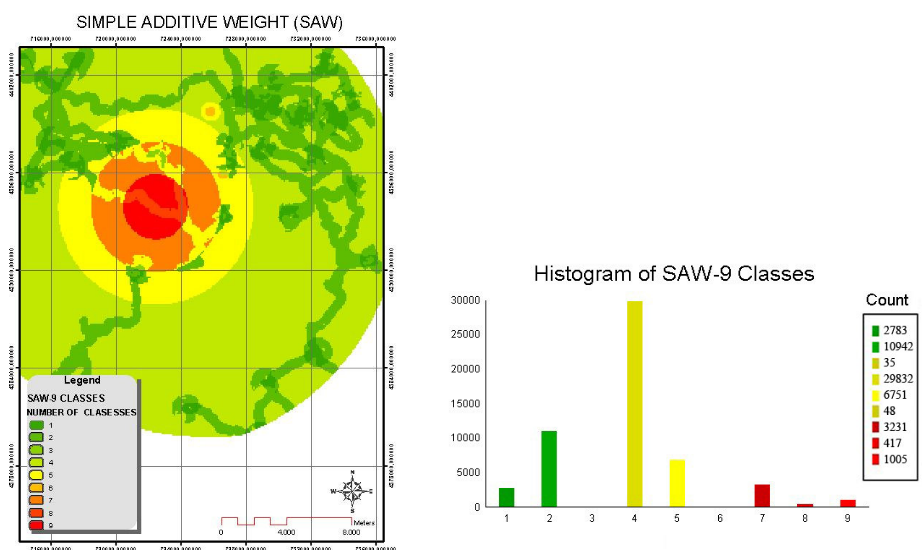
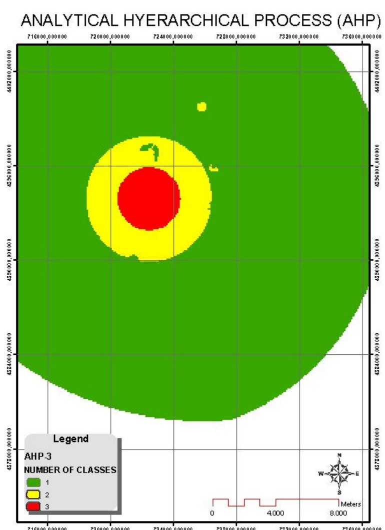


Figure 5-20 SAW classification with 9 classes

5.4.2. Reclassification According to Result of AHP

Result with classification into 3 classes for AHP method is shown in Figure 5-21 and the center of the circle colored by red has the maximum probability. Second maximum probability area covers a reasonable area. Therefore using this figure would be optimal. Figure 5-22 is the case with classification into 4 classes. It covers longer area in the center of the circle compared to Figure 5-21. Thus the total effort for this classification is higher than Figure 5-21.



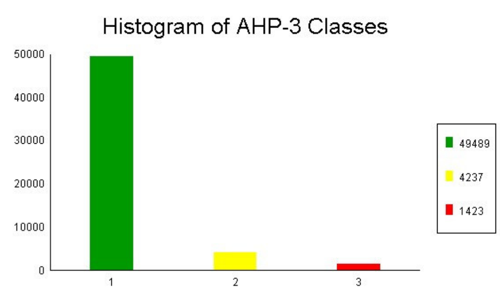


Figure 5-21 AHP classification with 3 classes

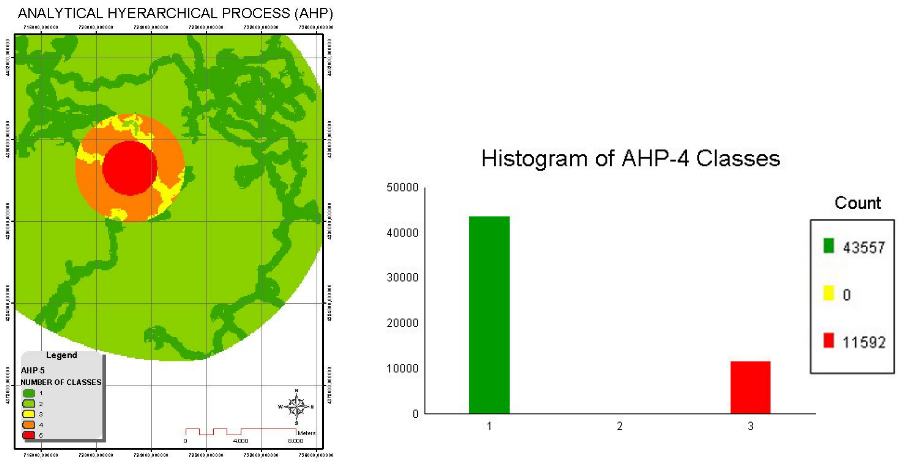


Figure 5-22 AHP classification with 4 classes

Results of classification into 5, 6, 7 and 9 classes for AHP method are shown in Figure 5-22, Figure 5-23, Figure 5-24, Figure 5-25 and Figure 5-26 respectively. Although there are slight differences, probability of areas are just about the same. Thus the total effort for these classifications is less than Figure 5-20 and Figure 5-22.

