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# *An Interactive Approach to the Central Facility Location Problem: Locating Pediatric Hospitals in Warsaw*

*Most of the conventional approaches to the central facility location problem neglect the interaction of analyst and decision-maker during the locational choice process. This paper presents a new interactive approach to the central facility location problem. It is assumed that the problem is formulated by an analyst as a multiobjective optimization problem. Then the decision-maker searches for a satisfactory solution working directly with the computer system. The interactive procedure was implemented on* IBM–PC XT/AT *as the decision support system* DINAS (*Dynamic Interactive Network Analysis System*) *which enables the solution of various multiobjective location-allocation problems.* DINAS *has been successfully used for solving a real-world planning problem, namely for finding locations for pediatric hospitals in the Warsaw region.*

## 1. INTRODUCTION

The central facility location problem is usually operationalized in terms of location-allocation models (see for example, Beaumont 1980). These models are concerned with finding the optimal location of facilities and, simultaneously, optimal allocation of consumers to them. The traditional approaches to this problem involve consideration of the suppliers' costs and users' benefits in the context of demand for the facility services. The rationale underlying the central

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facility location problem is to find the trade-off between users' benefits and suppliers' costs. On the basis of this general concept a variety of location-allocation models can be formulated.

Following the seminal article by Cooper (1963), numerous papers on the location-allocation problem have appeared in the geographical, management science, operations research, regional science, and regional economics literature (see for example, Ross and Soland 1980; Rushton 1984). Especially during the past decade one can observe a phenomenal increase in the number of publications related to this problem. These studies have been mainly concerned with developing models that optimize the spatial relations between consumers and central facilities and with modeling the service supply process in the context of facility location. At the same time significant progress has been made in formulating and solving location-allocation problems by various optimization techniques and methods (Hillsman 1980; Goodchild and Noronha 1983). Nevertheless, progress in the development of formal methodology for the central facility location problem has rarely been transferred into real-life situations (see Massam 1980 for application examples). Although many studies show the potential usefulness of the optimization methodology for improving the locational pattern of public services, it would be rather difficult to identify a location-allocation method that has been successfully implemented (see Lea 1981; Rushton 1984).

There are many reasons why decision-makers are reluctant to use location-allocation methods in the locational planning of public facilities. Densham and Rushton (1987) argue that the most important reason is the separation of analyst from decision-maker in the locational choice process. They stress that "the quality of the locational choices made is generally judged by the *quality* of the process of decision-making which generated the choices" (Densham and Rushton 1987, p. 56). In this case the roles of the analyst and decision-maker are inseparable. Most of the existing approaches to public facility location problems do not take into consideration any active role for the decision-maker during the decision process. Consequently, the most important features of the locational choice process are usually incompletely represented (see Lea 1981). This leads to a need for an interactive-decision approach to public facility location (for example, Nijkamp and van Delft 1977).

This paper presents a new interactive approach to the central facility location problem. It is assumed that the problem is formulated by an analyst as the multiobjective optimization problem. Then the decision-maker searches for a satisfactory solution working directly with the computer system. The basic concept of that approach is as follows. The decision-maker forms his requirements in terms of aspiration and reservation levels, that is, he specifies acceptable and required values for given objectives. The decision-maker works with the computer system in an interactive way so that he can change his aspiration and reservation levels during the session. The computer system searches for the satisfying solution while using an achievement scalarizing function as a criterion in single-objective optimization. Each computed solution presented to the decision-maker is an efficient (Pareto-optimal) solution. The decision-maker can accept the presented solution or change the aspiration and/or reservation levels to continue the process.

The interactive procedure was implemented on IBM–PC XT/AT as the decision support system DINAS (Dynamic Interactive Network Analysis System) which enables the solution of various multiobjective transportation problems with facility location (Ogryczak et al. 1988). DINAS is not a commercial system. It is rather a scientific transferable tool. Nevertheless DINAS has been already successfully used for solving real-world planning problems. Among others, the problem of pediatric hospital location in the Warsaw region, presented in this paper, provides an exemplification of a planning problem solution with the assistance of DINAS.

