International Journal of Industrial Engineering & Production Research

ISSN: 2008-4889

December 2011, Volume 22 Number 4
pp. 243-250

http://IJIEPR.iust.ac.ir/

A Multiple Objective Nonlinear Programming Model for Site Selection of the Facilities Based on the Passive Defense Principles

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KEYWORDS

Passive defense,
Site selection, Dispersion,
Security Multiple objective
decision making (MODM)

ABSTRACT

One of the main principles of the passive defense is the principle of site selection. In this paper, we propose a multiple objective nonlinear programming model that considers the principle of the site selection in terms of two qualitative and quantitative aspects. The purpose of the proposed model is selection of the place of facilities of a system in which not only it observes the dispersion principle but also reduces the system transportation costs. Moreover, the proposed model tries to select the sites that can fulfill other elements of site selection as well as dispersion in a way that it increases the trustworthiness of the selected network.

1. Introduction

Site selection is a kind of spatial planning during which the place of establishment will be determined. In the usual spatial planning, first the features of the zones is determined and then depending on their features and specifications, the activity or the activities that are suitable for each zone is determined. But in site selection, first the features of a particular activity is determined and then the places and zones that are more suitable for the determined activities will be assigned (Drezner, 1995).
The industrial site selection theories intend to explain the structure of the site selection of the industrial activities based on the factors and variables that are efficient in site selection and try to find the best sites for establishment of industrial centers. Most of these theories originate from economic thoughts formulated by the economists. They have tried to create these theories so that they relate the site variable to the main body of the economic theories. Generally, the industrial site selection theories can be divided into three methods (Church and Murray, 2009).
Minimum cost method in which, in the process of site selection, the attempt is made to minimize the production costs. The analysis of the available commercial area in which the main focus is on the demand and market and also maximizing the available area. Earning the maximum advantages that is, in fact, the logical result of the above methods. The ideas made by Lan Hard, Houver and Weber are mostly related to minimizing the costs. In 1890s, Lan Hard tried to show how it is possible to show a optimum site selection in simple conditions of two primary sources and one market in a triangle (Wesolowski, 1993).
The beginning of the industrial site election goes back to 1909 when Weber published his book Weber Standortder Industrien in this regard. In this book, he presented his paper findings on factorial industries. He took the fallowing three factors as the influential elements in industrial site selection: (Weber, 1965)
Workforce costs
Transportation costs
Association forces or non association of the transportation costs.
In 1948, Houver presented his work on industrial site selection. Comparing with Weber's theory, he divided

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Paper first received Aug.. 12, 2011, and in revised form Oct. 04, 2011.

the costs into transportation and production costs in a more argumentative manner (Wesolowski, 1993).
In recent years, the principle of site selection has been more emphasized and the scientists have proposed many theories on this domain (Hamacher et.al, 2004). In most of the above cases, the only important factor that is considered is the system costs. These models can not solely be applied in passive defense issues because they do not pay attention to the security of facilities places, limitation of their distances, their dispersion to increase the covered areas and reduce their recognizability by the enemy and avoid impairment of production network because of being closeness. If the facilities be placed near each other, they may be attacked in an inroad.
One of the defining objectives in location science is to maximize dispersion. Facilities can be dispersed for a wide variety of purposes, including keeping competitors of the same franchise system apart, dispersing criminal rehabilitation facilities from population centers, and locating nuclear power plants in such a way as to maximize security (Curtin and Church, 2006).
Dispersion models can be applied over a spectrum of scales: macroscale applications include such things as the location of radio transmitters or defense installations over a large geographic region; mesoscale applications include the location of schools, housing developments, landfills, or incinerators within a smaller, well-defined geographic region; and microscale applications of dispersion can include such things as product shelf location and factory or classroom layout studies (Alçada-Almedia et.al, 2009, Rakas et.al, 2004)
By far the most common use of dispersion models is for the location of undesirable facilities (see Church and Garfinkel, 1978; Drezner and Wesolowsky, 1985; Erkut and Neuman, 1989; Drezner and Wesolowsky, 1996). This literature is further divided into the location of noxious and obnoxious facilities. Noxious facilities are those that present some health risk to any population that would be exposed to either the damaging repercussions of an accident at the facility or the damaging consequences of long-term exposure to the facility. Examples of noxious facilities include coal-fired power stations, nuclear power plants, hazardous waste storage sites, oil storage tanks, ammunition dumps, landfills, and incinerators. Obnoxious facilities are not expected to cause health risks to populations, but they may have (or be perceived to have) deleterious social or economic consequences associated with their location and operation.
Examples of obnoxious facilities include prisons, activities that generate excessive noise, social service centers, and rehabilitation (e.g., drug treatment) centers (Murray et al. 1998). Obnoxiousness may result in disagreements between the facility operator and the local population that are based on ideological or attitudinal conflict (Sorensen, et.al, 1984). Facilities that are considered undesirable may have attributes that are both noxious and obnoxious (Berman and Wang, 2008).
The Purpose of this paper is to propose a model that can maximize the facilities dispersion measure. It can do so by maximization of the set of measured spatial (Euclidean) weighted distances. It should, also, select the sites that have reliability. This reliability refers to the ability to perform the duty and harmony with the environment. Additionally, we must minimize the transportation costs of the facilities. Col. John A. Warden III, a former USAF officer and theorist of air power, established a theory of strategic attack based on five levels of system attributes. They are:
Leadership
Organic/System Essentials
Infrastructure
Population
Fielded Military Forces.
Each level of system or "ring" was considered one of the enemy's centers of gravity. The idea behind Warden's five rings was to attack each of the rings to paralyze their forces, an objective also known as physical paralysis. (Movahedniya, 2007)