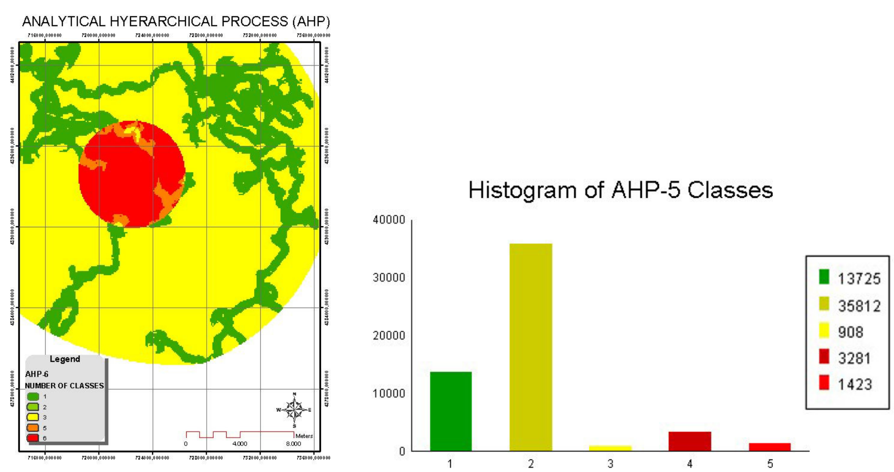


Figure 5-23 AHP classification with 5 classes

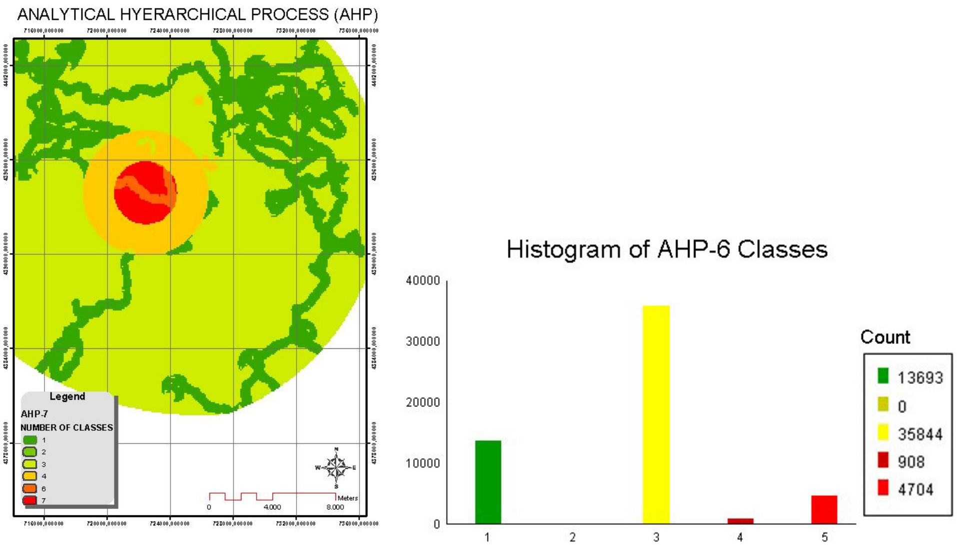


Figure 5-24 AHP classification with 6 classes

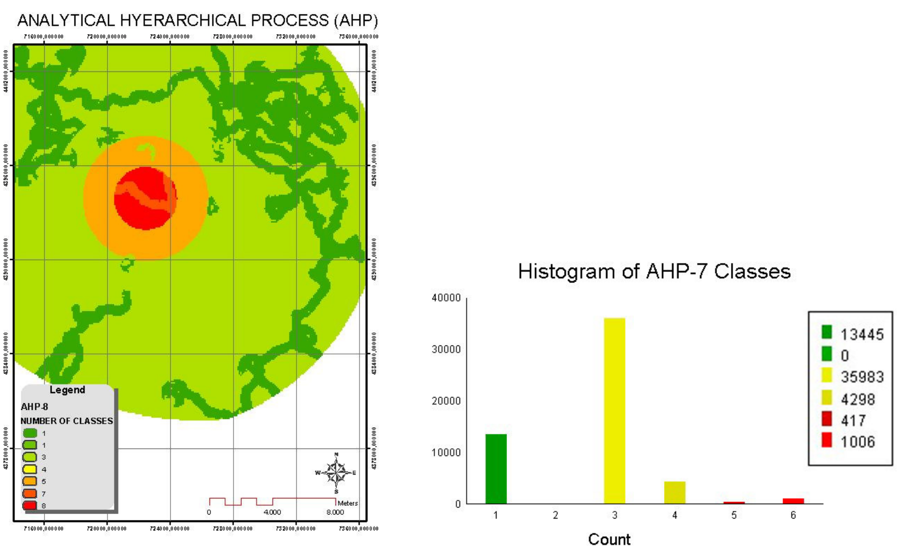


Figure 5-25 AHP classification with 7 classes

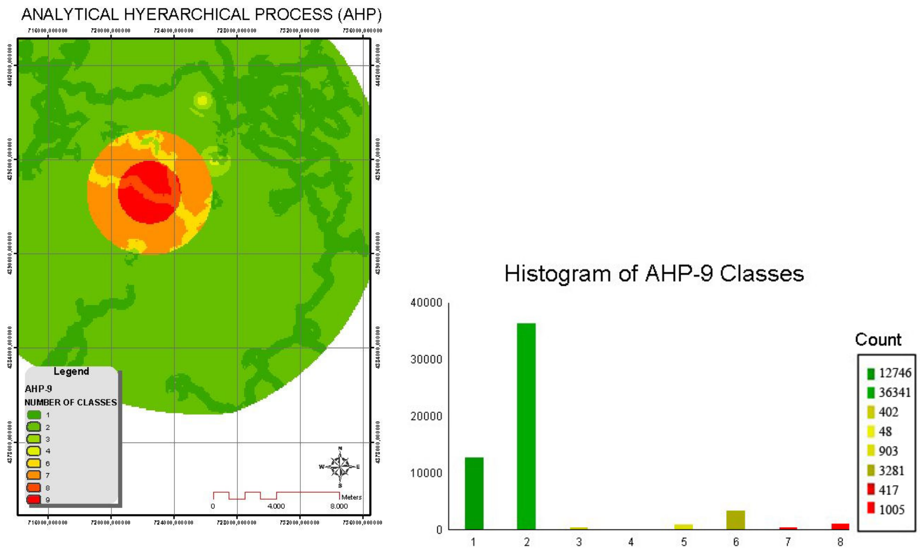


Figure 5-26 AHP classification with 9 classes

5.4.3. Reclassification According to Result of OWA

Results of OWA method is slightly the same apart from Figures 5-28 and 5-33. Figures 5-27, 5-29, 5-30, 5-31 and 5-32 give nearly the same search efforts.