## 2. INTERACTIVE APPROACH

### *A. The Reference Point Approach to Multiobjective Optimization*

Location-allocation problems can be formulated as multiobjective mixed integer programs (see Ross and Soland 1980, Ogryczak et al. 1989a; 1989b). The corresponding multiobjective program takes the following general form:

$$\text{optimize } \mathbf{q}$$

$$\text{subject to}$$

$$\mathbf{q} = \mathbf{F}(\mathbf{x}, \mathbf{y})$$
$$(\mathbf{x}, \mathbf{y}) \in Q$$

where

$\mathbf{q}$ represents the achievement vector,
$\mathbf{F} = (F_1, \ldots, F_k)$ represents the vector of $k$ objective functions, *optimize* means minimize or maximize each of several objective functions,
$Q$ denotes the feasible set of the program,
$\mathbf{x}$ is a vector of continuous decision variables,
$\mathbf{y}$ is a vector of discrete decision variables.

There are many different concepts for handling multiple objectives in mathematical programming. The most widely used is the so-called goal programming technique (see, for example, Ignizio 1982). The goal programming approach requires the setting of goals (targets) for each objective as data for the problem. An optimal solution is then defined as the one which minimizes the deviations from the goals. However, the goal programming techniques, especially for discrete problems and thereby for the location-allocation problem, can generate solutions which are not efficient (Pareto-optimal) (see Hallefjord and Jörsten 1988).

The so-called reference point approach (RPA), which was introduced by Wierzbicki (1982), can be regarded as a generalization of the goal programming approach that is free from the above weaknesses. This RPA concept was further developed in many papers and was used as a basis for construction of the (linear programming based) software package DIDAS (Dynamic Interactive Decision Analysis and Support System). The DIDAS package proved to be useful in analyzing conflicts and assisting in decision-making situations (Grauer, Lewandowski, and Wierzbicki 1984).

The basic concept of the reference point approach is as follows:

(1) the decision-maker forms his requirements in terms of aspiration levels, that is, he specifies acceptable values for each given objective;
(2) the decision-maker works with the computer in an interactive way so that he can change his aspiration levels during sessions of the analysis;
(3) the computer system, by minimization of some special scalarizing achievement function, provides the decision-maker with the efficient solution nearest to the specified aspiration levels or with even better objective values if the aspiration levels are attainable.

In our interactive scheme, we extend the DIDAS approach. The extension relies on additional use of reservation levels which allow the decision-maker to specify necessary values for given objectives as a form of the so-called soft bounds.

The reference point approach rests on Simon's (1958) theory of satisficing behavior, which in the location behavior context has been developed by Pred (1967). Simon uses the concept of bounded rationality to argue that the limited ability of decision-makers and limited availability of information imply that they "satisfice" rather than maximize. The decisions are usually made according to standards of adequacy and the standards are themselves the result of satisficing behavior. They can be expressed in terms of aspiration and/or reservation levels.

Thus, decision-making involves search activity to meet specified aspiration levels. These levels refer to desired outcomes of the decision-making for a set of objectives. On the other hand, the decision-makers can specify minimum standards or reservation levels. This refers to the minimum requirements and corresponds to some lower limits of tolerance for a set of alternatives (Nijkamp and Rietveld 1986).

Both aspiration and reservation levels depend on the quality and quantity of information about a given decision-making problem and on the ability of decision-makers to use the information. In the interactive decision-making process the aspiration and reservation levels are defined on the basis of some prior knowledge of the set of feasible alternatives. At the same time the aspiration levels depend on the decision-makers' ability to use the information and their preferences, experience, attitudes, cognition, perception, wishes, expectations, and so on. Consequently, it can be argued that the reference point approach provides an appropriate basis for interactive decision-making.

### *B. The Interactive Procedure for Handling Multiple Objectives*

The multiobjective analysis works in two stages. In the first stage the decision-maker is provided with some initial information which gives him an overview of the problem. The initial information is generated by optimization of all the objectives separately. More precisely, the following single-objective programs are solved:

$$\text{optimize}\left\{F_p(\mathbf{x},\mathbf{y}) + 1/k \sum_{i=1}^{k} \rho_i F_i(\mathbf{x},\mathbf{y}) : (\mathbf{x},\mathbf{y}) \in Q\right\} \quad p = 1,2,\ldots,k \tag{1}$$

where $F_i$ denotes the $i$th objective function and $\rho_i$ are arbitrarily small numbers (positive if the corresponding objective function $F_i$ is to be minimized and negative otherwise).

