INFOR, Vol. 48, No. 3, August 2010, pp. 143–153
ISSN 0315-5986 | EISSN 1916-0615

Goal Programming Model for Fire and Emergency Service Facilities Site Selection

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Abstract—The aim of this paper is to apply Goal Programming to select a site for a Fire and Emergency Service station in Sfax region in Tunisia. The decision making process involves incommensurable and conflicting objectives including proximity to industrial firms and response time. The concept of satisfaction function is utilized to explicitly introduce the Decision-Maker's preferences in the decision-making process.

Keywords Goal programming, multicriteria decision aid, Decision-Maker's preferences, location problem, emergency service facilities.

1. INTRODUCTION

Site selection is one of the frequently studied operational research problems where the Decision-Maker (DM) looks for the best location that meets his/her preferences. In such decision situations, the most important objectives are often the minimization of transportation and facility costs. For example, the main objective for police, fire fighters and ambulance services is to determine the best location for their stations so that either the average travel distance is minimized or the coverage area is maximized. In fact, Fire and Emergency services are crucial in saving lives and reducing injuries and must provide a high level of quality services. The effectiveness of a Fire and Emergency Service system is an important issue for most communities and municipal governments. Achieving effectiveness is a complicated process that depends on a number of factors such as the size of the emergency fleet, the location of the sites and the dispatching strategy. In this paper, we are considering only the location of the sites.

During the last two decades, the Emergency Service location problem has gained the attention and interest of academics and practitioners. A number of papers have been published dealing with theoretical developments and applications of the Emergency Service Location Problem where the following three approaches have been utilized: a) Queuing models (Larson, 1974; Harewood, 2002; Iannoni and Morabito, 2007; Atkinson *et al.*, 2008), b) Simulation (Savas, 1969; Goldberg *et al.*, 1990) and c) Mathematical Programming. Well known mathematical programming models are the traditional Set Covering Location Problem proposed by Toregas *et al.* (1971), the Maximal Covering Location Problem (MCLP) developed by Church and Revelle (1974), and the Maximal Expected Covering Location Problem developed by Daskin (1982). Among the best reviews of the Emergency Service Location models, we cite Marianov and Revelle (1995) and Brotcorne *et al.* (2003).

While there is an extensive literature on site selection problem only a small number of them consider it as a multidimensional decision-making problem. This problem is multidimensional in nature requiring consideration for social, economic, and political factors. These objectives are incommensurable and conflicting and their aggregation requires some tradeoffs (compromises). Techniques like

Received April 2009; Revision December 2009, March 2010; Accepted September 2010

Multi-Objective Programming, Goal Programming (GP) and Hierarchical Programming can be useful to identify the best location for the site selection problem.

Charnes and Storebeck (1980) developed a multilevel, Goal Oriented Location Covering Model for placing vehicles in a two-tier Emergency Medical Service system by applying the MCLP approach within a GP framework. Mladineo *et al.* (1987) utilized the PROMETHEE method for site selection of small scale hydro plants for many regions in order to make the unit costs as low as possible. Kwak and Schniederjans (1985) presented a generalized GP model for the site selection problem where several conflicting attributes were simultaneously involved. Karkazis (1989) developed a multicriteria approach for locating facilities in a competitive environment. Badri *et al.* (1998) utilized the Integer GP model for the Fire-Station Location problem. Alsalloum and Rand (2006) proposed a GP model for the problem of identifying the best location for the Emergency Medical Service stations problem. The authors considered the following two objectives: a) meet the demand within a pre-specified target time, and b) at least one vehicle, from any station, responds to the demand. Tamiz *et al.* (1998) provided an overview of the GP model where they highlighted how this powerful model can be applied to several areas of interest including the site selection problem.

The aim of this paper is to apply the GP model for site selection where the satisfaction function concept, developed by Martel and Aouni (1990), is used to explicitly integrate DM's preferences. Martel and Aouni (1992) applied their model for selecting a site to build an airport in the north of Quebec, Canada. We shall apply this model to select a Fire and Emergency Service location in the city of Sfax (Tunisia), considering several conflicting objectives. GP is one of the powerful models that simultaneously optimize several objectives and take into consideration the DM's preferences. The GP is a distance function model that allows obtaining the best compromise solution which maximizes performance measure regarding the considered objectives. Thus, the GP model will be used to assist the DM to select the best location for a new Fire and Emergency Service station for the city of Sfax in Tunisia.

The rest of this paper is organized as follows: in section 2 we will present the decision-making context. The definition of the objectives will be detailed within the third section. The formulation of the model and the different satisfaction functions are presented in section four. In section five we will provide some concluding remarks.

2. DECISION-MAKING CONTEXT

The city of Sfax is the second major city in Tunisia. Sfax is located at 270 km south of the capital city of Tunisia. The main features of Sfax are summarized in Table 1.

TABLE 1.
Features of the city of Sfax

Features	Size
Area (hectares)	710,000
Population	810,000
City Districts	15
Hospitals	8
Industrial Parks	15
Industrial Establishments	1805
Public Services	608
Oil Trade	350
Gasoline Stations	48
Oil Wells	12
Fire and Emergency Service Stations	3

From Table 1 we can see that the city of Sfax needs more Fire and Emergency Service stations to provide better service to its citizens. The city of Sfax has enjoyed tremendous economic and population growth in the past two decades causing a significant increase in demand for Fire and Emergency Services. At the time this research was conducted the city of Sfax had three Fire and Emergency Service stations that were operating: a) the Regional Department Station (central station) which responds to the majority of calls, b) the Kerkena Island Station covering only Kerkena Island, and c) the Sekiat Ezzit Station, 10 kilometres north of the central station. The Sekiat Ezzit station is a regional unit which covers a restricted area. The collective mission of these stations is to provide good and on time service for the region of Sfax. The locations of these stations are indicated on the map in Figure 1.

The capacity of the current stations is limited, but the demand is constantly increasing. The three stations are not able to ensure a good service quality and the service provided by the crew is not very effective. In order to avoid overwhelming of the employees and put the population at risk, it is urgent to add some stations to cover the increasing demand. Addition of new stations should improve the response time.