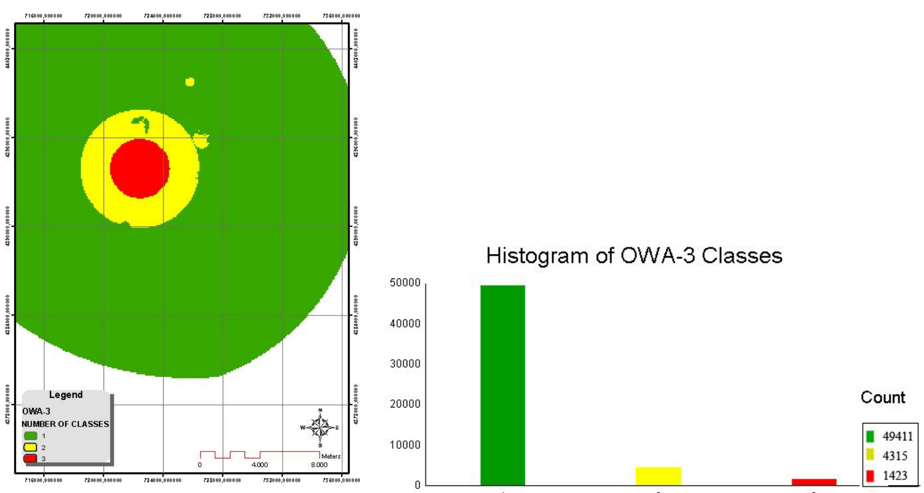


Figure 5-27 OWA classification with 3 classes

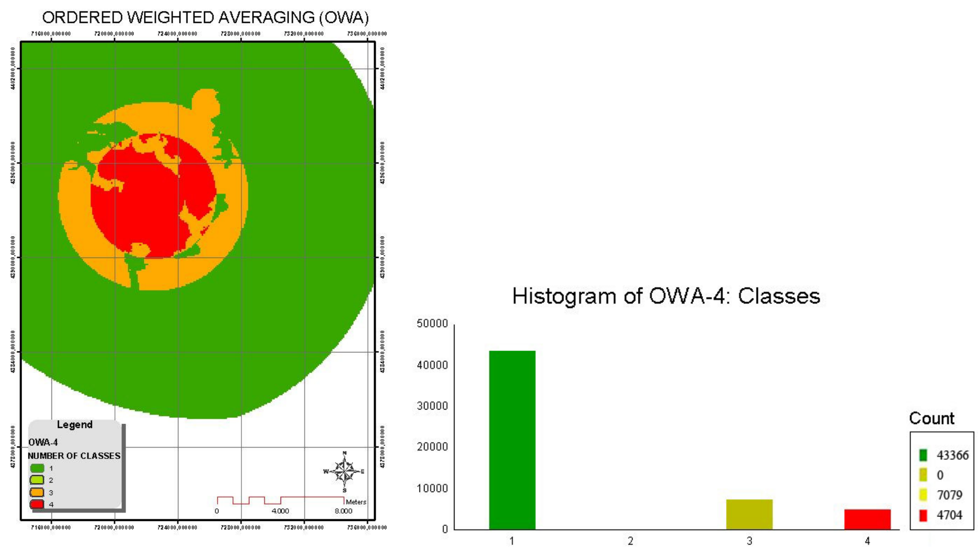


Figure 5-28 OWA classification with 4 classes

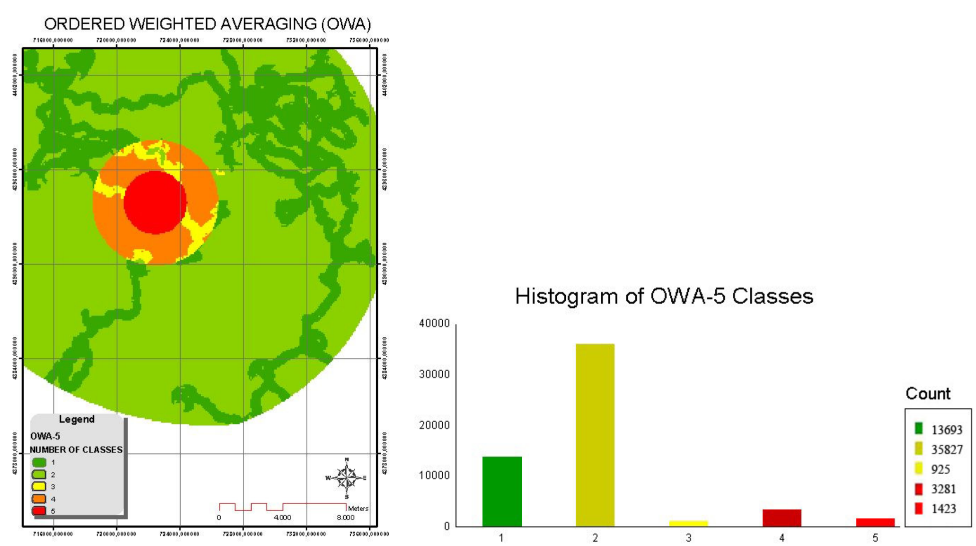


Figure 5-29 OWA classification with 5 classes

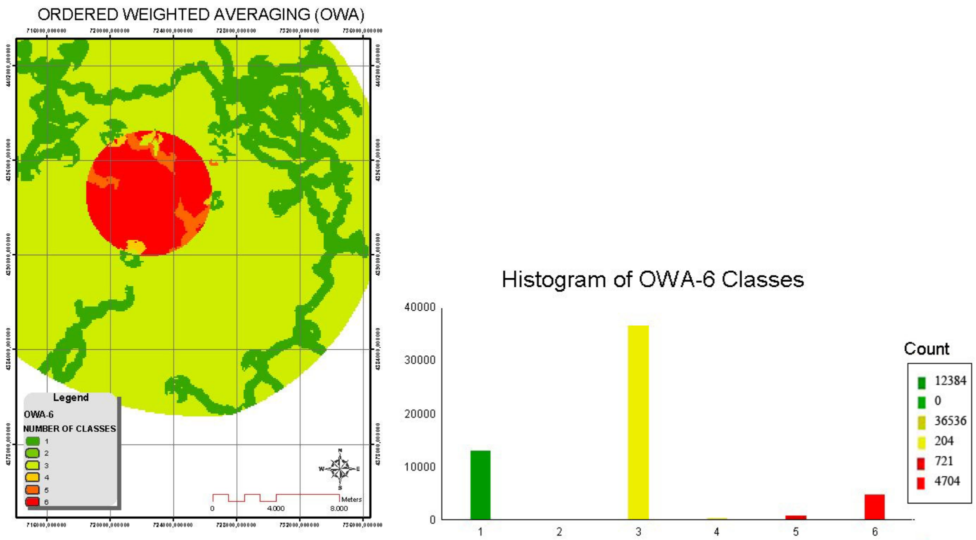


Figure 5-30 OWA classification with 6 classes

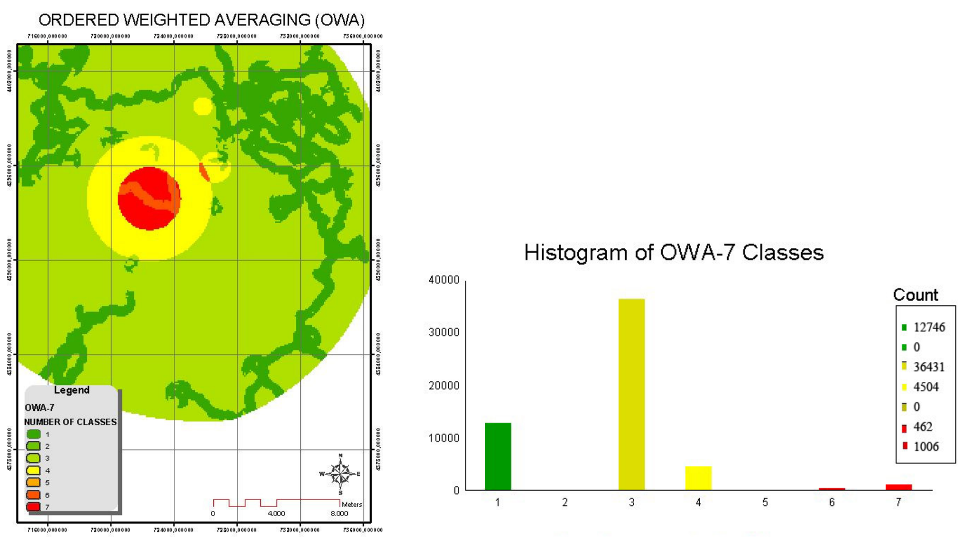


Figure 5-31 OWA classification with 7 classes

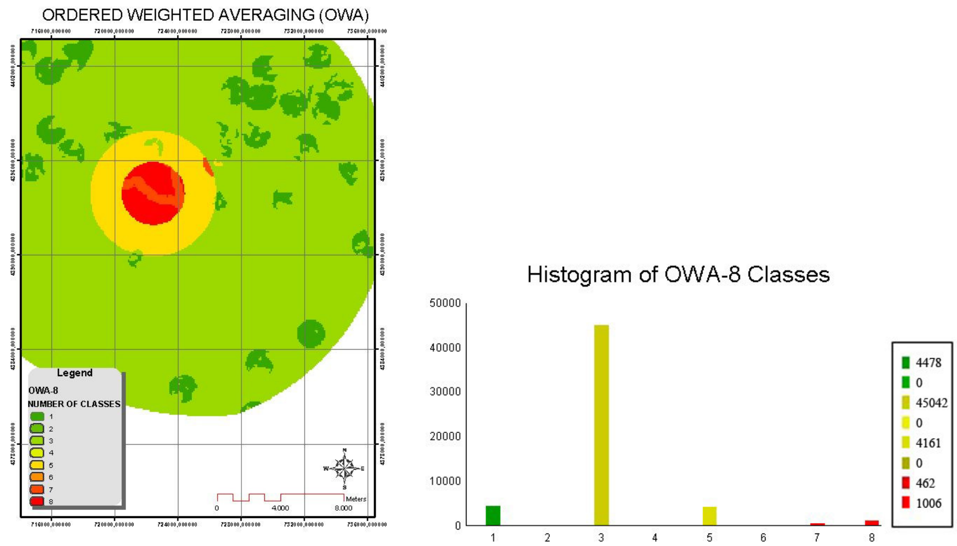


Figure 5-32 OWA classification with 8 classes

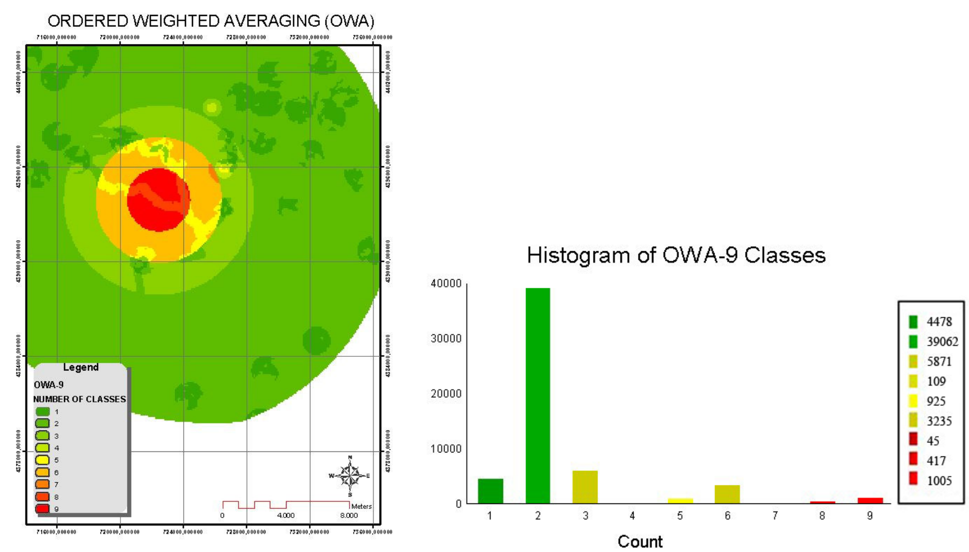


Figure 5-33 OWA classification with 9 classes

Important criteria for comparing the results are as follows:

- Signal points should be discriminated easily by the search expert,
- Road and settlement buffers should be discriminated from the reclassified map
- Size of the searching area should be between (5 x 5 km) and (10 x 10) km

Considering the above criteria Figure 5-17 and Figure 5-20 are suitable for SAW decision rule. Figure 5-26 is suitable For AHP decision rule and Figure 5-28, Figure 5-31 and Figure 5-33 are suitable for OWA method.

5.4.4. Dividing area into grids

Sweep width (w) value for this case is considered as 0.7 km according to values in Table A-3 listed in Appendix A.

User can determine the border of the search area with the help of rectangle tool in 'ARCGIS' toolbar. After drawing the area as a rectangle from the menu of search tool, the user can determine the number of rows and columns according the size of one side of the rectangle. User can also use different rectangles. However every time it should be calculated and summed up to calculate search time of search patterns.

Also the search area can be divided into more than one segment. In this case, search time for every segment should be calculated separately and added to calculate total time for the search with a chosen search pattern.

5.5. Discussions

The implications of this study are composed of three tests; which are listed below:

- Test of finding suitable MCDA methods: Three different MCDA methods (SAW, AHP and OWA) were tested according to search expert priorities. For each decision rule the changes of probability distribution were also examined.

- Test of class numbers while dividing area into sub search areas: every decision rule affecting the classification of the probability map was examined.

