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A GIS-based decision-support tool for public facility planning

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Abstract. The installation and operation of public facilities, such as schools or hospitals, involve important amounts of public spending, and therefore need to be carefully planned. Research efforts made since the early 1960s led to the development of a rich collection of optimization models and solution methods for public facility planning problems. It must be recognized, however, that the practical impact of the efforts made up to now is rather weak. This paper presents an interactive, user-friendly decision-support tool for public facility planning where the capabilities of geographic information systems and advanced optimization methods are put together. We hope that it will contribute to bridge the gap between research and practice that characterizes the way public facility planning is made at present. The application of the decision-support tool is illustrated for a real-world setting.

1 Introduction

The welfare of human communities is largely dependent upon the availability of public facilities such as schools, hospitals, police headquarters, libraries, and sports halls. The installation and operation of these facilities often (if not always) involve important amounts of public spending, and therefore need to be carefully planned.

Since the early 1960s, considerable efforts have been devoted to public facility planning by researchers from a wide variety of fields (spatial planning, operations research, management science, regional economics, economic geography, civil engineering). These efforts led to the development of a rich collection of optimization models and solution methods for dealing with the corresponding problems (Daskin, 1995; Drezner, 1995). These models find the best location and capacity (or size) for the facilities, as well as the best assignment of demand to facilities. The solution depends on the objective (or objectives) underlying the problems.

It must be recognized, however, that the processes through which public facility planning decisions are made rarely take advantage of those research efforts. This would be much more likely to happen if models were incorporated into interactive, user-friendly decision-support tools. The development of these kinds of tools is possible today, thanks to the advances in computing hardware and software that occurred in the last decade.

This paper presents a decision-support tool for public facility planning called MapFL (Mapping and Facility Location). The tool puts together the capabilities of geographic information systems (GIS) and advanced optimization methods, and is the main result of an R&D project developed at the University of Coimbra over three years.

GIS are among the computing technologies successfully adopted by the planning community in recent years. Since their origins in the early 1980s, they have been extensively used for facility planning, both in the public and in the private sector (Longley et al, 2001). The decision-support applications of GIS in this field can be classified into four categories (Antenucci et al, 1991; Yeh and Chow, 1996): land-suitability analysis, buffer-zone analysis, allocation analysis, and location-allocation analysis. Land-suitability analysis is carried out to identify (and rank) sites appropriate for the location of facilities according to some predefined criteria. Buffer-zone analysis is performed to determine the areas that are not properly covered by existing or planned facilities (the areas left outside covering circles or polygons drawn around the facilities). Allocation analysis is performed to identify optimum catchment areas for existing or planned facilities. Location-allocation analysis is carried out to determine the optimum location and capacity for facilities within a given territory. The decision-support tool presented in this paper fits into the fourth category.

The paper comprises five sections. Section 2 contains a brief presentation of public facility planning models and solution methods, focused on the two types of problem that the current version of MapFL is prepared to deal with. Section 3 describes the general structure of MapFL, and gives information on the corresponding input–output and problem-solving operations. Section 4 demonstrates the application of the package in a real-world setting (Vila Nova de Famalicão, one of the most important municipalities within the Porto metropolitan area, northern Portugal). The final section summarizes the work done so far and identifies directions for future research.

2 Public facility planning

In general terms, a (discrete) public facility planning problem consists of finding where, among a given set of sites, facilities of a given type should be located, and what their capacity should be, in order to meet some predefined objective (or objectives) while satisfying demand from a given number of centers. The word 'centers' refers to 'points' where demand is concentrated, and the word 'sites' refers to 'points' where facilities are or may be located, such as cities within a region or neighborhoods within a city. Furthermore, at the urban level, sites may also correspond to specific plots of land. Sites are classified as open or closed based on whether a facility is located there or not (figure 1).

Several alternative objectives may be retained within a public facility planning problem, like minimizing total costs or maximizing aggregate accessibility (with a

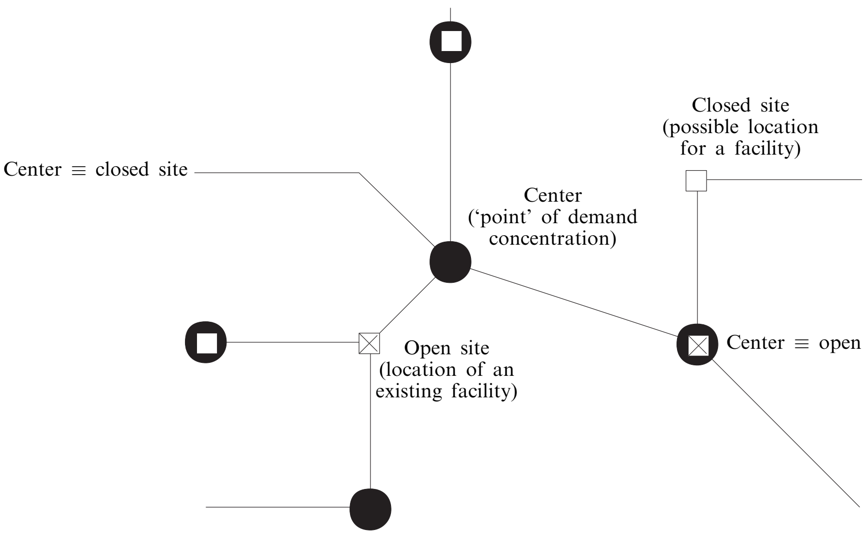


Figure 1. Geographic setting for facility planning.

given number of facilities), and several different constraints, on accessibility, budget, investment, capacity, design, etc, may need to be taken into account.

The best-known facility planning problems certainly are the facility (or plant, or warehouse) location problem and the p-median problem. These are the types of problem that the current version of MapFL is prepared to deal with. Both problems have an uncapacitated version, which applies when there are no constraints on the maximum and/or minimum capacity of facilities, and a capacitated version.