The Fire and Emergency Service in the city of Sfax, and across Tunisia, is a public institution with the mission of protecting the people, the properties and the environment. This protection is provided through prevention, mitigation, preparation, response, or emergency evacuation, and recovery. Moreover, Sfax is an industrial city with high risk of fire and discharge of hazardous material.

In spite of the necessity for additional Fire and Emergency Service stations in Sfax, the budget limitation and the high cost of new stations constitute the main constraint that compromises the achievement of adequate protection. Hence, only one new station will be considered. The director of Sfax Fire and Emergency Service has considered the following nine sites for the new station: Skhira (x_1), El Hincha (x_2), Industrial areas Poudirière 1 and 2 (x_3), Mahres (x_4), Tina (x_5), Menzel Cheker (x_6), Bir Ali Ben khlifa (x_7), Jbeniana (x_8) and Agareb (x_9). The decision maker would like that this new

ISSN 0315-5986 | EISSN 1916-0615
DOI 10.3138/infor.48.3.143

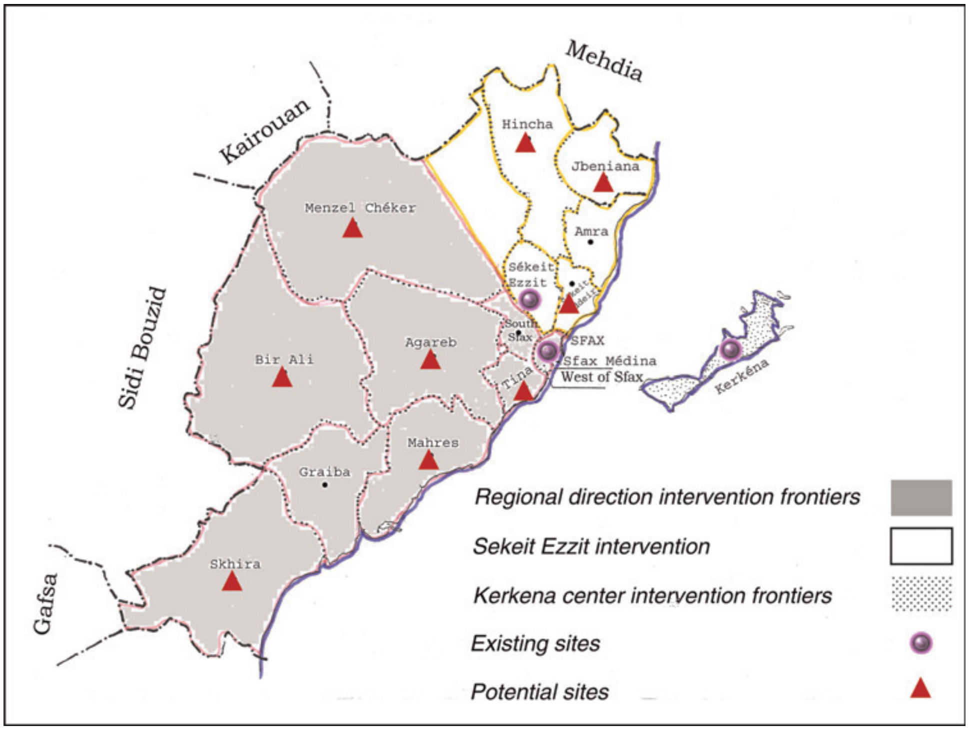


Figure 1. Actual and potential sites

station is able to respond to calls from all parts of the Sfax region. The nine sites have been evaluated through the following criteria: a) proximity to industrial firms, b) proximity to public institutions, c) size of the population, d) magnitude of the interventions, e) existing road system, f) response time, and g) railway connections.

The main objective of this study is to develop a model that would help the Fire and Emergency Service department to locate a new station in Sfax by considering several attributes. It is a selection problem where the set of alternatives is discrete. The DM will express his aspiration level (goal) for each objective and explicitly reveal his preferences regarding the deviations of the achievement from the aspiration levels for each objective. The site of the best compromise is the one that maximizes the satisfaction of the DM by aggregating different attributes that deal with economical, technical, social and environmental considerations.

3. DEFINITION OF OBJECTIVES

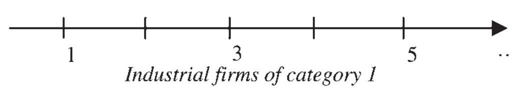
The financial cost is one of the most important objectives in many location problems. In this study, the installation cost is almost the same for all options. Hence, we shall not consider cost as a criterion. The DM (the director of Fire and Emergency Service) has provided some criteria for site selection which will be described in this section.

3.1 Proximity to Industrial Firms

The fact that Sfax is the second industrial city in Tunisia makes the proximity to industrial firms the main factor in the selection of the Fire and Emergency Service site. Around 1805 firms have been registered at the Sfax department of Fire and Emergency Service. These firms are classified into four risk categories.

a) Presence of Industrial firms of first category (C_1)

Industrial firms of first category include manufacturing companies having high levels of risk that requires an approval from the national security office. In the case an accident takes place in this category of firms, the damages would be quite significant and the task of controlling the fire would be very hard. These companies have a high level of risk which requires advanced techniques of prevention and intervention. The number of firms of this category would be the measure for this criterion.



The value of one on the scale means that we have one high risk firm which can be a source of significant human and environmental damage. Of course, the sites with more companies of this category have to be considered a prime candidate to have a station.

ISSN 0315-5986 | EISSN 1916-0615
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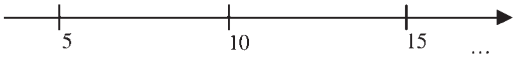
b) Presence of Industrial firms of second category (C_2)

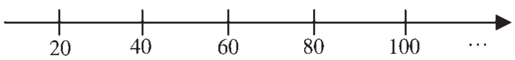
Industrial firms of second category include firms with a moderate level of risk. According to the DM, this category of risk is at midpoint between the firms of high and low risk. One needs at least five of these firms in a region to impose risk. Hence, the existence of several companies of this category within a region will require an intensive prevention and intervention in the case of fire or accidents. The measure of this criterion would be the number, in excess of four, of second category firms.