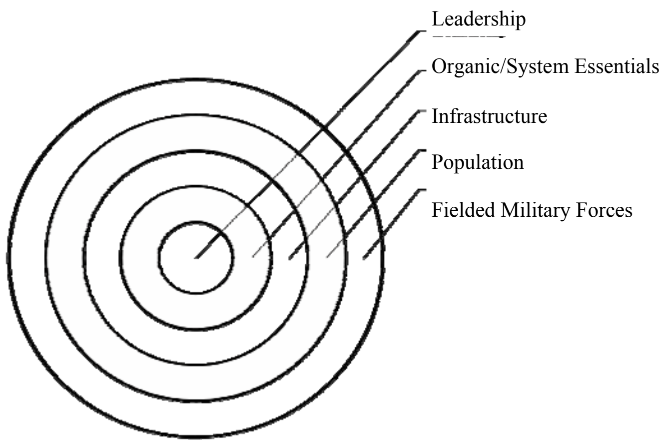

Fig. 1. Five Strategic Rings of Warden

It is worth mentioning that the proposed model is applicable in all the factors in Five Strategic Rings of Warden. But, here, we focus more on its application in the case of Warden's second strategic ring, that is, the production facilities of key products.
The rest of this paper organized as follows: In the following section, we explain the necessity of site selection in the passive defense and then analyze the problem and its requirements and the way of fulfilling them. We also deal with the limitations of the problem and the reason of their existence. In section 4, we make the hypotheses, nomenclature and present the proposed model. In section 5, the conclusion of the proposed model will be offered in a unique unit and a numerical example will be solved. And then, the results and the model capabilities, in comparison with other models, will be analyzed.

2. Passive Defense and Site Selection Necessity

In the modern wars, it is inevitable to perform the passive defense steps in order to confront the enemy's attacks and reduce the damages due to air, land and naval attacks. It is a fundamental issue that covers all key substructures, crucial, hypersensitive and important military and non-military centers, like refineries, power plants, ports, airports, large industrial complexes, military and politic headquarters, tele-communication centers, strategic bridges, military industries, air bases, missile pads, populated centers and tactical quarters, support and defense seats, etc (Movahedniya, 2007).

The paper approach to statistics and recorded experiences in old wars shows that the technology gap between enemy's modern armaments and insider defensive armaments, vulnerability of air defense systems against electronic wars, unawareness of these systems against fighters and cruise and ballistic missiles, launching rockets far away the range of defensive air armaments, lack of anti missile arms will make the crucial points as some simple targets for a successful and quick aiming by enemy's fighters and armaments. Therefore, it seems necessary and inevitable to observe the principles of passive defense and execute them in the country. To do so, one of the main principles is site selection. According to the proposed identification in the passive defense domain, site selection is: selecting the best and the most appropriate place for establishment in a way that it enables us to hide human force, facilities and activities appropriately. Thus, if site selection is done well, it minimizes the necessity to use artificial tools for camouflage (Movahedniya, 2007).