The uncapacitated facility location problem (UFLP) consists of finding the minimum-cost solution for the location and capacity of facilities, and for the assignment of demand to facilities. This problem can be represented with the following mathematical model (Balinski, 1966):

$$\text{minimize } C = \sum_{j \in J} \sum_{k \in K} (c_{v_k} + c_t d_{jk}) u_j x_{jk} + \sum_{k \in K} c_{f_k} y_k \,, \tag{1}$$

subject to

$$\sum_{k \in K} x_{jk} = 1, \qquad \forall j \in J, \tag{2}$$

$$x_{jk} \leqslant y_k, \qquad \forall j \in J,\ k \in K, \tag{3}$$

$$x_{jk} \geqslant 0, \qquad \forall j \in J,\ k \in K, \tag{4}$$

$$y_k \in \{0, 1\}, \qquad \forall k \in K, \tag{5}$$

where (taking dollars per year as the monetary units, users as the demand units, and kilometers as the distance units):

C is total costs (dollars per year),
J is the set of centers,
K is the set of sites,
c_{v_k} is the variable cost of a facility located at site k (dollars per year per user),
c_t is the transport cost (dollars per year per user per kilometer traveled daily one-way),
d_{jk} is the distance between center j and site k (kilometers),
x_{jk} is the fraction of demand from center j met at site k,
u_j is the demand from center j (users),
c_{f_k} is the fixed cost of a facility located at site k (dollars per year),

$$y_k = \begin{cases} 1, & \text{if a facility is located at site } k\,, \\ 0, & \text{otherwise.} \end{cases}$$

The objective function (1) of this mixed-integer optimization model expresses the minimization of total costs. Total costs consist both of facility costs (setup and operation) and of transport costs, paid by the promoter or the users of facilities. Facility costs are divided into two parts: a fixed part, assumed to be independent on facility size, and a variable part, assumed to be proportional to facility size. Operation costs include labor, energy, supplies, and maintenance. Because setup costs are concentrated in time, and operation and transport costs are distributed over time, they need to be either discounted or annualized (that is, referred to the same period of time). In the formulation, all costs are annualized.

Constraints (2) guarantee that the entire demand from each center will be met by some facility. Constraints (3) ensure that there will be no assignment of demand to closed sites, because $y_k = 0 \Rightarrow x_{jk} = 0, \forall j \in J$. Constraints (4) guarantee that assignment variables (x_{jk}) are nonnegative. Constraints (5) state that location variables (y_k) can only take two values, 0 (site closed) or 1 (site open).

The capacity of a facility can be determined by adding up the demand assigned to it. That is,

$$z_k = \sum_{j \in J} u_j x_{jk}, \qquad \forall k \in K,$$

where z_k is the capacity of a facility located at site k (users).

The optimum solution to the model presented above has one important property (called the single-assignment property): all demand from a given center is assigned to the same facility. Or, in other words, the demand from a given center is not split between two or more facilities. The facility to which the demand is assigned is the cheapest assignment facility (considering both variable facility costs and transport costs). This is not, necessarily, the facility the users would attend if they could choose it. When users can choose the facility they will attend according to some preference criterion, some constraints must be added to the model (Wagner and Falkson, 1975; Hanjoul and Peeters, 1987). For instance, if the preference criterion is proximity, the constraints should be:

$$\sum_{k': d_{jk} \geqslant d_{jk'}} x_{jk'} \geqslant y_k, \qquad \forall j \in J, k \in K.$$

The capacitated facility location problem (CFLP) is identical to the UFLP except for the presence of maximum and minimum capacity constraints. These constraints can be formulated as follows (Davis and Ray, 1969; Geoffrion and McBride, 1978):

$$\sum_{j \in J} u_j x_{jk} \leqslant z_{\max_k} y_k, \qquad \forall k \in K, \tag{6}$$

$$\sum_{j \in J} u_j x_{jk} \geqslant z_{\min_k} y_k, \qquad \forall k \in K, \tag{7}$$

where $z_{\max_k}$ ($z_{\min_k}$) is the maximum (minimum) capacity for a facility located at site k (users).

Once added to the UFLP model, constraints (6) ensure that the demand assigned to each open site will satisfy a given upper limit. Constraints (7) do the same with regard to a given lower limit. Note that constraints (3) could be deleted from the formulation, because constraints (6) are sufficient to guarantee that there will be no assignment of demand to closed sites. However, their presence is crucial to make the formulation integer friendly, and solution methods more efficient (about this important issue, see Effroymson and Ray, 1966; ReVelle, 1993; Williams, 1985).

The optimum solution to a CFLP does not have the single-assignment property in many occasions. This can make the solution difficult to implement in practice, because, it may be difficult (unpopular) to assign a fraction of the demand from a given center to some facility, and other fractions to more distant facilities, or to facilities of inferior quality. To avoid multiple-assignment solutions, constraints (4) must be replaced with

$$x_{jk} \in \{0, 1\}, \qquad \forall j \in J, k \in K. \tag{8}$$

The models presented above can be easily adapted to accommodate, for instance, local accessibility restrictions (that is, demand from all centers must be covered by a facility located within a given maximum distance, $d_{\max}$), existing facility constraints, and initial investment restrictions.

Local accessibility restrictions can be handled in several ways. One of them consists of eliminating from the models the variables x_{jk} for which $d_{jk} > d_{\max}$ (Khumawala, 1973). This can be achieved simply by changing K to $K_j = \{k\colon d_{jk} \leqslant d_{\max}\}$ both in the

x_{jk} terms of the objective function and in constraints (2), (3), and (4). Another way of dealing with local accessibility restrictions leads to a model that, although less compact, is more convenient when most modeling languages are used (a modeling language converts the conventional notation of optimization models into a notation appropriate for computer applications). It consists of replacing constraints (3) with the following constraints:

$$x_{jk} \leqslant a_{jk} y_k , \qquad \forall j \in J, \; k \in K, \tag{9}$$

where

$$a_{jk} = \begin{cases} 1 \Leftarrow d_{jk} \leqslant d_{\max} , \\ 0 \Leftarrow d_{jk} > d_{\max} . \end{cases}$$

The existing facilities constraints can refer either to situations where existing facilities can be replaced with new facilities or to situations where they must be kept. In the first case, new sites, coinciding with the sites where existing facilities are located, must be included in the set of sites. Depending on the costs of new and existing facilities, the optimum solution will automatically determine the existing facilities that should be replaced. In the second case, the following constraints must be added to the model:

$$y_k = 1, \qquad \forall k \in K^0 , \tag{10}$$

where K^0 is the set of (initially) open sites.