Industrial firms of category 2

c) Presence of Industrial firms of third category (C_3)

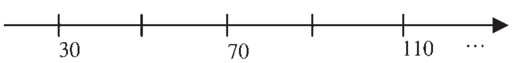
Industrial firms of third category include firms that have small level of risk which requires little fire and emergency interventions. The measure of this criterion would be the number, in excess of nineteen, of third category firms.



Industrial firms of category 3

d) Presence of Industrial firms of fourth category (C_4)

The firms of this category have very low risk. The Fire and Emergency Service of Sfax has classified them as companies with no risk. However their concentration within a small area makes the intervention difficult and less effective due to access problem. A region will be considered risky if we have at least 30 firms of this category. The measurement scale of this criterion would be as follows:



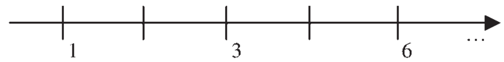
Industrial firms of category 4

3.2 Proximity to Establishments having Public Access

In addition to the risk due to industrial firms explained above, there is another type of risk posed by establishments having public access. Based on the number of people having access to the services provided by these establishments they are classified into five categories. An establishment with large number of people will be considered as a high risk entity. The five categories are presented below.

a) Presence of first category of establishments (C_5)

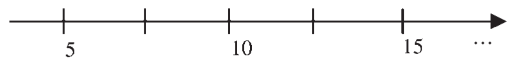
This criterion deals with establishments having high volume of public admission. In the case of an accident, the number of injured persons will be significant. In such situation, controlling the event will be a challenging task. A location having at least 1500 people will be considered as an establishment of first risk category. The number of establishments of this category would be the measure for this criterion.



Establishments with public access of category 1

b) Presence of second category of establishments (C_6)

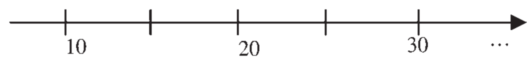
This criterion includes the establishments having an admission volume between 701 and 1500 people. This category of establishments is representing less risk compared to the first category. The following scale is utilized for measuring this criterion:



Establishments with public access of category 2

c) Presence of third category of establishments (C_7)

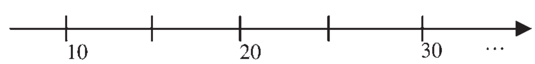
The third category of establishments is characterised by a moderate volume of admission which can be between 301 and 700 people. The measure of this criterion would be the number of third category establishments.



Establishments with public access of category 3

d) Presence of fourth and fifth category of establishments (C_8)

According to the DM, the three previous categories are forming a subset of establishments having a significant volume of admissions for public services. The establishments of categories 4 and 5 are those with a low level of risk because of the reduced volume of admissions. The Fire and Emergency Service of Sfax has decided to combine together these two categories. The measure of this criterion would be the number of fourth and fifth category establishments.



Establishments with public access of categories 4 and 5

3.3 Population Size (C_9)

Hogg (1968) puts the emphasis on the dependence between the fire incidences and population size. Thus, high concentration of residents may increase the chances of having more accidents. Such a situation complicates any intervention due to the number of the injured people. According to this criterion, a site in an area with high number of population will be considered more risky. The measure of this criterion would be the population in excess of 10,000 people.

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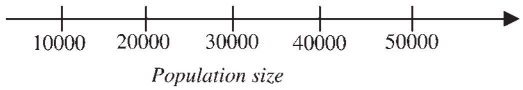
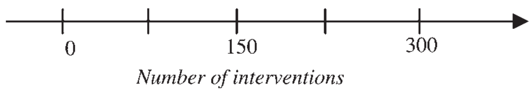


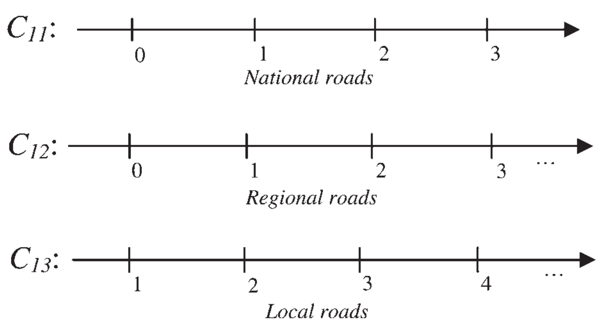
3.4 Number of Previous Interventions (C_{10})

According to the DM, the areas having a large record of accidents are considered high risk areas which require Fire and Emergency station. Some data regarding the previous interventions are available at the office of Fire and Emergency Service of Sfax. These data will be utilized by the DM to assess level of risk at different potential sites. The measure of this criterion would be the number of previous incidents. The scale of measurement is as follows:



3.5 Roads (C_{11}, C_{12}, C_{13})

Sfax is positioned on the main highway connecting the north and the south of the country. It has a road and street network of approximately 1000 kilometres long composed of: national, regional and local roads. These roads connect Sfax to different districts and neighbouring cities. The measure for these three criteria (three types of roads) would be the number of each kind of road in a region.

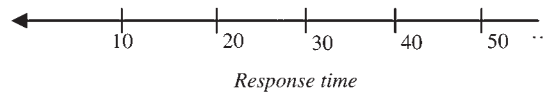


Characterized as a heavy traffic city, Sfax has experienced several major accidents. The frequency and intensity of the accidents can be explained by the narrowness of the roads and bridges, sharp curves and the poor quality of the roads. Moreover, the high volume of motorcycles and bicycles traffic increases the number of road accidents.

3.6 Response Time (C_{14})

Response time is an essential criterion in the analysis of each location. It is a good indicator of the Fire and Emergency Service performance. This criterion is directly linked to the selection process and allows the quality of the services to be assessed. The response time is calculated on the basis of the distance between the point of call and the nearest station. When a call comes in at the regional direction station, it will be assigned to the nearest station in order to reduce the response time. However, there are always demand points which require a high response time even when the dispatch leaves the nearest Fire and Emergency service station.