- Test of finding suitable search patterns for this kind of cases and environmental effects: for every probability distribution map five different search patterns were tested based upon their effectiveness.

Result of these tests has its preferred use conditions and one must understand the methods in order to choose the best one for the same conditions. All are useful for the same purpose of defining an importance rating over a range of criteria. SAW can only be used when the decision maker knows the exact percentage of each criterion contributing to the decision (Malczewski, 1999). AHP is most valuable when there is a great uncertainty and there are opposing forces at work in the decision process (Saaty, 1990). The OWA method should be used when the concept of decision risk makes sense in the decision process (Yager, 1988).

According to results of test of finding suitable MCDA methods, probability map determined by AHP decision rule provides more effective results than other decision rules. The smallest search effort values are calculated in AHP decision rule for every search pattern. From the Figure 5-34, it can be said that the most effective results were provided by the AHP method.

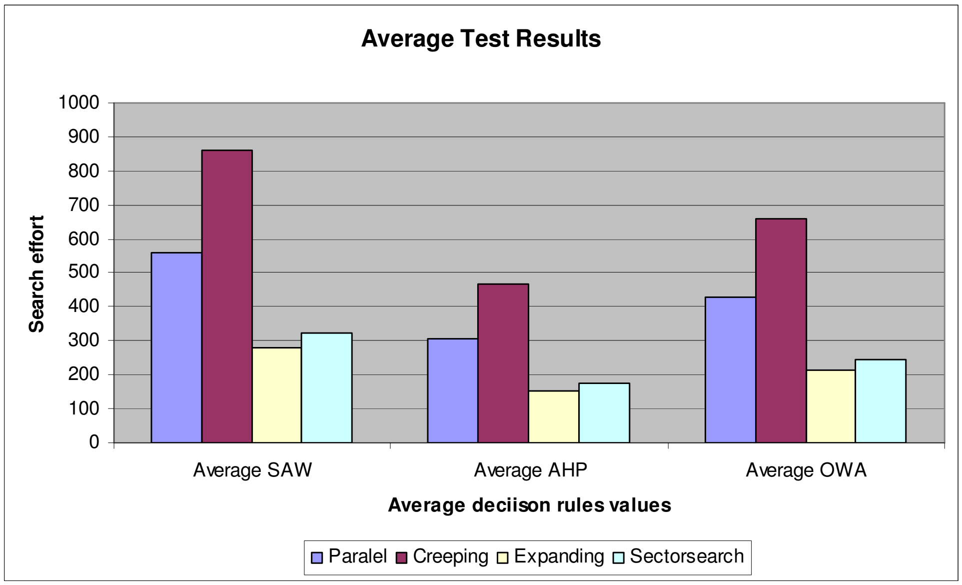
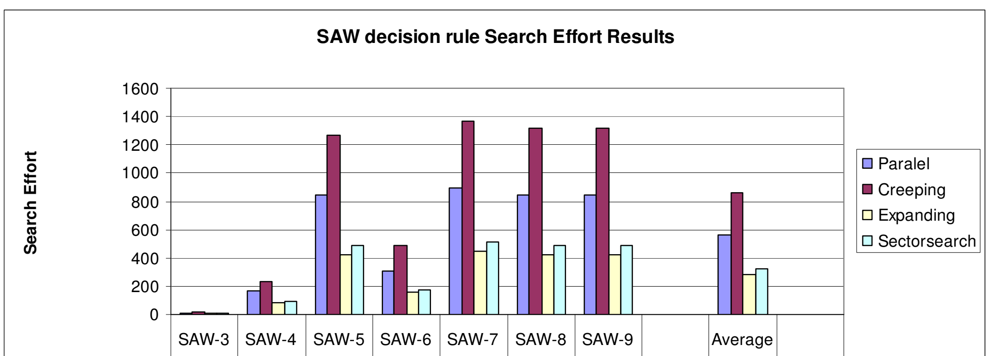


Figure 5-34 MCDA and Search Pattern Comparison

Figure 5-34 also shows effectiveness of search patterns with MCDA decision rules. The most effective search patterns are both Expanding Search Pattern and Sector Search Pattern. The less effective search patterns for this case are Parallel search pattern and Creeping Line Search Pattern. The considerable difference among these search patterns originated from their commence point to the search. Expanding Search Pattern and Sector Search Pattern start from the SAR operation from the center point of the POA. According to results seen in Figure 5-34 Creeping Search pattern method is the least effective search pattern. Hence, in that pattern the plane sweeps the area two times for every line. This increases the POD however it also increases the search time. Therefore search effectiveness of this pattern is less than other search patterns.

As it is discussed in Chapter 1, Search Effort (Z) is the product of the sweep width times the length of track in nautical miles in the search area. While testing search patterns efficiency, Z is used for this case. Coverage factor is not used, because the extent of the search areas for each pattern is equal.