Initial investment restrictions can be formulated as follows (Rojeski and ReVelle, 1970):

$$\sum_{j \in J} \sum_{k \in K} e_{vi_k} u_j x_{jk} + \sum_{k \in K} e_{fi_k} y_k \leqslant b ,$$

where

e_{vi_k} is the variable setup expenditure for a facility located at site k (dollars per user),
e_{vi_k} is the fixed setup expenditure for a facility located at site k (dollars),
b is the maximum initial investment (dollars).

The uncapacitated p-median problem (Up-med) consists of finding a maximum-accessibility solution to the location and capacity of a given number of facilities, instead of a minimum-cost solution (in principle, a minimum-cost solution is always preferable, but it is often difficult to set commensurable facility and transport costs). The maximum-accessibility solution is the solution that minimizes the aggregate distance between users and facilities. This problem can be represented with the following mathematical model (ReVelle and Swain, 1970):

$$\text{minimize}\, D = \sum_{j \in J} \sum_{k \in K} d_{jk} u_j x_{jk} , \tag{11}$$

subject to

$$\sum_{k \in K} x_{jk} = 1, \qquad \forall j \in J,$$

$$x_{jk} \leqslant y_k , \qquad \forall j \in J, \; k \in K,$$

$$\sum_{k \in K} y_k = p , \tag{12}$$

$$x_{jk} \geqslant 0, \qquad \forall j \in J, \; k \in K,$$

$$y_k \in \{0, 1\}, \qquad \forall k \in K,$$

where

D is the aggregate distance between users and facilities (kilometers),

p is the number of facilities.

That is, the Up-median problem is identical to the UFLP, except for the objective function (11), which expresses the minimization of aggregate distance, and constraint (12), which specifies the number of facilities to be located.

The capacitated p-median problem (Cp-med) is identical to the Up-median problem except for the presence of maximum and minimum capacity constraints [that is, constraints (9) and (10)].

Within the Up-med and the Cp-med, local accessibility restrictions, existing facility constraints, initial investment restrictions, and multiple-assignment situations can be handled in exactly the same way they are handled within the UFLP and the CFLP.

The FLP and p-med problems are among the simplest public facility planning problems. Others are considerably more complex, taking into account aspects such as time-varying demands (Antunes and Peeters, 2000; Van Roy and Erlenkotter, 1982), stochastic demands (Louveaux and Peeters, 1992), distance-sensitive demands (Perl and Ho, 1990), multiactivity facilities (Akinc, 1985), hierarchic facilities (Antunes, 1999; Moore and ReVelle, 1982), or hub facilities (O'Kelly, 1986).

The problems referred to above, like any other problems represented with mixed-integer optimization models, may be solved using three kinds of method: general (exact), specialized (exact), and (specialized) heuristic. General methods such as branch-and-bound are the easiest to use, because fast and reliable commercial mixed-integer optimization packages are now available (for example, CPLEX, LINDO, OSL, XA, XPRESS-MP). However, they apply only to relatively small problems [though, as shown in Ribeiro and Antunes (2000), much larger ones than a few years ago]. Specialized methods can be used to solve large and complex problems of the particular type under consideration, exploiting their distinct mathematical structure. However, they will normally require arduous programming work before they can be applied. Furthermore, it is often difficult to adjust a specialized method developed for a given problem to a slightly different problem. Examples of efficient specialized methods applicable to facility planning problems are the dual-ascent algorithm proposed by Erlenkotter (1978) for the UFLP and the Lagrangean-relaxation algorithm proposed by Beasley (1988) for the CFLP. Heuristic methods also permit us to solve large and complex problems, and the corresponding software is much easier to develop. However, they are not exact, in the sense that they guarantee only a local optimum, not necessarily close to the global optimum. Examples of classic heuristic methods applicable to facility planning problems are the ADD, DROP, and INTERCHANGE algorithms proposed by Kuehn and Hamburger (1963), Feldman et al (1966), and Teitz and Bart (1968), respectively for FLP and p-med problems.

3 GIS-based decision-support tool

The motivation behind the development of the optimization models and solution methods referred to in the previous section is (should be) to enhance public facility planning practice. However, if models and methods are not made available through an interactive, user-friendly input–output interface, the potential benefits derived from their utilization will rarely become effective.

Given the strong geographic nature of facility planning problems, GIS can be used to provide that kind of interface. Up until now, two basic approaches have been adopted for the applications of GIS in this area.

The simplest approach consists of using the built-in commands included in some GIS packages (for instance, the LOCATEALLOCATE command of ArcInfo). Some recent applications of this approach reported in the literature deal with open space planning in Hong Kong, China (Yeh and Chow, 1996), conservation reserve planning in Southwestern California, USA (Gerrard et al, 1997), and recyling depot planning in Ontario, Canada (Valeo et al, 1998).

The other approach consists of developing a customized GIS package by using the package's built-in programming language. An interesting application of this approach is presented in Camm et al (1997). This paper describes the utilization of MapInfo and MapBasic (MapInfo built-in programming language) to analyze and improve the product-sourcing and distribution operations of Procter & Gamble in North America (Procter & Gamble is one of the world's largest consumer goods company). The first efforts made by the authors of this paper to develop a GIS-based decision-support tool for public facility planning followed the approach adopted by Camm et al (1997), using ArcView instead of MapInfo (rarely used in Portugal) and Avenue (ArcView built-in programming language) instead of MapBasic.

The package MapFL presented in this paper derives from yet another approach. Instead of using a built-in programming language with limited capabilities (such as Avenue) to solve facility planning problems within a GIS package, the approach uses an all-purpose programming language to operate a GIS interface and to solve the facility planning problems. The programming language is Visual BASIC (VB) (Microsoft, 1998). The GIS interface is handled with MapObjects, an activeX control developed by the Environmental Studies Research Institute (ESRI, 1999). This institute is the maker of ArcView and ArcInfo, the world's best-selling GIS products. The facility planning problems are solved with two XPRESS-MP subroutine libraries (Dash Associates, 1999). XPRESS-MP is one of the many mixed-integer optimization packages currently available on the market. MapFL was designed to run under Windows 95, 98, ME, and NT.