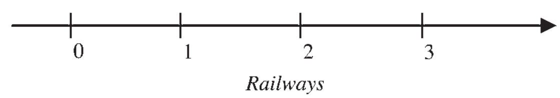
In addition to the current stations, the new station must meet the 10 minutes response time target. Beyond the existing stations, it is necessary that the additional station will meet the demand in this matter within a response time less than 10 minutes. The measure for this criterion would be the response time in excess of the 10 minutes standard time.



We would like to highlight the fact that some stations currently need more than fifty minutes to arrive to the site of accidents. One of the reasons for adding an extra station is that hopefully such lengthy times will be eliminated.

3.7 Railways: (C_{15})

The presence of the railways in a given area poses another kind of risk that can face the crew of the Fire and Emergency Service. It is a major risk to the community because it can be the cause of serious and fatal accidents, and can cause serious damage to humans and properties. The measure for this criterion would be the number of railway and road intersections.



The value of one means that we have one railway crossing which can be a source of serious human and environmental damages. The increase of the railways number means an increase of the accidents and damages.

Taking into account the fifteen criteria presented above, and in order to make the evaluation of the nine potential sites, we set up the following performance table.

This paper does not cover all criteria that might appear in general site selection problems. The criteria presented in our paper are relevant to the case of Fire and Emergency Service of Sfax. The DM has also provided the weights W_i of the criteria as presented in table 3.

4. MODEL FORMULATION

The decision-making process involves the following steps:

(i) Defining the different objectives (attributes) as presented in the previous section.
(ii) Setting the aspiration levels for each objective.

ISSN 0315-5986 | EISSN 1916-0615
DOI 10.3138/infor.48.3.143

TABLE 2.
Scores of potential sites on each attribute

		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	Goals	Weights
C_1	*Industrial firms of category 1*	4	1	1	1	6	1	0	0	2	5	0.2
C_2	*Industrial firms of category 2*	4	5	9	7	8	1	1	6	8	15	0.07
C_3	*Industrial firms of category 3*	1	16	135	6	36	1	3	6	4	50	0.02
C_4	*Industrial firms of category 4*	0	1	77	4	6	1	0	3	1	100	0.01
C_5	*EPA of category 1*	0	1	2	0	0	0	0	2	0	6	0.06
C_6	*EPA of category 2*	1	2	1	3	0	2	2	1	2	15	0.04
C_7	*EPA of category 3*	2	1	0	4	0	0	1	4	0	10	0.03
C_8	*EPA of category 4*	7	5	9	13	4	4	3	3	7	30	0.02
C_9	*Size of population*	29420	43180	10000	32420	34750	36260	55360	41390	34030	50000	0.08
C_{10}	*Interventions number*	18	9	46	245	117	4	30	2	15	320	0.16
C_{11}	*National roads*	2	1	0	1	1	2	2	0	1	3	0.05
C_{12}	*Regional roads*	2	1	1	1	0	3	0	2	1	5	0.02
C_{13}	*Local roads*	0	0	2	1	3	7	5	1	2	10	0.01
C_{14}	*Response time*	60	30	8	30	10	45	50	30	22	10	0.16
C_{15}	*Railways*	1	1	1	1	1	0	0	0	0	3	0.07

TABLE 3.
The relative importance of attributes

Aspects	Industrial firms	Establishments having public access	Population	Number of interventions	Roads	Response time	Railways
	0.3	0.15	0.08	0.16	0.08	0.16	0.07
Criteria	(C_1,C_2, C_3, C_4)	(C_5,C_6, C_7, C_8)	C_9	C_{10}	(C_{11},C_{12}, C_{13})	C_{14}	C_{15}
(W_i)	(0.2; 0.07; 0.02; 0.01)	(0.06; 0.04; 0.03; 0.02)	0.08	0.16	(0.05; 0.02; 0.01)	0.16	0.07

(iii) Preferences elucidation which includes the weight of the objectives and the satisfaction functions (the type of the functions and the thresholds).
(iv) Identification of the site list (potential sites for the Fire and Emergency Service of Sfax).
(v) The use of two GP models to select the best site.

First we apply weighted GP variant and later the GP with satisfaction function to determine which site provides the DM with highest satisfaction level.

4.1 Weighted Goal Programming Model Formulation

The Weighted Goal Programming (WGP) is one of the GP variants that have been widely applied in various fields where multiple objectives are involved. The WGP formulation was presented by Charnes and Cooper (1961) and it requires the identification of the objectives, the aspiration levels for objectives, and weights for the negative and positive deviations from aspiration levels. The overachievement (δ_i^+) and the underachievement (δ_i^-) of the objectives may carry different weights. The weights (W_i^+) and (W_i^-) reflect the relative importance of the positive and negative deviations respectively.

The mathematical formulation of the WGP is as follows:

$$\text{Min}\, Z = \sum_{i=1}^{p} (W_i^+ \delta_i^+ + W_i^- \delta_i^-)$$

Subject to:

$$f_i(x) - \delta_i^+ + \delta_i^- = g_i \quad (\text{for } i = 1, 2, \ldots p)$$
$$x \in F$$
$$\delta_i^+ \text{ and } \delta_i^- \geq 0 \quad (\text{for } i = 1, 2, \ldots p)$$

where:

$f_i(x)$: is the objective i,
g_i: is the aspiration level (goal) of the objective i,
F: is the feasible set of solutions,
δ_i^+, δ_i^-: are the positive and negative deviations respectively.

The WGP model has been utilized by the DM to select one site among nine potential sites. As described in section 3, there are fifteen attributes considered by the DM. The decision variables

ISSN 0315-5986 | EISSN 1916-0615
DOI 10.3138/infor.48.3.143

are defined as follows:

$$x_j = \begin{cases} 1, & \text{if the site } j \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

for $j = 1, 2, \ldots 9$.