The experience has shown that an appropriate and suitable site selection can solve many problems related to camouflage and concealment and also reduce the possible threats and vulnerabilities. The advantages of an appropriate site selection are as follows:

- The significant reduction of vulnerability.
- Creation a suitable defensive situation.
- Confronting the enemy with problems and limitations in his attacks and disable it to do any process.
- The reduction of dependency to defensive armaments.

In passive defense, site selection includes three bases: duty, dispersion and topography (Sahami, 2007).

Duty has the most important and highest role in comparison with other site selection factors. It is possible for a place to be suitable for establishment of a military or non military unit with regard to camouflage and concealment but not to be accommodating for our duty.

Dispersion is the distribution and decentralization of the forces, facilities, installations or domestic activities to reduce their vulnerability against threats. The main requirement in dispersion principle is the largeness and extent of a position. Since the dispersion of the facilities and installation makes the selected site vulnerable, it is necessary to disperse the facilities and installations. During site selection, we may find some places that have an especial form which distinguishes them from other areas. In these areas, therefore, every change in the form can be an indication of activity and human existence. In other words, every kind of new building that is not harmonious with the environment can help the enemy to recognize and identify that area as a crucial point to focus on. Considering the above principles and rules, we must select a site for facilities and installations so that it can satisfy the requirements of the passive defense. In the same way, we need a model to select the required site of the facilities and installations that can formulate all the limitations and demands.

3. Analysis of the Problem

In this problem, we deal with some places which are placed in one region. Their longitudinal and latitudinal distances (longitudinal and latitudinal coordinates) from a refer point is determined. These points, also, have a feature, named security coefficient that depends on some factors, including the ability of the points to help us to do our duty, the harmoniousness of the facilities with the environment, hiding the facilities from the enemy and other influential parameters that enables the enemy to identify the facilities. It is calculated by multiplying two above parameters by another one, named criticality (gravity).

We define the above parameters as follows:

- Duty: the ability to correctly perform the duty based on the facilities in a region that is identified with a number between zero and one. The more this number is for a facility; the more that facility has the ability is to perform his duty in that certain point.
- Criticality: it shows the intensity of the effects of enemy's attack on especial facility on the whole system and the usual circulation of the people life. The value of the criticality can be shown by a numerical parameter. The more severe the effects of the attack, the less the value of this parameter.
- Recognition: the possibility of the recognition of the site selected facility in that place according to the influential factors in recognition of an facility by enemy's offensive armaments. The more the measure of recognition, the less the value of this number.

For example, if facility in a certain point can perform his duty with a probability of 0.9, and criticality of 0.05 and recognition of 0.85, the security coefficient of that point for that facility will be calculated as follows:

Security coefficient= *duty* × *criticality* × *recognition* = *0.90 × 0.05 × 0.85= 0.0382*

These places have some distances too that are different from their spatial distances. The yare the same distances that must be traversed by the land forces who are busy with the system so that they can move from one place to another. In this issue, there are two kinds of interaction between the facilities that are defined as follows:

Repulsion interaction (disagreement): it is identified by a number between zero and one. The less this number is, the more disagreement will be between those two facilities. This interaction shows that whether these two facilities should be placed far from each other or no. This coefficient is imposed on the system by the essence two facilities application, official policies and other influential factors. The interaction of the synergetic relationship between two facilities: it is also identified by a number between zero and one that shows the relation weight between two facilities. The greater the value of this coefficient, there are more transportations between these two facilities and thus, the cost of the distance between two facilities.

Because of some spatial limitations and some other factors, we should determine the maximum air distance between different kinds of facilities. These distances are even defined for similar facilities. Our objectives in this model are:

a) We can achieve the maximum dispersion with a focus on maximization of the sum of weighted distances by repulsion coefficients. This purpose seeks to make the created network by site selected facilities, provide the dispersion principle in the passive defense and also be dispersed through the entire network.
b) Minimization the system transportation cost which identified by synergetic relationship coefficient.
c) Achieving the maximum created security by the network if it maximize the security coefficient of the selected sites.