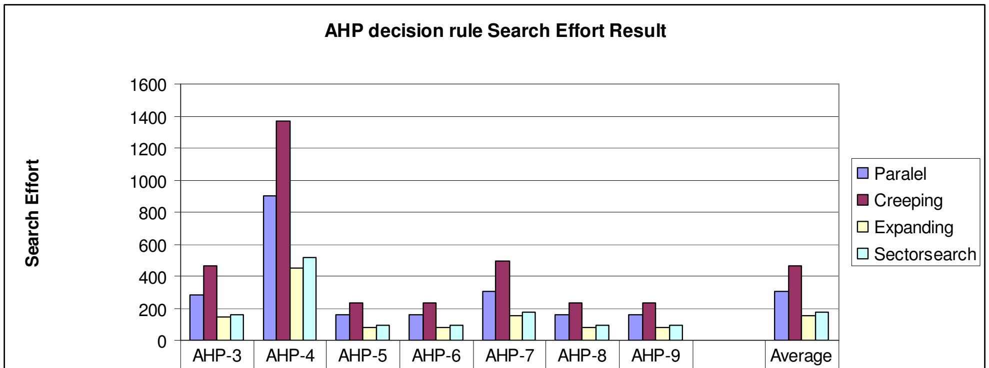
Search effort results for SAW method is shown in Figure 5-35. While calculating search efforts, program uses track line length and sweep width of the pattern as input. Generally, in SAW decision rule average search effort values were high (between 281 and 859). The highest search efforts for SAW method is 7 plot intervals in creeping line search pattern, 5, 8 and 9 plot intervals are also above the average search effort.



	SAW-3	SAW-4	SAW-5	SAW-6	SAW-7	SAW-8	SAW-9		Average	
Paralel	10,959	162,71	849,5	303,88	898,78	849,5	849,5		560,69	
Creeping	15,236	234,69	1269,4	492,27	1369,6	1318,6	1318,6		859,771	
Expanding	5,5565	81,651	425,42	154,77	450,08	426,1	426,1		281,383	
Sectorsearch	5,6968	91,149	488,78	173,09	517,31	488,78	488,78		321,941	

Figure 5-35 Search Efforts (Z) for SAW

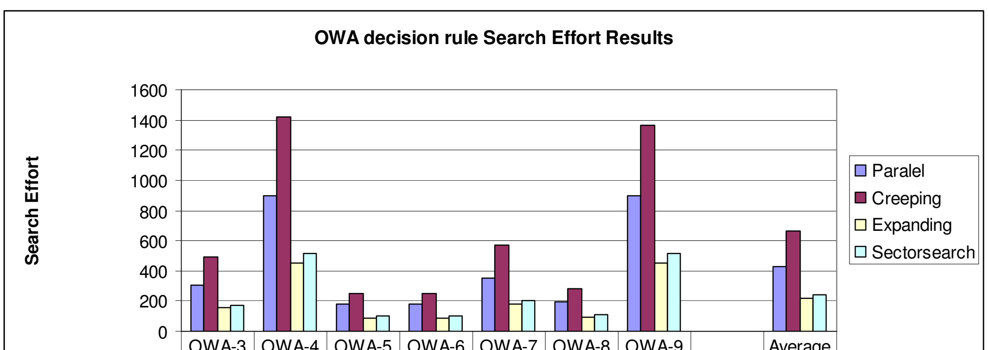
Figure 5-36 shows search effort values for AHP decision rule. Search effort values are nearly the same except 4 plot intervals. The average search effort values are (between 153,745 and 466). These values are nearly half of SAW method results.



	AHP-3	AHP-4	AHP-5	AHP-6	AHP-7	AHP-8	AHP-9		Average
Paralel	280,92	898,78	162,71	162,71	303,88	162,71	162,71		304,917
Creeping	467,84	1369,6	234,69	234,69	492,27	234,69	234,69		466,924
Expanding	144,76	450,08	81,651	81,651	154,77	81,651	81,651		153,745
Sectorsearch	160,62	517,31	91,149	91,149	173,09	91,149	91,149		173,659

Figure 5-36 Search Efforts (Z) for AHP

According to the results shown in Figure 5-37 average search effort values are between AHP and SAW decision rules. Search effort values are nearly the same except from 4 and 9 plot intervals. The average search effort values are (between 215 and 660).



	OWA-3	OWA-4	OWA-5	OWA-6	OWA-7	OWA-8	OWA-9		Average
Paralel	303,8	897,39	176,57	176,57	350,76	192,29	898,78		428,023
Creeping	492,27	1420,7	248,38	248,38	567,91	278,53	1369,6		660,824
Expanding	154,77	451,47	88,905	88,905	178,42	96,468	450,08		215,574
Sectorsearch	173,09	517,31	99,337	99,337	200,2	108,6	517,31		245,026

Figure 5-37 Search Effort (Z) for OWA

According to the results shown in Figure 5-38, the tool was tested for every search pattern. While calculating search time for each search pattern, weather conditions were assumed suitable from the air search. Figure 5-38 shows both test results of the decision rules according to search effort and test of finding suitable search patterns. Expanding and Sector search patterns are the most effective search patterns for five, six and eight plot intervals.

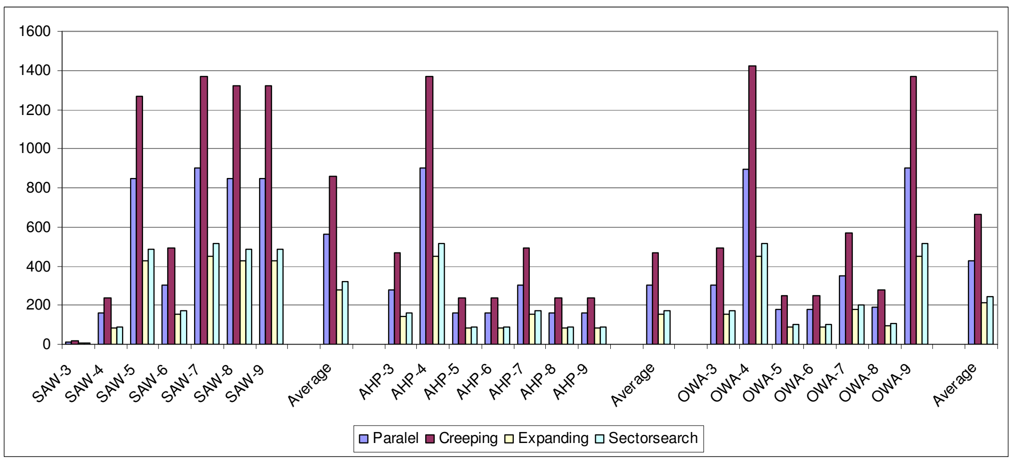


Figure 5-38 The result of comparing three decision rules

In the real life, operation for this case was driven out three days (Gerede, 2007). Except the use of GIS, TAF used expanding square search pattern in the search operation. The basic obstacle was weather conditions. In this study it is accepted that weather conditions are suitable for air search and rescue operation.

Results of our study showed that both expanding square and sector search pattern provide an effective result for this case. This study is differentiated from TAF's for the used methodologies. Basically, GIS is used as a main tool for data analysis, MCDA for weighting input layers. The last steps of both are nearly the same.

Moreover, results of this study supports used search patterns in the real SAR operation and recommend sector search pattern for such operations.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The adopted methodology, which integrates GIS, MCDA and Search Theory, for SAR planning leads to some considerable results. The conclusions derived from the study are as follows:

- When MCDA decision rules are tested, it is found that AHP provides much better results than SAW and OWA. This confirms that the pair wise comparison is more reliable for these conditions.

- Of the used three different MCDA decision rules, SAW decision rule provides the worst search effort results. The average search effort of SAW is considerably higher than both OWA and AHP. Therefore, OWA and AHP decision rules should be preferred by the search expert in ASAR cases.

- While dividing area into sub sectors; reclassification method which is firstly adopted for SAR operations is used. This method provides search expert reliable borders of the sub sectors in the probability mapping. This method also decreases the subjectivity of search expert while dividing area into sub search areas.