The set of the feasible solutions is defined as follows: $F = \left\{ x : \sum_{j=1}^{9} x_j = 1, x_j \in \{0, 1\} \right\}$

The software Hyper-LINDO was utilized to solve the WGP by considering the data available in Tables 1 and 2, the solution is $x_7 = 1$ and the rest of the decision variables are zero. Hence the best site is Bir Ali Ben Khlifa. This site has the largest population, an attribute with relatively high weight. Overall, this site has good evaluations. By applying the WGP model, the DM's preferences have been expressed only by the weights. However, we can allow the DM to elucidate his appreciation of the negative and positive deviations from each goal. The concept of satisfaction function will be utilized to integrate explicitly the DM's preferences structure for these deviations.

4.2 Goal Programming Model with Satisfaction Function Formulation

In order to integrate explicitly the DM's preferences for goal deviations, we have utilized the GP model with satisfaction functions to obtain the best site for the location of Fire and Emergency Service of Sfax. The concept of satisfaction function was introduced by Martel and Aouni (1990). This concept allows the DM to express explicitly his or her preferences (appreciation) of the distances (deviations) between the achievement and the aspiration levels of an objective. The general form of the satisfaction functions is as follows (Figure 2).

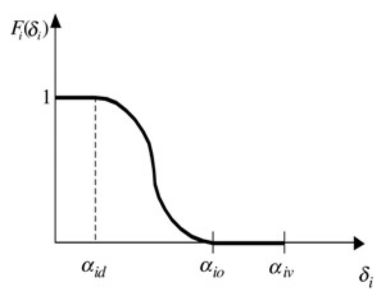


Figure 2. General form of the satisfaction functions

where:

$F_i(\delta_i)$: is the satisfaction function of objective i,
α_{id}: is the indifference threshold,
α_{i0}: is the *nil* satisfaction threshold,
α_{iv}: is the *veto* threshold.

The DM may appreciate the positive and the negative deviations differently. In such a case, the DM's preferences can be expressed through the satisfaction functions $F_i(\delta_i^+)$ and $F_i(\delta_i^-)$. Martel and Aouni (1990) present six types of satisfaction functions that the DM can adopt to elucidate explicitly his/her preferences. Their list is neither exhaustive nor restrictive. The DM may adopt a different shape that better reflects his/her preferences.

The mathematical formulation of the GP model with satisfaction functions is as follows:

$$\text{Max } Z = \sum_{i=1}^{p} (W_i^+ F_i^+(\delta_i^+) + W_i^- F_i^-(\delta_i^-))$$

Subject to:

$$f_i(x) + \delta_i^- - \delta_i^+ = g_i \quad (\text{for } i = 1, 2, \ldots p)$$
$$x \in F$$
$$0 \le \delta_i^+ \le \alpha_{iv}^+ \quad (\text{for } i = 1, 2, \ldots p)$$
$$0 \le \delta_i^- \le \alpha_{iv}^- \quad (\text{for } i = 1, 2, \ldots p)$$

To apply this model, the DM (the Fire and Emergency Service officer) should reveal his satisfaction functions for the fifteen attributes. These functions will be described in the coming subsections.

4.2.1 *Satisfaction Function for C_1 Deviations*

The Fire and Emergency Service officer looks for a site that may cover the maximum number of industrial firms of category 1. The DM prefers a site closer to areas having a large number of industrial firms of category 1. The goal value for this attribute is $g_1 = 5$, which means five industrial firms of category 1. The satisfaction function of this attribute is a level-criterion function (Type IV, Martel and Aouni, 1990). The equivalent mathematical representation of this satisfaction function is presented as follows:

$$F_1^-(\delta_1^-) = \begin{cases} f_1(\delta_1^-) = 1 & \text{if } 0 \le \delta_1^- \le 2 \\ f_2(\delta_1^-) = 0.8 & \text{if } 2\text{ },\ \delta_1^- \le 3 \\ f_3(\delta_1^-) = 0.5 & \text{if } 3\text{ },\ \delta_1^- \le 4 \\ f_4(\delta_1^-) = 0 & \text{if } 4\text{ },\ \delta_1^- \le 5 \end{cases}$$

4.2.2 *Satisfaction Function for C_2 Deviations*

The Fire and Emergency Service officer expresses less importance to the industrial firms of category 2. The nature of products of these companies is considered less risky. However, the risk will be important if the number of companies located within a specific area increases. The aspiration level for this attribute was established to $g_2 = 15$. The satisfaction function of this criterion is a level criterion function (Type IV) which can be mathematically presented as follows:

$$F_2^-(\delta_2^-) = \begin{cases} f_1(\delta_2^-) = 1 & \text{if } 0 \le \delta_2^- \le 5 \\ f_2(\delta_2^-) = 0.7 & \text{if } 5\text{ },\ \delta_2^- \le 10 \\ f_3(\delta_2^-) = 0.5 & \textit{if } 10\text{ },\ \delta_2^- \le 12 \\ f_4(\delta_2^-) = 0 & \text{if } 12\text{ },\ \delta_2^- \le 15 \end{cases}$$

ISSN 0315-5986 | EISSN 1916-0615
DOI 10.3138/infor.48.3.143

4.2.3 Satisfaction Function for C_3 Deviations

The third category of industrial firms contains the industrial firms in the city with less risk that requires less prevention. However, a large number of this category of firms is registered in Sfax city. According to this category, a location having at least 50 industrial firms belonging to the third category will be considered more risky. So, the goal for this criterion is $g_3 = 50$. A satisfaction function of type IV is selected for this attribute and its equivalent representation is provided below:

$$F_3^-\left(\delta_3^-\right) = \begin{cases} f_1\left(\delta_3^-\right) = 1 & \text{if } 0 \leq \delta_3^- \leq 20 \\ f_2\left(\delta_3^-\right) = 0.7 & \text{if } 20\ , \quad \delta_3^- \leq 35 \\ f_3\left(\delta_3^-\right) = 0.3 & \text{if } 35\ , \quad \delta_3^- \leq 45 \\ f_4\left(\delta_3^-\right) = 0 & \text{if } 45\ , \quad \delta_3^- \leq 50 \end{cases}$$