Thus, this paper goal is to locating facilities based on the passive defense goals with subject to the limitations of location theory and passive defense requirements.

Model

Hypotheses

- It is supposed that the number of the facilities is less or equal to the number of all the sites.
- The land distances can not be less than air distances.
- The presented repulsion coefficients are taken from the system specialists and experts.
- The synergetic relationship coefficient shows the coming and going cost according to the distance between two facilities. These coming and going can be due to non-production relationships too.
- The facilities that are in the process of site selection must be kept in a certain distance from each other. Because they may have poisonous and flammable material.
- The reference point is not a part of selected sites, but it is located at the below and left of all the sites.
- Except the facility site determination variable, other features and parameters related to the sites, facilities, costs and coefficients are known parts of the issue.
- All the distances are specified in a center to center mode.

Definitions

The set of selected points (P) has the following features for site selection:

- Longitudinal coordinate that shows the sites distance from the reference point on the X axis in the coordinate system.
- Latitudinal coordinate that shows the sites distance from the reference point on the Y axis in the coordinate system.
- Each two places have a distance from each other that must be traversed on the land.
- The total number of the selected sites is clean cut.

The set of different kind of facilities in site selection (t) has the following features:

- The repulsion coefficient between facilities is based on their kind not their places.
- The weight coefficient, also, is changed based on the kind of facilities and not their places.
- In site selection, the number of every kind of facility is certain.

Notation:

In order to define the considered model, we use the following symbols:

N : The total number of the selected sites.

n : The number of the kind of facilities.

X_i : The longitudinal coordinate of the selected site i.

Y_i : The latitudinal coordinate of the selected site i.

D_{ij} : The distance between two selected sites, i and j, that ranges from 1 to N.

R_{kl} : The repulsion coefficient between k and l facilities that ranges from 1 to t.

C_{kl} : The cost of communication between k and l facilities that ranges according to the distance unit.

H_k : The required number of k facility.

MD_{kl} : The minimum distance between the k and l facilities.

S_{ik} : The security coefficient of the place i for the facility k that ranges from zero to one.

α_i : The functional weight of the ith objective function in the final objective function.

The decision variable of the following model is defined as follows:

$$Z_{ik}\begin{cases}=1: & \text{If the facility of type } k \text{ is placed in } i.\\ =0: & \text{Otherwise}\end{cases}$$

Formulation of the Model

Because the mentioned purposes can not be explained with a single objective function and in some cases have contradictory with each other, we just can represent the issue as a multi-objective model. Therefore, we formulate the problem as follows:

$$Z_1 = Max\sum_{i=1}^{N}\sum_{j=1}^{N}\sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \times \left[\sum_{k=1}^{n}\sum_{l=1}^{n} Z_{ik} Z_{jl} R_{kl}\right] \quad (1)$$

$$Z_2 = Min\sum_{i=1}^{N}\sum_{j=1}^{N} D_{ij} \times \left[\sum_{k=1}^{n}\sum_{l=1}^{n} Z_{ik} Z_{jl} C_{kl}\right] \quad (2)$$

$$Z_{٣} = Max\,Min\,S_{ik} \quad (3)$$

Considering the following restrictions:

$$\sum_{k=1}^{n} Z_{ik} \le 1 \qquad \forall i = 1,\dots,N \quad (4)$$

$$\sum_{i=1}^{N} Z_{ik} = H_k \qquad \forall k = 1,\dots,n \quad (5)$$

$$(X_i - X_j)^2 + (Y_i - Y_j)^2 \times Z_{ik} \times Z_{jl} \ge MD_{kl} \qquad \forall i = 1,\dots,N-1, i+1 \le j \le N$$
$$k,l = 1,\dots,n, Z_{ik} = 1 \quad (6)$$

The objective function (1) is to maximizing the sum of weighted Euclidean distances by the repulsion coefficient. The objective function (2) is to minimizing weighted distances by the weight of interactional relationships. The objective function (3) is to maximizing the minimum security coefficient of the selected points that is the same as maximization of the total security coefficient of the selected network.