- According to the results obtained from the reclassification of probability distribution maps, the reasonable class numbers are determined as 5, 6, 7, 8 and 9 plot intervals for AHP decision rule. 3, 4 plot intervals are not reasonable for this situation.

- OWA decision rule has a similar character to AHP decision rule. The reasonable class numbers are determined as 5, 6, 7 and 8 plot intervals like AHP. However, besides 3, 4 plot intervals 9 plot interval is not reasonable for OWA decision rule.

- On the other hand, for SAW decision rule 4 and 6 plot intervals are reasonable. Hence 3,5,7,8 and 9 plot intervals provide higher search effort, they can not be considered as a reasonable solution.

- In the final stage, a functional comparison analysis of search patterns within the framework of search theory in terms of time domain, it is found that expanding square and sector search patterns provide shortest time to sweep the whole area.

- The main difference among these search patterns is commencing search points. Expanding square and sector search patterns started searching the area from the LKP point. Therefore, if LKP of the plane is known, it is a better solution to use Expanding square and sector search patterns.

- In this case, target is found around LKP, therefore giving the highest score to the LKP while weighting was reasonable.

- As a result with this methodology, the whole search area can be swept by the search aircraft in the limit of weather condition. Finding the location of missing aircraft in a short time is an achievement of developed methodology.

6.2. Recommendations

There are many modules and tasks that METUSAR tool could be expanded. Following recommendations can be useful for similar and further studies.

- In this study generic search patterns explained in NSAR (1998) were used. Therefore search expert was limited to find the best fitting search pattern to the area. For further studies, a search pattern which is suitable for the area automatically.

- Also, topographic obstacles were not encountered in determining the probability maps. It would be beneficial to assess topographic features of the area apart from generation of visibility maps.

- Aspects variations (Appendix C) should be taken into account while calculating search effectiveness. Because, the speed of the plane could be adjusted and this can affects the search effectiveness. In smaller areas aspects and special characteristics of the terrain should be considered. Also lots of parameters in smaller areas could be included in the study like size of object, composition of the surface, composition of the object (color, reflective ability) and vegetation (so many tree types, and not growing in uniform pattern).

- This tool only covers a small part of a search and rescue operation processes. Also, optimal ways of reaching the missing object is a new study subject.

- The features listed in this part are just suggestions of directions the METUSAR tool can be taken in the future works. Any of these extensions would increase the functionality and usability of this tool in real life cases.

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APPENDIX A

VARIABLES FOR SPECIFIC SEARCH TYPES

Table A-1 gives track speed and altitudes for electronic and visual searches. In this study, value of Search is chosen for SAR input variables. In the real case, search was conducted both day and night in order to find wreckage of the plane.

Table A-1 Search Types and Altitudes (IAMSAR, 2001)

Search	Type	Period	Target	Preferred Aircraft	Track/ Speed	Spacing	Altitude
1 and initial	trackline	day/ night	communication wreckage, electronic beacons	jet	300/600	50	10 000–40,000
2	electronic	day/ night	electronic beacons	jet	300/600	50	10 000–40 000
3	visual (aids)	night	fires, flares, torch, etc.	turbo-prop	150/300	20	1500–3000
4	visual (aids)	day	mirrors, dye	prop	130/190	10	1500–2000
5	visual (rafts)	day	rafts	prop, helo	100/180	3.1	300–1500
6	visual (wreckage)	day	wreckage	prop, helo	75/130	0.3	200–500
All aircraft to keep radar search.							
NOTE: Initial, electronic and visual (aids) searches could take place simultaneously at night and visual (aids)/(rafts)/(wreckage) searches could take place during the ensuing daylight hours; six searches being completed by the end of a 24 or 36 hour period.							

Table A-5 shows sweep widths and search factor for a specific condition. Table A-3 shows search correction factors according to properties of the terrain. In this case 60-85 % of the area was mountainous and covered by snow.

Table A-2 Sweep width for visual searches (km/nm) (IAMSAR, 2001)

		Visibility (km(NM))				
Search Object	Height (m(ft))	6 (3)	9 (5)	19 (10)	28 (15)	37 (20)
Person	150 (500)	0.7 (0.4)	0.7 (0.4)	0.9 (0.5)	0.9 (0.5)	0.9 (0.5)
	300 (1000)	0.7 (0.4)	0.7 (0.4)	0.9 (0.5)	0.9 (0.5)	0.9 (0.5)
	450 (1500)	--	--	--	--	--
	600 (2000)	--	--	--	--	--
Vehicle	150 (500)	1.7 (0.9)	2.4 (1.3)	2.4 (1.3)	2.4 (1.3)	2.4 (1.3)
	300 (1000)	1.9 (1.0)	2.6 (1.4)	2.6 (1.4)	2.8 (1.5)	2.8 (1.5)
	450 (1500)	1.9 (1.0)	2.6 (1.4)	3.1 (1.7)	3.1 (1.7)	3.1 (1.7)
	600 (2000)	1.9 (1.0)	2.8 (1.5)	3.7 (2.0)	3.7 (2.0)	3.7 (2.0)
Aircraft less than 5700 kg	150 (500)	1.9 (1.0)	2.6 (1.4)	2.6 (1.4)	2.6 (1.4)	2.6 (1.4)
	300 (1000)	1.9 (1.0)	2.8 (1.5)	2.8 (1.5)	3.0 (1.6)	3.0 (1.6)
	450 (1500)	1.9 (1.0)	2.8 (1.5)	3.3 (1.8)	3.3 (1.8)	3.3 (1.8)
	600 (2000)	1.9 (1.0)	3.0 (1.6)	3.7 (2.0)	3.7 (2.0)	3.7 (2.0)
Aircraft over 5700 kg	150 (500)	2.2 (1.2)	3.7 (2.0)	4.1 (2.2)	4.1 (2.2)	4.1 (2.2)
	300 (1000)	3.3 (1.8)	5.0 (2.7)	5.6 (3.0)	5.6 (3.0)	5.6 (3.0)
	450 (1500)	3.7 (2.0)	5.2 (2.8)	5.9 (3.2)	5.9 (3.2)	5.9 (3.2)
	600 (2000)	4.1 (2.2)	5.2 (2.9)	6.5 (3.5)	6.5 (3.5)	6.5 (3.5)

Table A-3 Search correction factors (IAMSAR, 2001)

Search Object	15-60% Vegetation or Hilly	60-85% Vegetation or Mountainous	Over 85% Vegetation
Person	0.5	0.3	0.1
Vehicle	0.7	0.4	0.1
Aircraft less than 5700 kg	0.7	0.4	0.1
Aircraft over 5700 kg	0.8	0.4	0.1

Table A-4 Recommended search altitudes (IAMSAR, 2001)

Search Object	Terrain	Recommended Altitudes
Person, light aircraft	Moderate Terrain	60-150 m (200-500 ft)
Large aircraft	Moderate Terrain	120-300 m (400-1000 ft)
Person, one-person raft, light aircraft	Water or Flat Terrain	60-150 m (200-500 ft)
Medium-sized liferaft and aircraft	Water or Flat Terrain	300-900 m (1000-3000 ft)
Pyrotechnical signal at night	Night	450-900 m (1500-3000 ft)
Medium-sized aircraft	Mountainous Terrain	150-300 m (500-1000 ft)