4.2.4 Satisfaction Function for C_4 Deviations

The fourth category of the industrial companies includes those considered as not classified. These firms are dispersed within the city of Sfax, they require a preventive coverage against the risk. The high density of these industrial firms presents another kind of risk requiring an adequate coverage. The aspiration level of this attribute is $g_4 = 100$. The satisfaction function of this criterion is also of type IV which is mathematically presented as follows:

$$F_4^-\left(\delta_4^-\right) = \begin{cases} f_1\left(\delta_4^-\right) = 1 & \text{if } 0 \leq \delta_4^- \leq 30 \\ f_2\left(\delta_4^-\right) = 0.8 & \text{if } 30\ , \quad \delta_4^- \leq 50 \\ f_3\left(\delta_4^-\right) = 0.5 & \text{if } 50\ , \quad \delta_4^- \leq 70 \\ f_4\left(\delta_4^-\right) = 0 & \text{if } 70\ , \quad \delta_4^- \leq 100 \end{cases}$$

4.2.5 Satisfaction Function for C_5 Deviations

The classification of the establishments regarding the access to public services is based on the number of people attending the establishment. So, the greater the number of people attending the establishment is, the greater the risk will be. The first category presents the high level of risk attained by these establishments. The target set for this attribute is $g_5 = 6$. The satisfaction function of this objective is of Type IV. The equivalent mathematical representation of this satisfaction function is presented as follows:

$$F_5^-\left(\delta_5^-\right) = \begin{cases} f_1\left(\delta_5^-\right) = 1 & \text{if } 0 \leq \delta_5^- \leq 3 \\ f_2\left(\delta_5^-\right) = 0.75 & \text{if } 3\ , \quad \delta_5^- \leq 4 \\ f_3\left(\delta_5^-\right) = 0.4 & \text{if } 4\ , \quad \delta_5^- \leq 5 \\ f_4\left(\delta_5^-\right) = 0 & \text{if } 5\ , \quad \delta_5^- \leq 6 \end{cases}$$

4.2.6 Satisfaction Function for C_6 Deviations

The second category includes the establishments having a public access in the range of 701 to 1500 people. The goal set for this attribute is 7, which means that the existence of seven establishments presents an important risk that required adequate coverage. The satisfaction function of this objective is of type IV and the equivalent mathematical representation is as follows:

$$F_6^-\left(\delta_6^-\right) = \begin{cases} f_1\left(\delta_6^-\right) = 1 & \text{if } 0 \leq \delta_6^- \leq 6 \\ f_2\left(\delta_6^-\right) = 0.7 & \text{if } 6\ , \quad \delta_6^- \leq 8 \\ f_3\left(\delta_6^-\right) = 0.5 & \text{if } 8\ , \quad \delta_6^- \leq 12 \\ f_4\left(\delta_6^-\right) = 0 & \text{if } 12\ , \quad \delta_6^- \leq 15 \end{cases}$$

4.2.7 Satisfaction Function for C_7 Deviations

The third category of establishments with public access has a capacity of 300 to 701 people. It will be considered as highly risky when we will have a concentration of 10 or more of establishments of this type. The goal of this objective has been set to $g_7 = 10$. A satisfaction function of type IV was adopted for this attribute and its equivalent representation is as follows:

$$F_7^-\left(\delta_7^-\right) = \begin{cases} f_1\left(\delta_7^-\right) = 1 & \text{if } 0 \leq \delta_7^- \leq 5 \\ f_2\left(\delta_7^-\right) = 0.5 & \text{if } 5\ , \quad \delta_7^- \leq 7 \\ f_3\left(\delta_7^-\right) = 0.25 & \text{if } 7\ , \quad \delta_7^- \leq 8 \\ f_4\left(\delta_7^-\right) = 0 & \text{if } 8\ , \quad \delta_7^- \leq 10 \end{cases}$$

4.2.8 Satisfaction Function for C_8 Deviations

The highest number of establishments with public access in the city of Sfax belongs to the fourth category making its coverage a challenging task. The threshold of 30 establishments requires the creation of a new station. Hence, the goal of this attribute has been set by the DM to 30 establishments ($g_8 = 30$). The satisfaction function for this attribute is of type IV and its equivalent representation is as follows:

$$F_8^-\left(\delta_8^-\right) = \begin{cases} f_1\left(\delta_8^-\right) = 1 & \text{if } 0 \leq \delta_8^- \leq 5 \\ f_2\left(\delta_8^-\right) = 0.8 & \text{if } 5\ , \quad \delta_8^- \leq 10 \\ f_3\left(\delta_8^-\right) = 0.5 & \text{if } 10\ , \quad \delta_8^- \leq 20 \\ f_4\left(\delta_8^-\right) = 0 & \text{if } 20\ , \quad \delta_8^- \leq 30 \end{cases}$$

4.2.9 Satisfaction Function for C_9 Deviations

The Fire and Emergency Service station must be located in proximity to a community to be served, and closer to areas with high number of population. It must equally respond to the population requirements in the shortest possible time. The target set for this criterion is $g_9 = 50000$. A deviation beyond this value means that the site is located in an area less populated than 50000. The satisfaction function of this attribute is of type V known as the criterion with linear preference and indifference range. The equivalent mathematical representation of

ISSN 0315-5986 | EISSN 1916-0615

this satisfaction function is as follows:

$$F_9^-\left(\delta_9^-\right)=\begin{cases} f_1\left(\delta_9^-\right)=1 & \text{if } 0\le\delta_9^-\le 10000 \\ f_2\left(\delta_9^-\right)=-0.00003\delta_9^-+1.3 & \text{if } 10000,\ \delta_9^-\le 45000 \\ f_3\left(\delta_9^-\right)=0 & \text{if } 45000,\ \delta_9^-\le 50000 \end{cases}$$

4.2.10 *Satisfaction Function for C_{10} Deviations*

The Fire and Emergency Service of Sfax maintains some data regarding the annual number of interventions. These data are sorted for the purpose of identifying the areas with high needs for interventions. The aspiration level for this attribute has been set to 320 interventions ($g_{10} = 320$). The DM has provided the satisfaction function of type V for this attribute. The equivalent mathematical representation of this satisfaction function is provided below:

$$F_{10}^-\left(\delta_{10}^-\right)=\begin{cases} f_1\left(\delta_{10}^-\right)=1 & \text{if } 0\le\delta_{10}^-\le 50 \\ f_2\left(\delta_{10}^-\right)=-0.004\delta_{10}^-+1.2 & \text{if } 50,\ \delta_{10}^-\le 300 \\ f_3\left(\delta_{10}^-\right)=0 & \text{if } 300,\ \delta_{10}^-\le 320 \end{cases}$$