The so-called pay-off matrix

$$\mathbf{R} = (q_{pj})_{p=1,2,\ldots,k;\, j=1,2,\ldots,k}$$

which yields information on the range of numerical values of each objective is then constructed. The $p$th row of the matrix $\mathbf{R}$ corresponds to the vector $(\mathbf{x}^p, \mathbf{y}^p)$ which solves the $p$th program (1). Each quantity $q_{pj}$ represents a value of the $j$th objective of this solution (that is, $q_{pj} = F_j(\mathbf{x}^p, \mathbf{y}^p)$).

The vector with elements $q_{pp}$, that is, the diagonal of $\mathbf{R}$, defines the utopia (ideal) point. This point, denoted further by $\mathbf{q}^u$, is usually not attainable but is presented to the decision-maker as a limit to the best numerical values of the objectives. To be more precise, it provides the decision-maker with lower limits for minimized objective functions and upper limits for maximized ones. The $j$th column of the matrix $\mathbf{R}$ depicts values of the objective function $F_j$ obtained during several optimizations. Taking into consideration such a column we notice that the best value in that column is $q_{jj} = q_j^u$. Let $q_j^n$ be the worst value, that is,

$$q_j^n = \max_{1 \leqslant p \leqslant k} q_{pj} \quad \text{or} \quad q_j^n = \min_{1 \leqslant p \leqslant k} q_{pj}$$

if the objective function $F_j$ is to be minimized or maximized, respectively. The point $\mathbf{q}^n$ is called the nadir point and may be presented to the decision-maker as a guideline to the worst values of the objectives. Thus, for each objective $F_j$, reasonable but not necessarily tight lower and upper bounds are known after the first stage of the analysis.

In the second stage an interactive selection of efficient solutions is performed. The decision-maker controls the selection by two vector-parameters: his aspiration level $\mathbf{q}^a$ and his reservation level $\mathbf{q}^r$. Both of them should, certainly, take values between the utopia point $\mathbf{q}^u$ and the nadir point $\mathbf{q}^n$. The support system searches for the satisfying solution while using an achievement scalarizing function as a criterion in the single-objective optimization. Namely, the support system computes the optimal solution to the following problem:

minimize

$$\max_{1 \leqslant p \leqslant k} u_p(\mathbf{q}, \mathbf{q}^a, \mathbf{q}^r) + \rho/k \sum_{p=1}^{k} u_p(\mathbf{q}, \mathbf{q}^a, \mathbf{q}^r)$$

subject to

$$\mathbf{q} = \mathbf{F}(\mathbf{x}, \mathbf{y})$$

$$(\mathbf{x}, \mathbf{y}) \in Q$$

where $\rho$ is an arbitrarily small number and $u_p$ is a function which measures the deviation of results from the decision-makers' expectation with respect to the $p$th objective, depending on a given aspiration level $\mathbf{q}^a$ and a reservation level $\mathbf{q}^r$.

The computed solution is an efficient (Pareto-optimal) solution to the original multiobjective model. It is presented to the decision-maker as a current solution. The decision-maker is asked whether he finds this solution satisfactory or not. If the decision-maker does not accept the current solution he has to enter new aspiration and/or reservation levels for some objectives. Depending on this new information supplied by the decision-maker a new efficient solution is computed and presented as the current solution. The process is repeated as long as the decision-maker needs.

The function $u_p(\mathbf{q}, \mathbf{q}^a, \mathbf{q}^r)$ is a strictly monotone function of the achievement vector $\mathbf{q}$ with value $u_p = 0$ if $\mathbf{q} = \mathbf{q}^a$ and $u_p = 1$ if $\mathbf{q} = \mathbf{q}^r$. In our approach, we use a piece-wise linear function $u_p$ defined as follows:

$$u_p(\mathbf{q}, \mathbf{q}^a, \mathbf{q}^r) = \begin{cases} -a_p|\mathbf{q}_p - \mathbf{q}_p^a|/|\mathbf{q}_p^r - \mathbf{q}_p^a|, \text{ if } \mathbf{q}_p \text{ is better than } \mathbf{q}_p^a \\ |\mathbf{q}_p - \mathbf{q}_p^a|/|\mathbf{q}_p^r - \mathbf{q}_p^a|, \text{ if } \mathbf{q}_p \text{ is between } \mathbf{q}_p^a \text{ and } \mathbf{q}_p^r \\ b_p|\mathbf{q}_p - \mathbf{q}_p^r|/|\mathbf{q}_p^r - \mathbf{q}_p^a| + 1, \text{ if } \mathbf{q}_p \text{ is worse than } \mathbf{q}_p^r \end{cases}$$

where $a_p$ and $b_p$ $(p = 1, 2, \ldots, k)$ are given positive parameters. Provided that the parameters $a_p$ and $b_p$ satisfy inequalities: $a_p < 1$ and $b_p > 1$ the achievement functions $u_p$ are convex and thereby they can be modeled via the linear programming methodology (see Ogryczak et al. 1989a for details).