Table A-5 Sweep width table

Instruction	Example Value
1. In Table N-9, identify type of search object.	a person
2. Locate the row under that search object type corresponding to the height closest to the aircraft's altitude AGL. • Refer to Table N-11 for recommended altitudes.	150 metres
3. Locate the row under that search object type corresponding to the height closest to the aircraft's altitude AGL.	150 metres
4. Locate the column that has the visibility that most closely corresponds to the meteorological visibility at the scene. • Obtain from local weather bureau office or use pilot's estimate.	6 km
5. Locate the uncorrected sweep width (W) corresponding to the chosen row and column. • Interpolation to obtain sweep widths for heights and visibilities between the tabulated values is permissible.	0.7 km
6. In Table N-10, locate the row with the search object type.	a person
7. Locate the column that most closely describes the amount of vegetation and/or nature of the terrain. • Obtain from local knowledge or use pilot's and/or observer's estimate(s).	15-60% Vegetation *or* Hilly
8. Find the terrain/vegetation correction factor (f_t) in the corresponding row and column.	0.5
9. Multiply the uncorrected sweep width (W) by the correction factor (f_t) to get the corrected sweep width (W_c).	0.7 x 0.5 = 0.35 km ($W \times f_t = W_c$)
10. Determine the track spacing (S) of the parallel sweep search pattern flown by the aircraft • This small track spacing would likely require a helicopter.	0.6 km
11. Compute coverage with the shortcut formula $C = W_c/S$.	0.35 / 0.6 = 0.58 ($W_c / S = C$)
12. Enter the POD vs. Coverage graph with the Coverage and read the corresponding POD from the vertical axis. • For the mathematically inclined, compute POD with the formula $POD = 1 - e^{-C} = 1 - \exp(-C)$ and get 44.196%. • This added precision is completely superfluous.	44%

It is important for pilots to reports what they can observe, including:

- Meteorological visibility (6 km in haze)
- Amount of vegetation (50 % moderate three cover in valleys with low brush elsewhere)

- Nature of the terrain (hilly with numerous rocky outcrops visible in un forested areas)
- Weather (overcast, light rain, wind)
- Any other observations that might effect estimates of search effectiveness, the subject's continued chances of survival or decisions about whether to deploy ground parties. Sightings are particularly important.

APPENDIX B

OVERVIEW

This Appendix lists the Forms, Class modules and functions that were used in the program (Table B-1). To assist the reader in understanding this code, textual notation is used in the body of the code.

Table B-1 Summary Information of used GUI

Form Name	Class Module	Function	Page
FrmAHP	ClsAHP	Contains AHP decision rule GUI	51
FrmSAW	ClsSAW	Contains SAW decision rule GUI	49
FrmOWA	ClsOWA	Contains OWA decision rule GUI	51
FrmPatternSelection	ClsPatternSelection	Provide a form to a user making selection appropriate search pattern.	54
FrmSector	ClsSector	Provide probability map into smaller sectors	53
FrmTrack	ClsTrack	Provides reclassifying probability maps	52

B.2 MapAlgebraClass for AHP

This script performs main calculations about Multi Criteria Decision Analysis (MCDA).

Code for frmAHP form

Variables

```
Private m_MxDoc As IMxDocument
Private m_Map As IMap
Private m_Outraster As String
Private m_Extension As String
Private m_App As IApplication
Private m_InRaster As IRaster
Private m_CatTable As IRasterCatalogTable
Private m_Outws As IWorkspace
```

'The code above is necessary for being communication with arc map

Functions

Private Sub WieghtedSum()

All of the calculations are done in this piece of code. User inputs get by the help of text boxes in the forms and used as a double variable.

```
Dim n As Double ' n is the number of compared layer
Dim lamda As Double  ' lamda is an average of layer values
Dim CI As Double ' CI is used for Consistency index
Dim RI As Double 'RI is used for random index

n = 5 '
lamda = (cra + crb + crc + crd + cre) / 5
CI = (lamda - n) / (n - 1)
 RI = 1.12 ' this is constant for n=5 layers
 cr = CI / RI
 Text17.Text = cr
If cr < 0.5 Or cr = 0.5 Then
MsgBox "Decision is relatively Consistent"'Prompts the user about Consistency of
choices
```

```
ElseIf cr < 1 And cr > 0.5 Then
MsgBox "Your Decision is almost Consistent"
```
Prompt the user about Consistency of choices

```
Else
MsgBox "Your Decision is not seem consistent it is very high try again"
End If
End Sub
```

Get list values to the Form

```
List3.AddItem "Last Known Position"
List3.AddItem "Cities"
List3.AddItem "Roads"
List3.AddItem "Second Position"
List3.AddItem "Direction"
Command2.Enabled = True

Private Sub Command2_Click()
Call WieghtedSum
Command4.Enabled = True
End Sub
Private Sub Command3_Click()
```

Algorithm for ARCMAP communication

```
Dim m_MxDoc As IMxDocument
Dim m_Map As IMap
Dim pLayer As ILayer ‘ Creates Layers
Set pLayer = m_Map.Layer(i)  ‘ Sets the value of Layer
Dim pRLayer As IRasterLayer
```

'Create a Spatial operator

```
Dim pAlgbOp As IMapAlgebraOp
Set pAlgbOp = New RasterMapAlgebraOp
```

‘Set output workspace

```
Dim pEnv As IRasterAnalysisEnvironment
```

```
Set pEnv = pAlgbOp
Dim pWS As IWorkspace                    '
Dim pWSF As IWorkspaceFactory
Set pWSF = New RasterWorkspaceFactory
Set pEnv.OutWorkspace = pWS
```

'Bind a raster

```
Dim Grid1 As String
Call pAlgbOp.BindRaster(pInRaster, "Grid1")
Call pAlgbOp.BindRaster(pInRaster2, "Grid2")
Call pAlgbOp.BindRaster(pInRaster3, "Grid3")
Call pAlgbOp.BindRaster(pInRaster4, "Grid4")
Call pAlgbOp.BindRaster(pInRaster5, "Grid5")
```

'Perform Spatial operation

```
Dim pvalue As String
pvalue = Text6(0).Text

Dim strExpression As String
strExpression = "([Grid1] * " & pvalue & ") + ([Grid2] * " & pvalue2 & ")+ ([Grid3] * " & pvalue3
& ")+ ([Grid4] * " & pvalue4 & ")+ ([Grid5] * " & pvalue5 & ")"

Dim pOutRaster As IRaster
Set pOutRaster = pAlgbOp.Execute(strExpression)
Dim pRlayer6 As IRasterLayer
Set pRlayer6 = New RasterLayer
pRlayer6.CreateFromRaster pOutRaster
```

‘Add created layer in to ARCMAP

```
m_Map.AddLayer pRlayer6
```

B.3 MapAlgebraClass for SAW

Code for frmAHP form

The difference of these forms is getting of variables and calculations. Basically, SAW Form gets the SAR expert's preferences, and then processes it according to SAR decision rule.