4.2.11 *Satisfaction Function for C_{11} Deviations*

The manager of Fire and Emergency Services prefers a site closer to the national roads in order to cover the risk presented by heavy traffics. Many dangerous accidents happened on these roads. This reality has to be considered in the selection of the new site. The goal for this attribute has been set to 3 and the satisfaction function of this attribute is of type IV and it can be represented as follows:

$$F_{11}^-\left(\delta_{11}^-\right)=\begin{cases} f_1\left(\delta_{11}^-\right)=1 & \text{if } 0\le\delta_{11}^-\le 1 \\ f_2\left(\delta_{11}^-\right)=0.8 & \text{if } 1,\ \delta_{11}^-\le 2 \\ f_3\left(\delta_{11}^-\right)=0 & \text{if } 2,\ \delta_{11}^-\le 3 \end{cases}$$

4.2.12 *Satisfaction Function for C_{12} Deviations*

The number of accidents happened on the regional roads during recent years has been so high that this attribute becomes important for the site selection process. The goal set for the regional roads is $g_{12} = 5$. The satisfaction function associated with this criterion is also of type IV and the associated equivalent representation is as follows:

$$F_{12}^-\left(\delta_{12}^-\right)=\begin{cases} f_1\left(\delta_{12}^-\right)=1 & \text{if } 0\le\delta_{12}^-\le 2 \\ f_2\left(\delta_{12}^-\right)=0.8 & \text{if } 2,\ \delta_{12}^-\le 3 \\ f_3\left(\delta_{12}^-\right)=0.5 & \text{if } 3,\ \delta_{12}^-\le 4 \\ f_4\left(\delta_{12}^-\right)=0 & \text{if } 4,\ \delta_{12}^-\le 5 \end{cases}$$

4.2.13 *Satisfaction Function for C_{13} Deviations*

The city of Sfax encompasses a high number of local roads. The goal set for this attribute is $g_{13} = 10$ and the satisfaction function is of type IV. The mathematical representation of this function is as follows:

$$F_{13}^-\left(\delta_{13}^-\right)=\begin{cases} f_1\left(\delta_{13}^-\right)=1 & \text{if } 0\le\delta_{13}^-\le 3 \\ f_2\left(\delta_{13}^-\right)=0.8 & \text{if } 3,\ \delta_{13}^-\le 5 \\ f_3\left(\delta_{13}^-\right)=0.6 & \text{if } 5,\ \delta_{13}^-\le 8 \\ f_4\left(\delta_{13}^-\right)=0 & \text{if } 8,\ \delta_{13}^-\le 10 \end{cases}$$

4.2.14 *Satisfaction Function for C_{14} Deviations*

The Fire and Emergency Service officers attempt to minimize the response time, so the goal set for this criterion is $g_{14} = 10$. Reducing the travel time in order to improve the service level is the main objective of the DM. The satisfaction function of this attribute is known as the criterion with linear preference (type III) and the associated equivalent mathematically representation is as follows:

$$F_{14}^+\left(\delta_{14}^+\right)=\begin{cases} f_1\left(\delta_{14}^+\right)=-0.02\delta_{14}^++1 & \text{if } 0\le\delta_{14}^+\le 50 \\ f_2\left(\delta_{14}^+\right)=0 & \text{if } 50,\ \delta_{14}^+\le 60 \end{cases}$$

4.2.15 *Satisfaction Function for C_{15} Deviations*

According to the DM, the presence of a railway in a given area is a source of risk. The DM has set the goal value for this attribute to $g_{15} = 3$. The satisfaction function of this attribute is of type IV and the equivalent mathematically representation is presented below:

$$F_{15}^-\left(\delta_{15}^-\right)=\begin{cases} f_1\left(\delta_{15}^-\right)=1 & \text{if } 0\le\delta_{15}^-\le 1 \\ f_2\left(\delta_{15}^-\right)=0.75 & \text{if } 1,\ \delta_{15}^-\le 2 \\ f_3\left(\delta_{15}^-\right)=0 & \text{if } 2,\ \delta_{15}^-\le 3 \end{cases}$$

The satisfaction functions that we have presented have been introduced in the mathematical program 2 and we have utilized the data presented in Table 1. We have considered the weights of the attributes as provided by the DM (see Table 2). The obtained mathematical program is a nonlinear program. The linearization procedure developed by Oral and Kettani (1992) and modified by Aouni (1996) was used to obtain an equivalent linear program. The software hyper-LINDO was used to obtain the following solution: $x_4^* = 0$, $x_j^* = 0$ ($j = 1, 2, 3, 5, 6, 7, 8$ and 9), $Z = 0.768$. The recommendation is to have the Fire and Emergency Service at the site of Mahres. The global performance (maximum satisfaction) of this recommendation is $Z(x_4^*) = 0.768$ which can be interpreted as the global achievement level of the objectives preferred by the DM and indicated through the satisfaction functions. In fact, this recommendation

DOI 10.3138/infor.48.3.143

represents the solution of the best compromise that globally meets the DM's expectations.