*C. The DINAS system*

DINAS is a decision support system designed for solving multiobjective transshipment problems with facility location on IBM-PC XT/AT or compatibles. A network model of the problem consists of nodes that are connected by a set of direct flow arcs. An arc, according to the standard graph terminology, allows for a flow in only one direction. Therefore some pairs of nodes can be connected by two independent (reverse) arcs characterized by different sets of data. The set of nodes is partitioned into two subsets: the set of fixed nodes and the set of potential nodes. The fixed nodes represent "fixed points" of the transportation network, that is, points which cannot be changed. Each fixed node is characterized by two quantities: supply and demand. The potential nodes are introduced to represent possible locations of new points in the network. Some groups of the potential nodes represent different versions of the same facility to be located (for example, different sizes of a warehouse). For this reason, potential nodes are organized in groups of alternatives referred to as selections. Selections are mathematically modeled via the so-called multiple choice constraints (see Ogryczak et al. 1988; 1989c, for details). Each selection is defined by the list of potential nodes as well as by lower and upper numbers of nodes which have to be selected (located). Each potential node is characterized by a capacity which bounds maximal flow through the node. The capacities are also given for all acrs but not for the fixed nodes.

Several linear objective functions are considered in the problem. The objective functions are introduced into the model by given coefficients associated with several arcs and potential nodes. They will be called cost coefficients independently of their real character in the objective functions. The cost coefficients for potential nodes are, however, understood in a different way than for arcs. The cost coefficient connected to an arc is treated as the unit cost of the flow along the arc whereas the cost coefficient connected to a potential node is considered as the fixed cost associated with the use (location) of the node rather than as the unit cost.

DINAS can process problems consisting of

—up to seven objective functions,
—a transportation network with up to one hundred nodes and three hundred arcs,
—up to fifteen potential locations.

DINAS consists of three programs prepared in the C programming language:

—an interactive procedure for efficient generation of solutions,
—a solver for single-objective problems,
—a network editor for input data and results examination.

Operations available in the DINAS interactive procedure are partitioned into three groups, corresponding to three branches of the main menu: PROCESS, SOLUTION, and ANALYSIS. The PROCESS branch contains basic operations connected with processing the multiobjective problem and generation of several efficient solutions. Included are operations such as editing and converting the problem, computation of the pay-off matrix, and finally, generation of a sequence of efficient solutions depending on the edited aspiration and reservation levels.

The SOLUTION branch contains additional operations connected with the current solution. The decision-maker can examine in detail the current solution using the network editor or analyze only short characteristics such as objective values and selected locations. Values of the objective functions are presented in three ways: as a standard table, as bars in the aspiration/reservation scale, and as bars in the utopia/nadir scale. The bars show the percentage level of each objective value with respect to the corresponding scale. The decision-maker may also print the current solution or save it for use in the next runs of the system with the same problem. A special command is available to delete the current solution from the solution base if the decision-maker finds it is quite unacceptable.

The ANALYSIS branch collects commands connected with operations on the solution base. The main command COMPARE allows the decision-maker to perform a comparison of all the efficient solutions from the solution base or of some subset of them. In the comparison only the short characteristics of the solutions are used, that is, objective values in the form of tables and bars as well as tables of selected locations. Moreover, some commands which allow the decision-maker to select various efficient solutions from the solution base as the current solution are included in this branch. There exists also an opportunity to restore some (saved earlier) efficient solution to the solution base.

A special solver has been prepared to provide the multiobjective analysis procedure with solutions to single-objective problems. The solver is hidden from the user but it is the most important part of the DINAS system. It is a numerical kernel of the system which generates efficient solutions. Even for a small transshipment problem with facility location the corresponding linear program is rather large. For this reason it cannot be solved directly with the standard simplex algorithm. In order to solve the program on IBM–PC XT/AT microcomputers it was necessary to take advantage of its special structure. A general concept of the solver was presented by Ogryczak et al. (1989c).