Variables

```
Dim m_MxDoc As IMxDocument
Dim m_Map As IMap
Dim pLayer As ILayer
Dim pLayer2 As ILayer
Dim pLayer3 As ILayer
Dim pLayer4 As ILayer
Dim pLayer5 As ILayer
```

Functions

'Creating a Spatial operator

```
Dim pAlgbOp As IMapAlgebraOp
Set pAlgbOp = New RasterMapAlgebraOp
```

' Set output workspace

```
Dim pEnv As IRasterAnalysisEnvironment
Set pEnv = pAlgbOp
Dim pWS As Iworkspace

Dim pWSF As IWorkspaceFactory

Set pWSF = New RasterWorkspaceFactory
Set pEnv.OutWorkspace = pWS
```

' Bind a raster

```
Dim Grid1 As String
Call pAlgbOp.BindRaster(pInRaster, "Grid1")
Call pAlgbOp.BindRaster(pInRaster2, "Grid2")
Call pAlgbOp.BindRaster(pInRaster3, "Grid3")
```

```
Call pAlgbOp.BindRaster(pInRaster4, "Grid4")
Call pAlgbOp.BindRaster(pInRaster5, "Grid5")
```

'Perform Spatial operation

```
Dim pvalue As String
Dim pvalue2 As String
Dim pvalue3 As String
Dim pvalue4 As String
Dim pvalue5 As String
pvalue = Text6.Text
pvalue2 = Text7.Text
pvalue3 = Text8.Text
pvalue4 = Text9.Text
pvalue5 = Text10.Text


Dim strExpression As String
strExpression = "([Grid1] * " & pvalue & ") + ([Grid2] * " & pvalue2 & ")+ ([Grid3] * " & pvalue3
& ")+ ([Grid4] * " & pvalue4 & ")+ ([Grid5] * " & pvalue5 & ")"


Dim pOutRaster As IRaster
Set pOutRaster = pAlgbOp.Execute(strExpression)
Dim pRlayer6 As IRasterLayer
Set pRlayer6 = New RasterLayer
pRlayer6.CreateFromRaster pOutRaster
Private Sub Command2_Click()
Text6.Text = a
Text7.Text = b
Text8.Text = c
Text9.Text = d
Text10.Text = e
cmdOk.Enabled = True

End Sub


Dim i As Integer

For i = m_Map.LayerCount - 1 To 0 Step -1

    Set pLayer(i) = m_Map.Layer(i)


 Next i
 Dim pRLayer() As IRasterLayer
 Dim pInRaster() As IRaster
 ReDim pRLayer(Layersayisi)
 ReDim pInRLayer(Layersayisi)
 Dim g As Integer
```

```
For g = (m_Map.LayerCount - 1) To 0 Step -1

   Set pRLayer(g) = pLayer(g)
 Set pInRaster(g) = pRLayer(g).Raster

 Next g
End Sub
```

B.4 POA SegmentModule

This scripts used for accessing the pixel value of the grid. *AcessValueOfRaster* function accesses raster table of the grid and gets pixel values of raster cells. Secondly determines minimum and maximum pixel values of the grid and divide it user defined value. Finally remaps old values to a user defined values.

```
Sub AccessValueOfRasterTable(pRaster As IRaster, sFieldName As String, RowIndex As Integer)
End Sub

   'Create a raster descriptor and specify the field to be used for reclassify

   Dim sFieldName As String
   sFieldName = "Value"
   Dim pRasDescriptor As IRasterDescriptor
   Set pRasDescriptor = New RasterDescriptor
   pRasDescriptor.Create pInRaster, Nothing, sFieldName

   'Create a RasterReclassOp operator
   Dim pReclassOp As IReclassOp
   Set pReclassOp = New RasterReclassOp
    'Create a StringRemap object and specify remap
   Dim pNumberRemap As INumberRemap
   Set pNumberRemap = New NumberRemap
    Dim mins As Double
    Dim maxs As Double
'Call AccessValueOfRasterTable(pInRaster, "Value", NumOfValues – 1)
```

```
MinValue = -1
Dim MaxValue As Double
MaxValue = pLayer.Value
fark = (MaxValue - MinValue) / com
For i = 1 to com
   pNumberRemap.MapRange MinValue, (MinValue + fark), i
   MinValue = MinValue + fark
Next i
pNumberRemap.MapRangeToNoData 100, 200
End Sub
```

B.5 SearchPatternComparison module

This module divides the area in to user defined grids. Firstly user defines a rectangle.

' Create the RasterExtractionOp object

```
Dim pExtractionOp As IExtractionOp
Set pExtractionOp = New RasterExtractionOp
```

' Declare the input dataset object

```
Dim pInputDataset As IGeoDataset
```

' Call function to open a dataset

```
Dim pLayer As ILayer
Set m_MxDoc = m_App.Document
```

' Create an envelope (minimum rectangle area of the selected object)

```
Set pEnvelope = New Envelope
pEnvelope.PutCoords dblXMin, dblYMin, dblXMax, dblYMax
Set pOutputDataset = pExtractionOp.Rectangle(pInputDataset, pEnvelope, True)
End Sub
```

Function that generate grid based on draved envelope

```
Public Function GenerateGrid(strWorkPath As String, strName As String, pEnv As IEnvelope,
End Function
```

Function that convert envelope to polygon

```
Private Function Env2Polygon(pEnv As IEnvelope) As IPolygon
End Function
```

Functions that making result grids

```
Private Function MakeFields(pEnv As IEnvelope) As IFields
End Sub
```

APPENDIX C

ASPECT VARIATIONS OF THE AREA

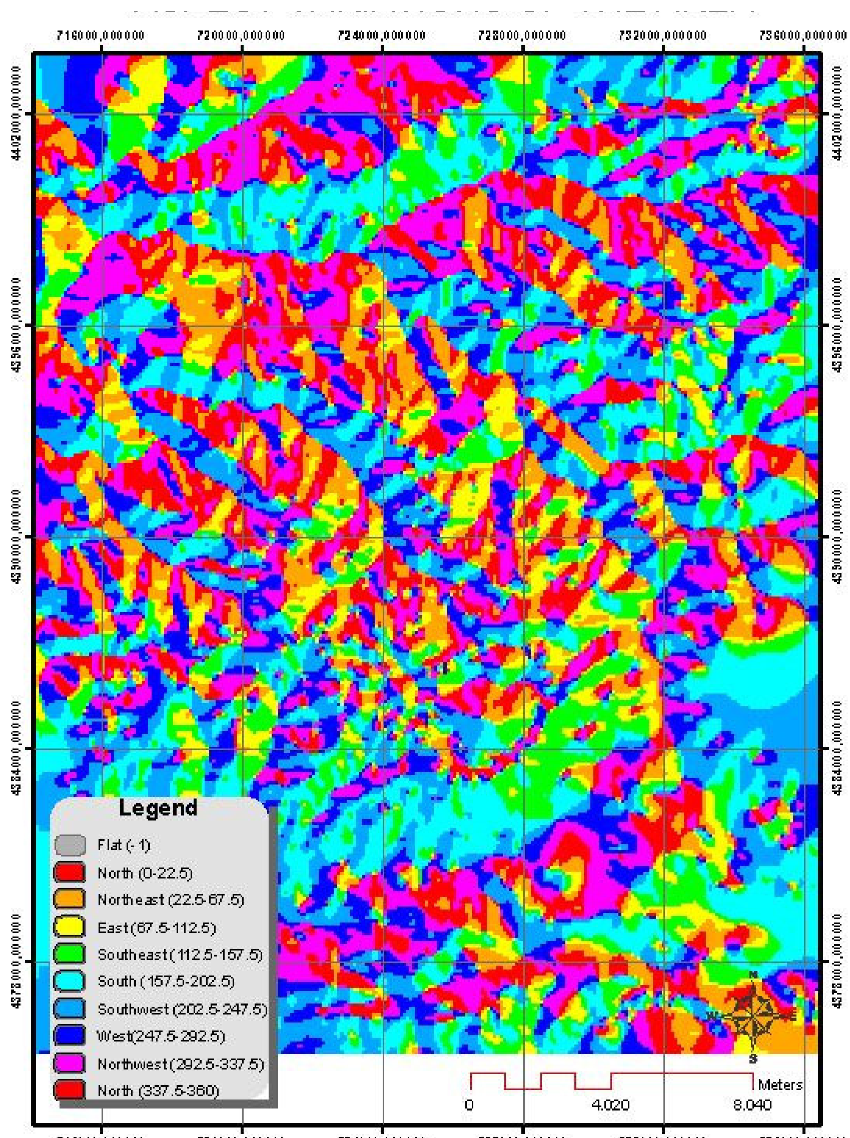

Figure C-1 Aspect variations of the area