The decision to follow this approach instead of the approach adopted initially (that is, ArcView plus Avenue) can be justified on several grounds. First, the programming effort involved in the implementation of the new approach is much smaller. On the one hand, because VB provides a high-quality environment to generate, test, and modify computer code. On the other hand, because the computer code can incorporate OLE (Object Linking and Embedding) automation components provided by Microsoft and many other companies. Second, MapObject draws faster than any other mapping software, because it runs directly on the MFC (Microsoft Foundation Class). Third, VB programs can perform database operations, such as queries and searches, extremely fast. Fourth, VB programs use much less computer memory than Avenue programs built for the same purpose, because Avenue runs inside ArcView, and ArcView is quite exigent with regard to memory usage. Finally, VB programs can run in any Windows PC, whereas Avenue programs can only run in PCs where ArcView is installed.

Detailed information on the general structure of MapFL, and on the corresponding input – output and problem-solving operations, is given below.

3.1 General structure

The general structure of MapFL is shown in figure 2 (see over). The GIS module manages all geographic data relating to centers and sites, and to the transport network connecting them. For each planning instance, this information needs to be supplemented with information about the type of problem to solve and specific constraints to be taken into account. All information is then automatically assembled in a problem file written in an appropriate text format. The XPRESS-MP libraries interpret the problem file and solve the problem. The optimum solution is made available to the user both through

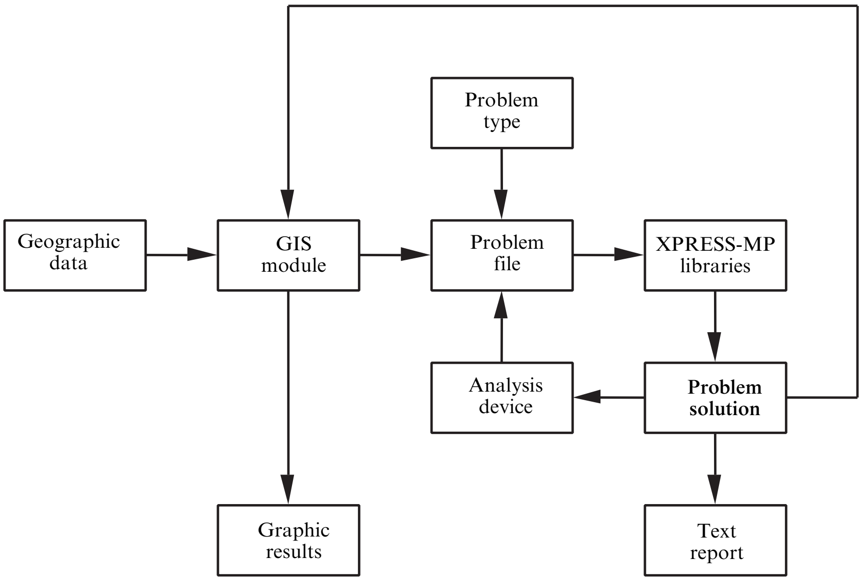


Figure 2. General structure of MapFL.

a text report and in graphic format. The latter is produced with the GIS module. The optimum solution may be inspected with an analysis device.

3.2 Input operations

Data input consists of three distinct parts. The first part includes the location of centers and sites, and (if desired) the design of the transport network. These data are supplied to MapFL as information themes or layers (theme is the appropriate word according to MapObjects syntax). The second part includes the type of problem to be solved (FLP and p-med in the present version) and specific constraints to be taken into account (maximum and minimum capacity, existing facilities, local accessibility, single-facility assignment, closest-facility assignment). The third part includes the attributes of centers, sites, transport nodes, and transport links. These data are supplied to MapFL in tables comprising as many columns (fields) as the number of attributes to be considered, and as many lines (records) as the number of features (centers, sites, transport nodes, and transport links) included in the problem. Some attributes are essential whereas others are optional. The essential attributes are those corresponding to data needed to define the facility planning problems. Demand is an essential attribute for both FLP and p-med problems. Other attributes are essential only for some problems. For instance, setup and operation costs are essential for FLP problems, but not for p-med problems.

Information themes and attribute tables can be built with the editing tools provided by MapFL. With regard to information themes, input operations can be made rather easily if performed on top of a raster image representing the territory under consideration (image theme). Alternatively, information themes and attribute tables can be built with another computer application (for instance, ArcView), and then saved in the shapefile(.shp) format.

All data may be displayed, changed, or printed whenever necessary.

3.3 Problem solving

The facility planning problems are solved with two XPRESS-MP subroutine libraries—the Modeler Subroutine Library (XMSL) and the Optimizer Subroutine Library (XOSL).

The former interprets a text file describing the problems (data and models) in appropriate format, and generates input for XOSL. The latter determines the optimum solution to the problems using branch-and-bound and branch-and-cut techniques (relaxed LP problems are solved using either primal-simplex, dual-simplex or Newton-barrier algorithms). The libraries are called to the main program as Dynamic Linking Libraries (DLL).

Instead of using XPRESS-MP libraries, it would have been possible to use any other commercial mixed-integer optimization libraries available on the market, or to develop a library of specialized and/or heuristic methods from scratch.

The decision to resort to XPRESS-MP libraries was taken for two main reasons. First, XPRESS-MP outperformed several other packages with regard to speed and reliability on tests conducted a few years ago by one of the authors of this paper (Antunes, 1994), and has been updated often since then to incorporate recent theoretical advances in mixed-integer optimization. Second, XPRESS-MP can solve FLP and *p*-med problems with up to 200 centers and 200 sites to optimality within a few minutes (if not seconds) of computing time. Real-world problems rarely exceed this size (and even when they do, they can be simplified at no significant cost through proper aggregation of centers and sites). This does not mean, however, that XPRESS-MP will solve all possible problems to optimality within the maximum computing time set by the user (the MapFL default for this parameter is one hour). In this case, MapFL issues the warning 'search not completed', and retains the best solution found.