DINAS is armed with the built-in network editor EDINET. EDINET is a full-screen editor specifically designed to input and edit data for the generalized network model. The essence of the EDINET concept is a dynamic movement from some current node to its neighboring nodes and vice versa, according to the network structure. The input data are inserted by a special mechanism of windows while visiting several nodes. Independently, a list of nodes in alphabetic order and a graphic view of the network are available at any time. A special window is also used for defining objective functions.

## 3. PLANNING OF HOSPITAL LOCATIONS IN THE WARSAW REGION

### A. *The Problem*

In this section a real-world planning problem is introduced. This problem is related to locational choice of pediatric hospitals in the Warsaw region. According to the long-term plans of Warsaw's health authority the capacity of pediatric hospitals in the region should increase from 994 beds in 1986 to 2,432 in 2010 (Ministerstwo Zdrowia i Opieki Społecznej 1985). This increase of hospital capacities should follow the predicted growth of population. Demographic projections forecast that, broadly speaking, the number of people 0–15 years old in the Warsaw inner city will decrease, while there is expected to be an increase of the child population in the outer zone of the region (Biuro Planowania Rozwoju Warszawy 1982). Consequently, a reorganization of the hospital network in the region is planned. It involves the location of new facilities and hospital capacity, shifting from areas of low demand to areas of high demand. In this connection eight sites for potential location of new pediatric hospitals were chosen. It is planned that at least four new hospitals will be built by 2010. Thus, there are 163 alternative locational patterns and each of them generates many possible allocation schemes. Our task is to choose the best plan. However, to do it a brief description of the interest groups and their preferences in the locational choice is needed.

*B. The Interest Groups*

There are four interest groups which are involved in the choice of sites for pediatric hospitals in Warsaw: public authorities (local and regional), health authorities (local and regional), professionals (doctors, nurses, etc.), and the client population (potential patients). They have various and often conflicting preferences for locational choice. In the case of Poland, the locational choice process is essentially controlled by the public authority. However, in subsequent stages of the locational choice the planners and decision-makers have to discuss the plans with the health authority, professionals, and population via their representatives in municipal government and various lobbies. Moreover, in the Polish health care system the allocation of patients to hospitals is also centrally planned by the health authority, that is, a given region is subdivided into hospital districts (Malczewski and Ogryczak 1988). The main objective of the public authority is to minimize the costs of service provision, including investment and operating costs. This objective conflicts with the maximization of accessibility to hospitals, which is the main objective of the other interest groups. According to a health authority recommendation the population should be allocated to their nearest hospital, so that the travel cost to individuals is minimized. This is in principle consistent with the objective of the client population, providing that the users behave according to a nearest facility utilization rule. However, for a number of reasons, patients do not usually choose the closest available hospital (see Mayhew and Leonardi 1982). There is a great deal of evidence to show that the patients' spatial behavior is mainly influenced by two factors: the perceived quality and quantity of services offered at a hospital and the accessibility costs to that destination in relation to other alternatives (Malczewski 1989a). Consequently, the level of satisfaction of patients for a locational pattern can be expressed by means of a gravity model.

Finally, environmental objectives should be considered. There is a growing awareness that in the hospital location process the planners and decision-makers should take into account the quality of the environment. It is an objective of both professionals and patients, although in principle it can conflict with maximization of accessibility to hospitals (see Malczewski 1989b for details).

*C. The Model*

The problem under consideration can be formalized as a multiobjective mixed integer programming problem as follows.

The main data of the problem are defined by the following groups of parameters (see Malczewski [1989a, 1989b] for a detailed description of the parameters for the hospital location problem in the Warsaw region):

$D_i$ is the total demand for pediatric hospitalization in location $i$ ($i = 1, 2, \ldots, m$),
$s_j^{max}$ is the upper bound on hospital size in location $j$ ($j = 1, 2, \ldots, n$),
$h^{min}$ is the minimum number of hospitals to be built,
$h^{max}$ is the maximum number of hospitals to be built,
$d_{ij}$ is the actual distance between locations $i$ and $j$,
$\beta$ is the constant calibrated for the hospital network,

$C$ represents the total investment funds for establishing the hospitals,
$E$ represents the total predicted operating expenditures,
$c_j$ is the investment cost per unit size in location $j$,
$e_j$ is the operating cost per unit size in location $j$,
$r_j$ is the reception of pollutants (dust in the present study) at location $j$.
$\varkappa$ is the environment quality standard; that is, the permissible dust fall given by the Polish pollution standard is 250 t/km$^2$/year.