The restrictions (4) are to have confidence that there is only one facility in each place. The restrictions (5) are to have confidence that all kinds of facilities are located and the restrictions (6) observing the air distance limitations between the facilities. Using this form it makes the calculations simple and the problem of site selection in passive defense will change the qualitative form of problem to a quantitative form that the understanding of this form is much easier than qualitative form.

4. The Proposed Method

Many solutions have been made for the multi-objective questions in the literature. We use the following solution (see Roy, 1996 , Branke et.al, 2008). First, solve each objective function separately according to the limitations. We call the obtained answer z_i. In these cases, we calculate other measures of objective function and call the worst of every objective function z_i and then to equalize the unit of the objective functions to each other, we divide the objective function by the measure of the difference of these two obtained measure for it in the previous step. Then, we multiply it by a coefficient that is presented by the group of system experts and decision makers for each objective function. Thereafter, we change all the objective functions as a one objective function. Here, because the second objective function seeks to minimize, we impose it in the final objective function with a minus mark. By division of the functions by their measure of efficiency, not only we equalize their unit, but also we avoid them to extravagate from their efficiency measure. The final objective function is formulated as follows:

$$Z_4 = Max\left(\alpha_1 \times \frac{Z_1}{Z_1^{opt}} - \alpha_2 \times \frac{Z_2}{Z_2^{opt}} + \alpha_3 \times \frac{Z_3}{Z_3^{opt}}\right) \quad (7)$$

Now that the model has been changed to a model with a unique objective function, we can solve it by some software designed for solving the planning issue, like Lingo and GAMS.

It is worth mentioning that the presented model need more time to solve the problems by the above softwares if the measure of N and t becomes greater ($N = 10, t = 5$). In order to solve these high measures, we advice using the Heuristic and Meta-Heuristic algorithms. For example, if $N = 13$ and $t = 6$, the number of the limitations of the issue is equal to 3063.

5. Numerical Example:

Consider a situation which there is 4 facilities to be located in 6 sites.

The environmental features of the selected sites are as follows: the first and the third sites are located in the slope of a great mountain that prevents the offensive armaments to see and attack to them. The second site is located in a mountain slope but the mountain is not very high and it is also located in a way that is easy to be identified by the enemy. The fourth and fifth sites are located in the deserts near the city. The sixth and the seventh sites also are located in the around deserts but at a longer distance with the city. All the numerical measures related to the sites and facilities are included in the following tables.

Tab. 1. Cost of communication between facilities (C_{kl})

Facility \ Facility	Power Plant	Refinery	Airport	Aviation Industries
Power Plant	0.1	0.3	0.3	0.3
Refinery	0.3	0.5	0.2	0
Airport	0.3	0.2	0.2	0.3
Aviation Industries	0.3	0	0.3	0.4

Tab. 2. Type and Required Numbers for each facility (N, n, H_k)

Type	Power Plant	Refinery	Airport	Aviation Industries
Required numbers	2	1	1	1

Table 3: Parameters for facilities security coefficient

Site \ Facility	Power Plant			Refinery			Airport			Aviation Industries		
	recognition	Criticality	Duty	recognition	Criticality	Duty	recognition	Criticality	Duty	recognition	Criticality	Duty
Site No. 1	0.75	0.95	1	0.75	0.9	1	0.3	0.8	0	0.9	0.7	0.1
Site No. 2	0.7	0.95	1	0.6	0.9	0.9	0.7	0.8	0	0.5	0.7	0
Site No. 3	0.75	0.95	1	0.75	0.9	1	0.6	0.8	0	0.9	0.7	0.1
Site No. 4	0.6	0.95	1	0.5	0.9	0.9	0.7	0.8	1	0.7	0.7	1
Site No. 5	0.6	0.95	1	0.5	0.9	0.9	0.7	0.8	1	0.7	0.7	1
Site No. 6	0.6	0.95	0.9	0.5	0.9	0.9	0.7	0.8	0.5	0.7	0.7	1
Site No. 7	0.6	0.95	0.9	0.5	0.9	0.9	0.7	0.8	0.4	0.7	0.7	۱