3.4 Output operations

Problem solutions are presented (and saved onto disk) in three formats:

(1) a text report, containing a brief description of the problem, and numerical information on the optimum solution value, the optimum facility locations and capacities, and the optimum demand assignments;

(2) two themes of graphic information, describing optimum facility locations (point theme) and optimum demand assignments (line theme);

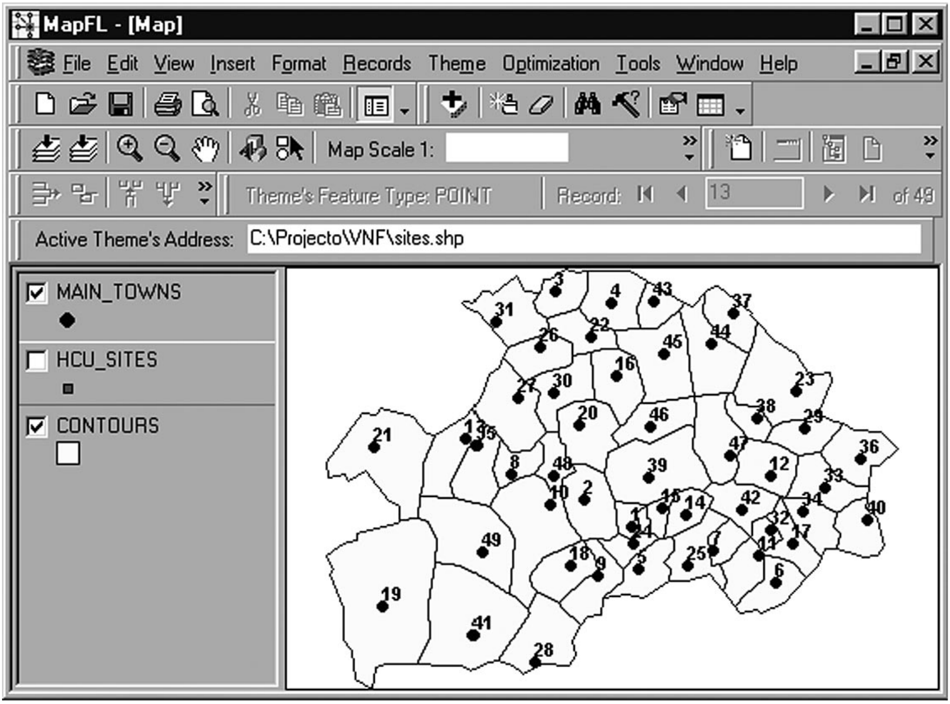
(3) the attribute tables associated with both themes, containing numerical information on optimum facility capacities and optimum demand assignments.

Several operations for the analysis of spatial information can be easily made using the GIS module of MapFL. Examples are: buffering features, finding features with particular attributes near other features, finding features that fall inside a given area, and finding features that intersect other features.

The sensitivity of the optimum solution with regard to the addition or deletion of some facility or facilities, or to a shift in the location of some facility, can be analyzed with a device provided within MapFL.

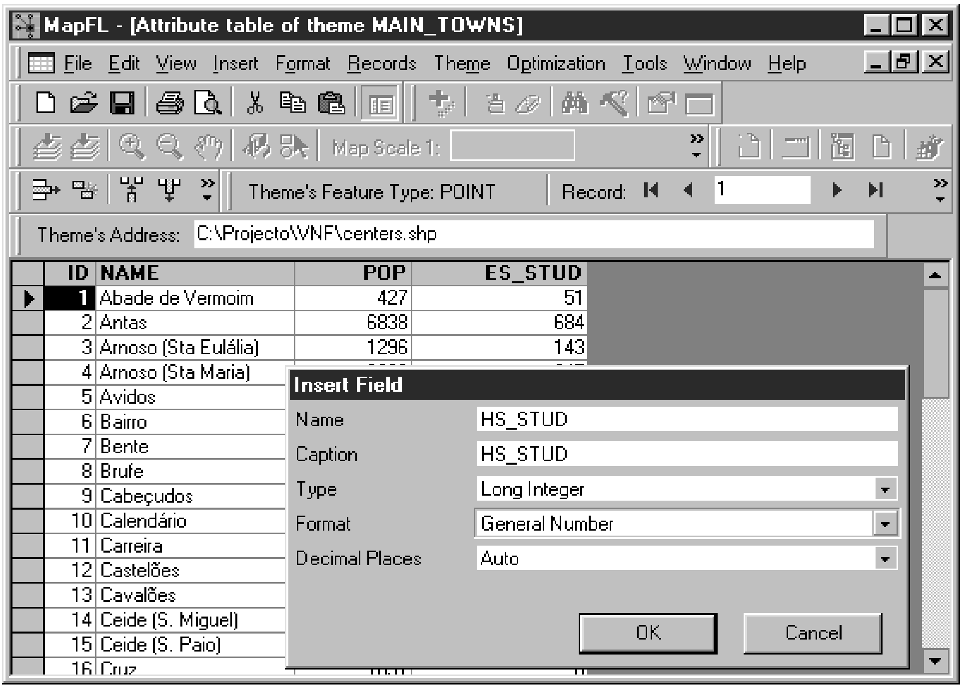
4 Real-world application

The setting for the first application (and initial testing) of MapFL was the municipality of Vila Nova de Famalicão, in northern Portugal. With approximately 120 000 inhabitants, Vila Nova de Famalicão is one of the most important municipalities in the Porto Metropolitan Area. The municipality comprises 49 communities (*freguesias*), whose borders are represented in figure 3 (see over) by the polyline theme CONTOURS. Also visible in the figure is the point theme MAIN_TOWNS (circles 1 – 49), representing the main towns of each community. The demand for most types of public facilities can be assumed as being concentrated in these towns. The point theme HCU_SITES, representing the sites where health care units (the smallest facilities including in the Portuguese National Health System) are or may be located, could also be made visible. However,



HCU_SITES Sites for the location of health care units

Figure 3. Geographic setting for the real-world application.



ES_STUD Number of elementary-school students.
HS_STUD Number of high-school students.

Figure 4. Attribute table of theme MAIN_TOWNS.