5. CONCLUDING REMARKS

The officer of the regional department of Fire and Emergency Service has considered the proposed solution as satisfactory. Since the considered attributes are conflicting, none of the nine sites can simultaneously optimize all objectives. The model was seeking for the best compromise that maximizes the DM's satisfaction and respects the budgetary constraints. Indeed, the best site was Mahres that can provide good services to some nearest sites such as Tina, Skhira, Agareb, Bir Ali Ben Khlifa and Menzel Chaker. During the decision-making process we noticed that the DM was cooperative and was able to easily provide the thresholds of the satisfaction functions. This process involved interviews with the director of the Regional office of Sfax Fire and Emergency Service. In the first interview, we asked to identify the potential sites and the factors leading to these choices. One of the major factors was to serve the locations with a high risk of fire. Based on the geographical characteristics of the city of Sfax and the network of access roads nine risky sites have been identified. The cost was not an issue for the DM since it did not vary from one site to site. In the second round of interviews and discussions, we asked to establish and define the attributes (objectives), the goals and the relative importance of each objective. The collected information was introduced in the weighted goal programming variant. The solution obtained from this model was not acceptable to the DM. This solution did not meet the DM's expectations. We proposed the use of the Goal Programming Model and the satisfaction function which was accepted. The decision-making process has started by explaining the meaning and the role of the thresholds in the satisfaction functions. We also explained how these functions measure the intensity of preferences regarding the distance (deviation) between the aspiration and the achievement levels of the attributes. In order to provide assistance in the process of preference elucidation, we introduced six types of the satisfaction functions suggested by Martel and Aouni (1990). These types of functions were useful to establish for each attribute the shape of the satisfaction function and the different thresholds. The developed model was solved and the solution was presented to the DM. The DM's feedback was positive and he found that the selected site would allow the Fire and Emergency Service to cover the zone within a reasonable response time. In fact, among all nine sites this site has the highest rate of emergency interventions. Overall, we found that the DM was very cooperative during the decision making process and he was satisfied with the obtained solution. The proposed model is considered as a multicriteria decision aid tool that helps to deal with the problem of selecting a site for Fire and Emergency Service. This model can be combined with the Geographical Information System to have an integrated decision support system that may assist the DM for better management of fire and emergency response.

REFERENCES

Alsalloum, O. I. and Rand, G. K. (2006), "Extensions to emergency vehicle location models", *Computers and Operations Research*, 33(9): 2725–2743.

Aouni, B. (1996), "Linéarisation des expressions quadratiques en programmation mathématique: des bornes plus efficaces", *Proceedings of The Annual Conference of the Administrative Sciences Association of Canada, Management Science*, 17(2): 38–46.

Atkinson, J. B., Kovalendo, I. N., Kuznetsov, N., and Mykhalevych, K. V. (2008), "A hypercube queuing loss model with customer-dependent service rates", *European Journal of Operational Research*, 191(1), 223–239.

Badri, M. A., Mortagy, A. M., and Alsayed, C. A. (1998), "A multi-objective model for locating fire stations", *European Journal of Operational Research*, 110(2): 243–260.

Brotcorne, L., Laporte, G., and Semet, F. (2003), "Ambulance location and relocation models", *European Journal of Operational Research*, 147(3): 451–463.

Charnes, A. and Cooper, W.W. (1961), *Management models and industrial applications of linear programming*, Wiley, New York.

Charnes, A. and Storbeck, J. (1980), "A goal programming model for the siting of multilevel EMS system", *Socio-Economic Planning Sciences*, 14(4): 155–161.

Church, R. and Revelle, C. (1974), "The maximal covering location problem", *Papers of the Regional Science Association*, 32(1): 101–118.

Daskin, M.S. (1982), "Application of an expected covering model to emergency medical service system design", *Decision Sciences*, 13(3): 416–439.

Goldberg, J., Dietrich, R., Chen, J. M., Mitwasi, M. G., Valenzuela, T., and Criss, E. (1990), "Validating and applying a model for locating emergency medical vehicles in Tucson, AZ", *European Journal of Operational Research*, 49(3): 308–324.

Harewood, S.I. (2002), "Emergency ambulance deployment in Barbados: A multi-objective approach", *Journal of the Operational Research Society*, 53(2): 85–192.

Hogg, J. (1968), "The siting of fire stations", *Operational Research Quarterly*, 19(3): 275–287.

Iannoni, A.P. and Morabito, R. (2007), "A multiple dispatch and partial backup hypercube queuing model to analyze emergency medical systems on highways", *Transportation Research, Part E*, 43(6): 755–771.

Karkazis, J. (1989), "Facilities location in a competitive environment: A Promethee based multiple criteria analysis", *European Journal of Operational Research*, 42(3): 294–304.

Kwak, N. K. and Schniederjans, M. J. (1985), "A Goal Programming model for selecting a facility location site", *R.A.I.R.O Recherche Opérationnelle/Operations Research*, 19(1): 1–14.

Larson, R.C. (1974), "A Hypercube queuing model for facility location and redistricting in urban emergency services", *Computers and Operations Research*, 1(1): 67–95.

INFOR, Vol. 48, No. 3, August 2010, pp. 143–153
ISSN 0315-5986 | EISSN 1916-0615
DOI 10.3138/infor.48.3.143

Marianov, V. and Revelle, C. (1995), "*Siting emergency services*", in: Drezner, D. (ed), Facility location: a Survey of applications and methods, Springer, New York.

Martel, J.M. and Aouni, B. (1990), "Incorporating the decision-maker's preferences in the goal programming model", *Operational Research Society*, 41(12): 1121–1132.

Martel, J.M. and Aouni, B. (1992), "Méthode multicritère de choix d'un emplacement: le cas d'un aéroport dans le nouveau Québec", *INFOR*, 30(2): 97–117.

Mladineo, N., Margeta, J., Brans, J.P., and Mareschal, B. (1987), "Multicriteria ranking of alternative locations for small scale hydro plants", *European Journal of Operational Research*, 31(2): 215–222.

Oral, M. and Kettani, O. (1992), "A linearization procedure for quadratic and cubic mixed integer problems", *Operations Research*, 40(1): 109–116.

Savas, E.S. (1969), "Simulation and cost-effectiveness analysis of New York's emergency ambulance service", *Management Science*, 14(12): 608–627.

Tamiz, M., Jones, D., and Romero, C. (1998), "Goal programming for decision making: an overview of the current state-of -the-art", *European Journal of Operational Research*, 111(3): 569–581.

Toregas, C., Swain, R., Revelle, C., and Bergman, L. (1971), "The location of emergency service facilities", *Operations Research*, 19(5): 1363–1373.

INFOR, Vol. 48, No. 3, August 2010, pp. 143–153
ISSN 0315-5986 | EISSN 1916-0615
DOI 10.3138/infor.48.3.143

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