The locational and allocation decisions are modeled by the following decision variables:

$x_{ij}$ represents the patient allocation from demand location $i$ to hospital $j$,

$$y_j = \begin{cases} 1 \text{ if a hospital is located at site } j, \\ 0 \text{ otherwise,} \end{cases}$$

$s_j$ is the size of hospital in location $j$.

According to the discussion in the previous section the following five objective functions are specified.

—minimization of the aggregate travel cost for the population:

$$F_i = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} x_{ij}, \tag{2}$$

—maximization of the level of users' satisfaction for a location pattern of hospitals:

$$F_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} \exp(-\beta d_{ij}) x_{ij}, \tag{3}$$

—minimization of the investment costs:

$$F_3 = \sum_{j=1}^{n} c_j s_j y_j, \tag{4}$$

—minimization of the operating costs:

$$F_4 = \sum_{j=1}^{n} e_j s_j y_j, \tag{5}$$

—minimization of the environmental pollution at hospital sites:

$$F_5 = \sum_{j=1}^{n} r_j y_j. \tag{6}$$

The problem is to optimize (minimize or maximize, respectively) the above objective functions subject to the following constraints:

$$\sum_{j=1}^{n} x_{ij} = D_i \qquad \text{for } i = 1, 2, \ldots, m, \tag{7}$$

$$\sum_{i=1}^{m} x_{ij} = s_j \qquad \text{for } j = 1, 2, \ldots, n, \tag{8}$$

$$\sum_{j=1}^{n} c_j s_j y_j \leqslant C \qquad \text{for } j = 1, 2, \ldots, n, \tag{9}$$

$$\sum_{j=1}^{n} e_j s_j y_j \leqslant E \qquad \text{for } j = 1, 2, \ldots, n, \tag{10}$$

$$r_j y_j \leqslant \varkappa \qquad \text{for } j = 1, 2, \ldots, n, \tag{11}$$

$$h^{\min} \leqslant \sum_{j=1}^{n} y_j \leqslant h^{\max} \tag{12}$$

$$x_{ij} \geqslant 0 \qquad \text{for } i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m, \tag{13}$$

$$s_j \leqslant s_j^{max} \qquad \text{for } j = 1, 2, \ldots, n. \tag{14}$$

*D. An Interactive Multiobjective Analysis*

The model (2)–(14) was solved using the DINAS system. Firstly, an optimization of each objective function separately has been performed. Table 1 displays the outcomes in the form of a pay-off matrix. This matrix enables the decision-makers to analyze the conflicting nature of the decision-making problem. Comparing the elements of Table 1 vertically one can notice an intense conflict between the accessibility (objective $F_1$ and $F_2$) on one hand, and the investment and operating costs ($F_3$ and $F_4$) as well as environment quality ($F_5$) on the other. The least attractive values of $F_3$, $F_4$, and $F_5$ are obtained when the aggregate travel cost is minimized. This conflict is somewhat less intensive in the case of users' satisfaction maximization and $F_3$, $F_4$, and $F_5$. Moreover, there is some conflict between the

TABLE 1
The Pay-off Matrix

| Minimized function | Objective value | | | | |
|---|---|---|---|---|---|
| | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ |
| $F_1$ | 39099.0 | 12385.9 | 888.8 | 519.6 | 1141.4 |
| $F_2$ | 40776.4 | 12534.6 | 666.0 | 395.8 | 917.3 |
| $F_3$ | 63822.6 | 9812.9 | 443.2 | 270.0 | 447.6 |
| $F_4$ | 62304.9 | 11418.0 | 446.3 | 249.6 | 474.8 |
| $F_5$ | 66396.0 | 6104.9 | 443.8 | 260.0 | 444.1 |

TABLE 2
Results of the Interactive Multiobjective Analysis

| Step | | Outcomes of Objectives $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| | aspiration level | 39099.0 | 12534.6 | 443.2 | 249.6 | 444.1 |
| | reservation level | 66396.0 | 6104.9 | 888.8 | 519.6 | 1141.4 |
| | compromise solution | 47834.7 | 8812.4 | 555.3 | 327.1 | 661.4 |
| 2 | | | | | | |
| | aspiration level | 39099.0 | 12534.6 | 443.2 | 249.6 | 444.1 |
| | reservation level | 66396.0 | 6104.9 | 450.0 | 300.0 | 1141.4 |
| | compromise solution | 63897.2 | 7304.6 | 444.8 | 260.4 | 497.3 |
| 3 | | | | | | |
| | aspiration level | 39099.0 | 12534.6 | 443.2 | 249.6 | 500.0 |
| | reservation level | 66396.0 | 6104.9 | 450.0 | 300.0 | 1141.4 |
| | compromise solution | 62408.3 | 7393.3 | 446.1 | 278.3 | 601.2 |
| 4 | | | | | | |
| | aspiration level | 39099.0 | 12534.6 | 443.2 | 249.6 | 500.0 |
| | reservation level | 60000.0 | 7000.0 | 450.0 | 300.0 | 1141.4 |
| | compromise solution | 59801.2 | 7481.3 | 487.4 | 294.3 | 712.2 |