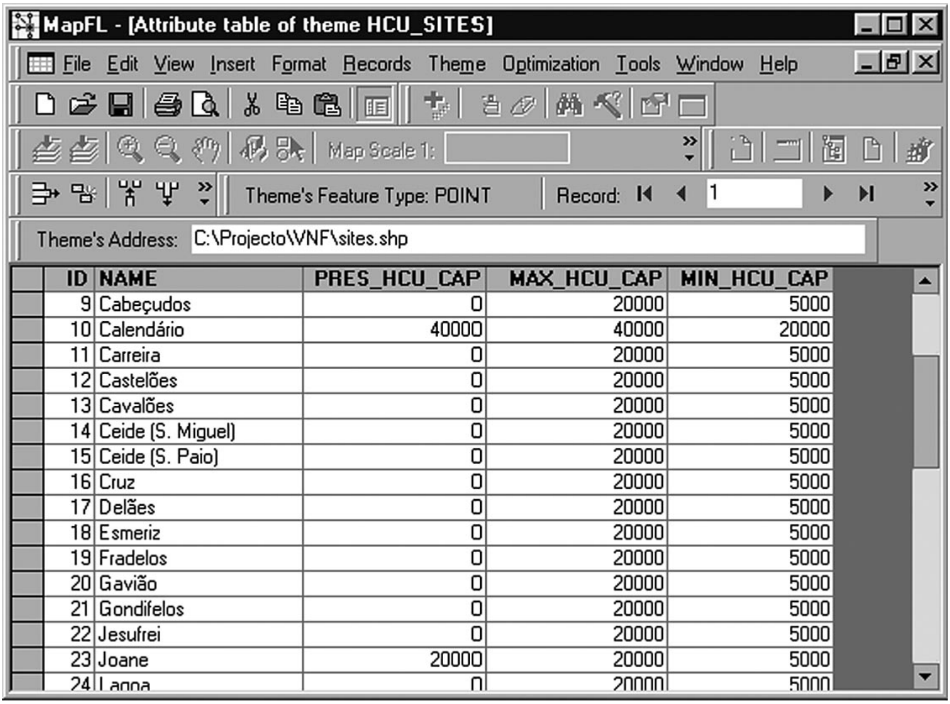
this is not necessary here because MAIN_TOWNS and HCU_SITES are assumed to coincide (that is, health care units cannot locate outside main towns).

The attribute table for the theme MAIN_TOWNS is shown in figure 4 (rear window). The table contains information on the total population and the number of elementary-school students living in each community (fields POP and ES_STUD). The creation of these fields was made with the Insert Field command, included in the Field menu. The use of the Insert Field command is illustrated in figure 4 (front window). There, the command is being activated to create a field containing information on the number of high-school students living in each community (field HS_STUD).

The attribute table for the theme HCU_SITES is shown in figure 5. The table contains information on the capacity of the two existing health care units located at Calendário and Joane (main towns 10 and 23), and on the maximum and minimum capacity to be installed at these and other sites (fields PRES_HCU_CAP, MAX_HCU_CAP, and MIN_HCU_CAP).

The particular application described here consists of determining a maximum-accessibility solution for the location and capacity of eight new health care units in the municipality of Vila Nova de Famalicão. The decision to build eight new health care units is consistent with both the financial capabilities of the municipality and the capacity standards set by the Portuguese Health Administration. According to these standards, the maximum capacity of a new health care unit is 20 000 inhabitants, and the minimum capacity is 5000 inhabitants. The capacity of a health care unit is defined as the population assigned to the unit.

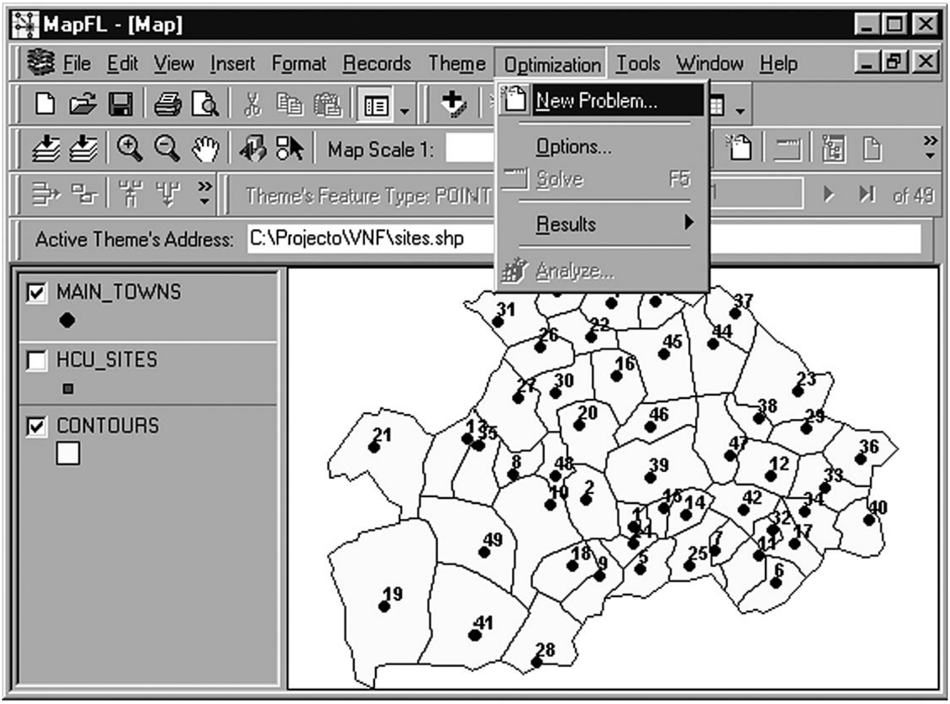
The application of MapFL to solve this (or any other) problem is launched with the command New Problem, included in the Optimization menu (figure 6, over). The



ID	NAME	PRES_HCU_CAP	MAX_HCU_CAP	MIN_HCU_CAP
9	Cabeçudos	0	20000	5000
10	Calendário	40000	40000	20000
11	Carreira	0	20000	5000
12	Castelões	0	20000	5000
13	Cavalões	0	20000	5000
14	Ceide (S. Miguel)	0	20000	5000
15	Ceide (S. Paio)	0	20000	5000
16	Cruz	0	20000	5000
17	Delães	0	20000	5000
18	Esmeriz	0	20000	5000
19	Fradelos	0	20000	5000
20	Gavião	0	20000	5000
21	Gondifelos	0	20000	5000
22	Jesufrei	0	20000	5000
23	Joane	20000	20000	5000
24	Lagoa	0	20000	5000

PRES_HCU_CAP Present capacity of health care units.
MAX_HCU_CAP Maximum capacity of health care units.
MIN_HCU_CAP Minimum capacity of health care units.

Figure 5. Attribute table of theme HCU_SITES.



HCU_SITES Sites for the location of health care units.

Figure 6. Launching the real-world problem.