Tab. 4. Repulsion Coefficients (R_{kl})

Facility \ Facility	Power Plant	Refinery	Airport	Aviation Industries
Power Plant	1	0	1	0.7
Refinery	0	1	1	0.7
Airport	1	1	1	0.6
Aviation Industries	0.7	0.7	0.6	1

Tab. 5. Security coefficient in each place for facilities (S_{ik})

Sites \ Facility	Power Plant	Refinery	Airport	Aviation Industries
Site No. 1	0.713	0.675	0.000	0.063
Site No. 2	0.665	0.486	0.000	0.000
Site No. 3	0.713	0.675	0.000	0.063
Site No. 4	0.570	0.405	0.560	0.490
Site No. 5	0.570	0.405	0.560	0.490
Site No. 6	0.513	0.405	0.280	0.490
Site No. 7	0.513	0.405	0.224	0.490

Tab. 6. Coordinates of candidate sites

Coordinate \ Sites	Site No. 1	Site No. 2	Site No. 3	Site No. 4	Site No. 5	Site No. 6	Site No. 7
longitudinal coordinate(X_i)	57	30	50	20	63	0	10
latitudinal coordinate(Y_i)	45	65	46	5	30	62	84

Tab. 7. Minimum required Euclidean distances between facilities (MD_{kl})

Facility / Faility	Power Plant	Refinery	Airport	Aviation Industries
Power Plant	·	5	45	15
Refinery	5	0	40	15
Airport	45	40	60	40
Aviation Industries	15	15	40	0

Tab. 8. Distances between candidate sites (D_{ij})

Sites / Sites	Site No. 1	Site No. 2	Site No. 3	Site No. 4	Site No. 5	Site No. 6	Site No. 7
Site No. 1	0	47	7	92	20	107	87
Site No. 2	47	0	40	75	60	45	35
Site No. 3	7	40	0	85	20	100	80
Site No. 4	92	75	85	0	70	85	90
Site No. 5	20	60	20	70	0	120	135
Site No. 6	107	45	100	85	120	0	45
Site No. 7	87	35	80	90	135	45	0

After solving the presented model, we assume that the weight of the first and third objective function show the security importance of the constituted network by the system and the weight of the second objective function shows the importance of the network costs which all are determined by the government. Since the government policy is in a way that the security of the system has a more importance to it than the costs, we considered the weights in a way that shows this policy. Then, using LINGO software, we solved some examples of different weight measures for objective functions. The results are as follows:

Tab. 9. Results for objective functions by using different Weight measures

Weight of objective functions			Suggested Sites				Values of each objective function		
Z_1	Z_2	Z_3	Type No. 1	Type No. 2	Type No. 3	Type No. 4	Z_1	Z_2	Z_3
1(Z_1^{opt})	0	0	7 , 5	1	4	6	815.13	371	0.49
0	1(Z_2^{opt})	0	5 , 3	1	4	2	577.29	255	0
0	0	1(Z_3^{opt})	5 , 2	1	4	7	756	332	0.49
0.3	0.1	0.6	7 , 1	2	4	5	771.89	340.8	0.486
0.35	0.2	0.45	6 , 2	7	4	5	804.25	336	0.405
0.4	0.2	0.4	7 , 5	2	4	1	756.59	329.4	0.063

6. Conclusion

Since one of the main principles of passive defense is facility site selection in a manner that the possibility of the total network being damaged by the enemy be reduced, we presented a model in this paper that can select the site in a manner that not only the created network can perform its duty with maximum security coefficient but also the possibility of

identification by the enemy be reduced to a minimum. At the same time, the proposed model helps the system to achieve to its maximum reliability when attacked by the enemy. What is important in this model is achievement to the above purposes with a significant reduction in the costs that is one of the main purposes of the passive defense.
This paper formulates the problem of site selection in passive defense and it considers all objectives of site selection in passive defense that is the unique model in this issue. Because this model just deals with the second Warden's Strategic Ring, it is suggested that this model be elaborated for other rings too. Also, the model is applied for industrial site selection, particularly air industries. Because so far there was no research in this aspect, we hope that the results of this research use in future researches and the problems in the passive defense site selection field had solved.

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