minimization of investment and operating costs and environmental pollution, since the decrease (increase) of one of these objective values does not always result in the decrease (increase) of the other objective functions.

Having computed the pay-off matrix DINAS provides the decision-maker with two reference vectors: the utopia vector and the nadir vector. The utopia vector represents the best values of each objective considered separately (the diagonal of the pay-off matrix), and the nadir vector expresses the worst values of each objective encountered during optimization of another objective function. The utopia vector is, obviously, not attainable, that is, there are no feasible solutions with such objective values.

As the first step of the interactive searching for a compromise solution, the utopia and nadir vectors, were taken as the aspiration and reservation levels, respectively. As a result the so-called neutral efficient solution has been obtained. This solution is situated approximately "in the middle" of the efficient set (see Table 2).

The neutral efficient solution was presented to the experts (decision-makers), who stated that the outcome of the investment and operating costs should be improved. Given the new reservation level for $F_3$ and $F_4$, a new compromise solution was generated and again presented to the decision-makers, etc., until finally a satisfying compromise solution was achieved at the fourth step. The subsequent steps of this procedure are shown in Table 2. Figure 1 presents the structure of the final compromise solution. This solution can be regarded as a budget dominated variant, that is, the investment and operating costs dominate this solution, while the accessibility and environmental aspects receive relatively less attention.