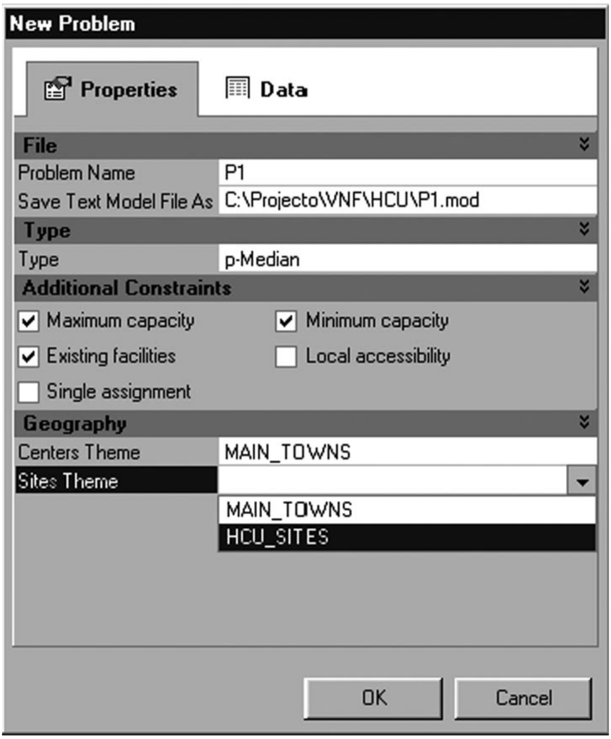


Figure 7. Setting up the properties for the real-world problem.

command gives access to the boxes shown in figures 7 and 8. The first one (Properties) serves to specify the type of problem being considered (C*p*-med with existing facilities) and the themes containing the geographic information for centers and sites. The second one (Data) serves to define the number of facilities (ten), the fields containing the data for facility demand, existing facilities, and capacity limits, and the method for obtaining the distances between centers and sites. Three methods are possible: calculation of Euclidean (straight-line) distances, calculation of shortest-path distances using Floyd's algorithm (1962), and import from an external source (that is, a distance matrix in text format).

After specifying the properties and data for the problem, the corresponding optimization model can be solved through the Solve command (Optimization menu). The results for the problem then become available through the Results command (Optimization menu).

The most important results are shown in figures 9 and 10 (see over). Figure 9 displays the themes FACILITIES1 and ASSIGNMENTS1, which represent the optimum facility locations (squares) and optimum demand assignments (straight lines). Figure 10 (front window) is the attribute table associated with the theme FACILITIES1. It contains information on the optimum facility capacities, expressed in absolute terms and also in relative terms, as a percentage of total capacity [fields CAP and CAP(%)]. As required, all new health care units have a capacity of between 5000 and 20 000 inhabitants.

The impact of changing the number of facilities, or adding, deleting, or moving a facility, upon the optimum solution obtained with MapFL can be inspected, as shown in figure 11 (see over) (front window), with the Analyze command (Optimization menu). There, the command is being used to examine the impact of moving the health care unit located in São Cosme (main town 45), which is one of the sites where a new health

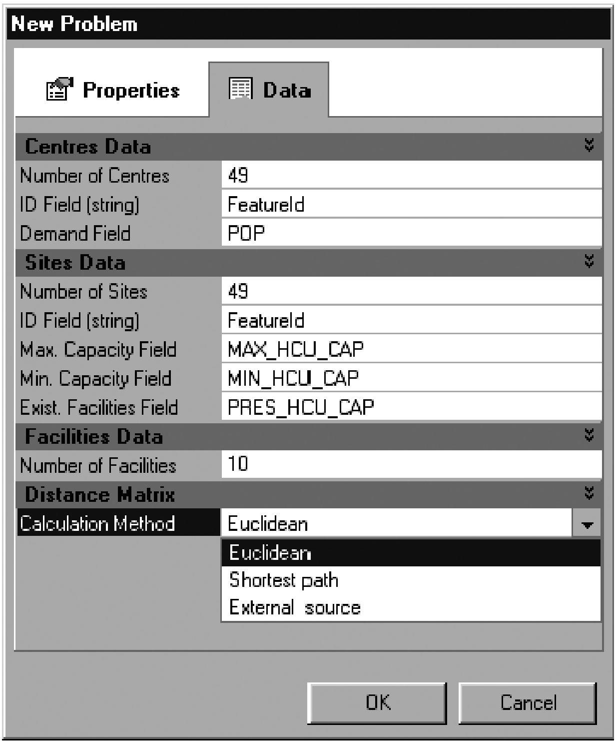


Figure 8. Setting up the data for the real-world problem.

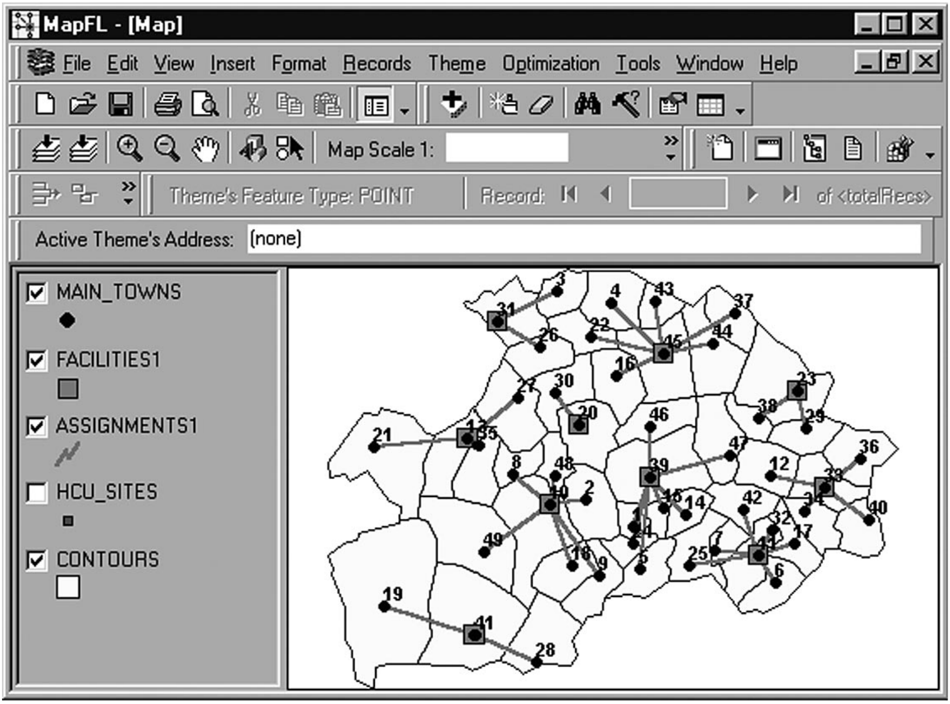
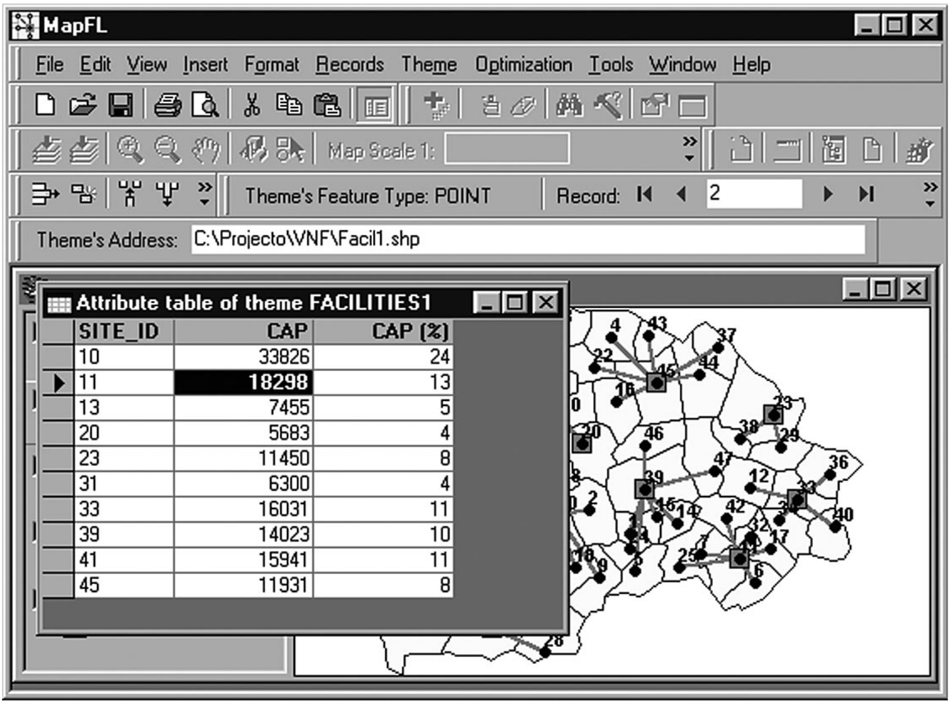


Figure 9. Graphic solution for the real-world application.



SITE_ID	CAP	CAP (%)
10	33826	24
11	18298	13
13	7455	5
20	5683	4
23	11450	8
31	6300	4
33	16031	11
39	14023	10
41	15941	11
45	11931	8

Figure 10. Attribute table of theme FACILITIES1.

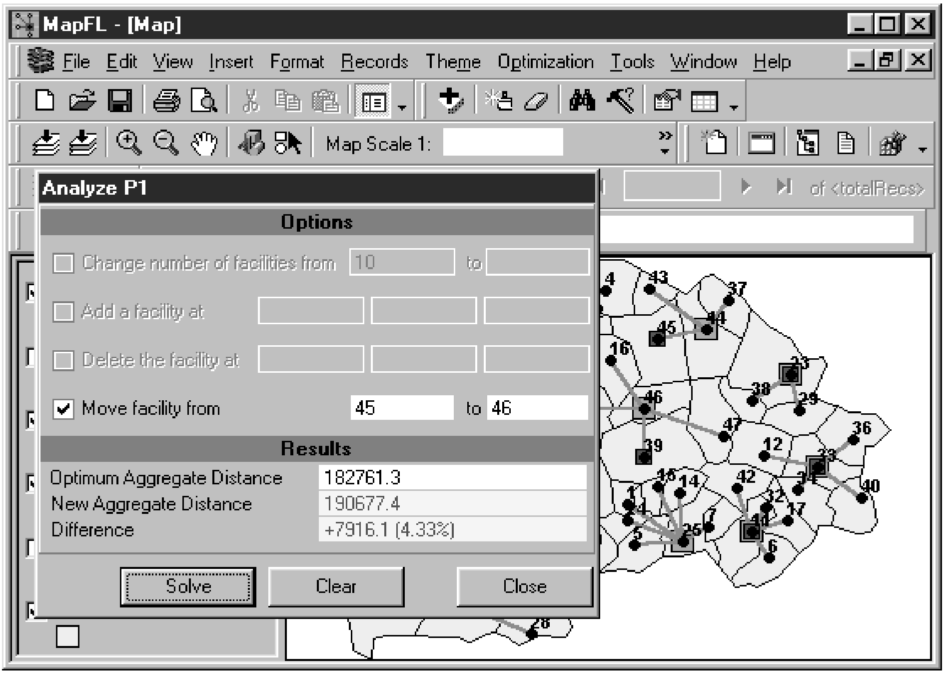


Figure 11. Analysis device.

care unit would be optimally located, to the neighboring community of São Martinho (main town 46). This option is specified in the upper part of the window. The lower part of the window contains information on the results of implementing the move. As expected, the aggregate distance between users and facilities will increase (by a little more than 4%). The new facility locations and demand assignments are also shown in figure 11 (rear window).

5 Conclusion

The package MapFL presented in this paper is an interactive, user-friendly decision-support tool for public facility planning, combining the capabilities of GIS (for input–output operations) with advanced optimization methods (for problem solving). MapFL was designed to help public facility planning institutions making better, more reflective, decisions, thus contributing to bridge the gap between theory and practice that characterizes the way public facility planning is made at present. In addition to this, it was designed to provide a convenient framework for the storage and visualization of information about public facilities. The institutions that can benefit from using MapFL are of two basic types: specialized planning departments of central and regional administrations (for sectors such as education, health, public safety, culture, and sports) within central administrations, and the spatial planning departments of local administrations.

The present version of MapFL can handle only two types of public facility planning problems: facility location problems and p-median problems. These are relatively simple problems, which often do not fully capture the complexity of real-world situations. In the near future, the main efforts to improve MapFL will be aimed at expanding the field of application of MapFL to other, more realistic, problems. In particular, the focus will be put on comprehensive public facility planning (that is, planning decisions are made taking simultaneously into account several types of facilities). The reason for this is that, at least at the local level, public facility planning primarily takes place within spatial planning processes, which are (or should be) comprehensive. The public facility planning literature is particularly sparse on this subject.

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