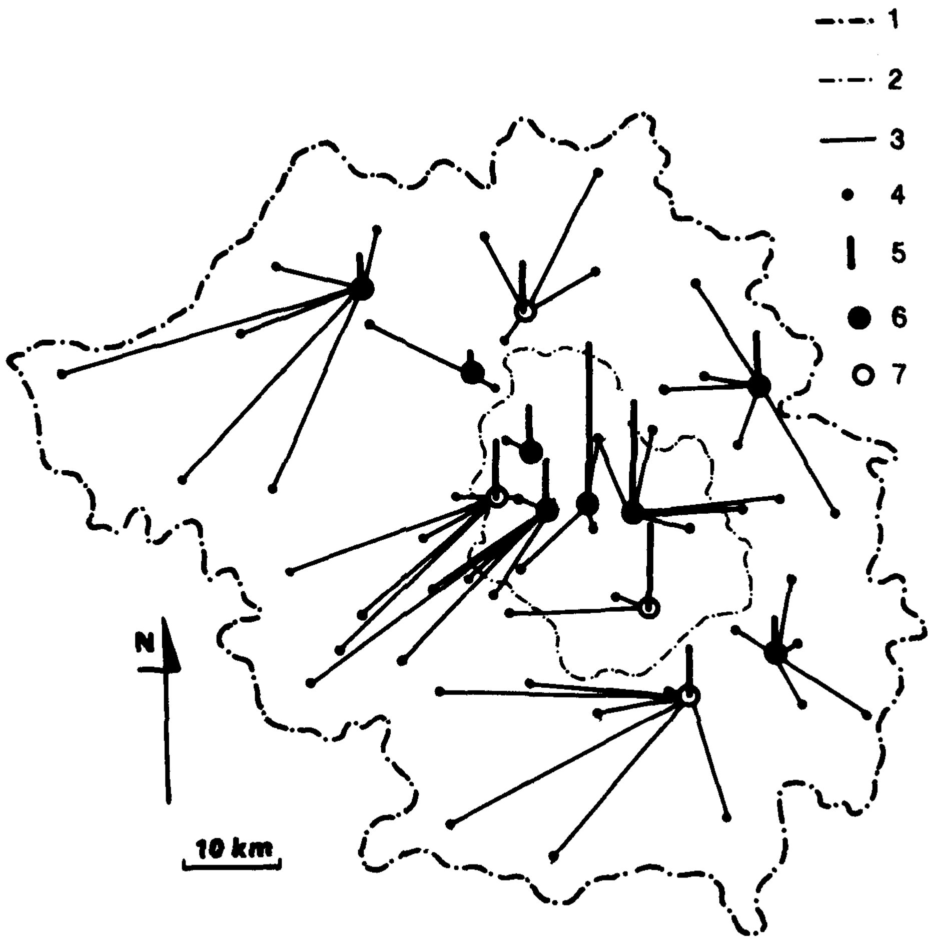


FIG. 1. *The Multiobjective Location of Pediatric Hospitals and the Allocation of Patients to the Hospitals.* 1. Administrative boundary of the Warsaw region; 2. administrative boundary of Warsaw; 3. allocation of patients to hospitals; 4. administrative center of areal unit; 5. size of hospital; 6. existing hospitals; 7. new hospitals.

## 4. CONCLUDING REMARKS

Traditional approaches to public facility location problems have been criticized recently for separating the role of analyst from the role of decision-maker in the locational-choice process. In order to enhance the applicability of the public facility methodology, a feed-back procedure between information provided by the analyst and the preferences of decision-makers is needed. This leads to the concept of an interactive decision-support system.

In this paper an interactive procedure is presented which seems to be an attractive basis for such a decision-support system. The decision-maker searches for a satisfactory solution specifying his requirements with unsophisticated parameters: aspiration and reservation levels, that is, he simply defines acceptable and required values for given objectives. Each solution generated by the system is an efficient (Pareto-optimal) one, that is, any objective value cannot be improved without making worse another one. However, there are, usually, plenty of such efficient solutions and the system cannot replace the decision-maker in making the final choice. The system only makes this choice easier by providing the decision-maker with convenient control parameters (like a steering-wheel) to navigate through the efficient set. The system can be used to support a group decision-making process that makes the final decision less subjective.

Experiences with the DINAS system confirm the appropriateness of the methodology. The system allows the decision-maker to interact directly with the data-base system (that is, the network editor) and with the model-base system. It can be argued that DINAS can contribute to the improvement of the quality of planning by involving the decision-makers in the location choice process from the outset (Massam and Malczewski 1990). In our project the decision-makers have been involved in the formulation of the optimizing model by providing information about the objectives and constraints of the locational decisions; on the other hand, the decision-makers' preferences and priorities (expressed in terms of their aspiration and reservation levels) have been defined on the basis of information provided by the system. We have observed that during the interactive process the decision-makers have gradually learned about the set of feasible alternatives and the consequences of possible decisions. While searching for the best solution the decision-makers have changed their preferences and priorities due to the process of learning. In this context, one should emphasize that the interactive process is very easy and supported by many analytical tools (including graphics). So, it was possible to reach a satisfactory solution in a few interactive steps.

It is obvious that the outcome of the interactive procedure reflects both the information provided by DINAS and the ability of the decision-makers to use the information as well as their personal characteristics such as knowledge, experience, intuition, initiative, creativity, etc. It is hard to examine to what extent these characteristics have found reflection in the final solution. It is important, however, to note that the decision-makers involved in our project have extensively referred to planning norms or standards that exist in the Polish planning system and which are usually used in the planning process. This partly explains why the decision-makers have stressed the importance of the investment and operating costs objectives. These parameters are clearly specified in the Polish planning system in terms of the cost per hospital bed. However, it is a matter of deliberation whether the present planning norms can be applied to the long-term planning process.

Also, the existing environment quality standards affected the decision-makers' aspiration and reservation levels. In this case there are prospective pollution standards that can be used in long-term planning. Consequently, the pollution standard (that is, the dust fall) has been incorporated into the optimization model. On the other hand, the decision-makers found difficulty in specifying their aspiration and reservation levels for the accessibility objectives. It was particularly true in the case of the maximization of the level of users' satisfaction for a location pattern of hospitals. In this context one can note that there are no norms or standards that might help to define aspiration or reservation level.

The model presented in this paper is essentially a static one. It took the forecasted distribution of demand, locational preferences of patients, and environmental pollution in a given year (2010 in this study), and predicted total financial resources in a given planning period as the input data. Consequently, the locations determined on the basis of this model display the final pattern of facility locations. It would be desirable, however, to develop a time schedule for investment activities, that is, to determine the sequence of facility locations. Information about the optimal path to the final stage of the locational pattern is clearly as important as the determination of the final pattern itself. Therefore, further research should be directed toward the incorporation of a dynamic facility location model into the interactive decision-making process.

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