# A SDSS FOR INTEGRATED MANAGEMENT OF HEALTH AND EDUCATION FACILITIES AT THE LOCAL LEVEL: CHALLENGES AND OPPORTUNITIES IN A DEVELOPING COUNTRY

Renato da Silva LIMA
Researcher
Department of Transportation,
São Carlos School of Engineering
University of São Paulo
Av. Trabalhador São-carlense, 400
13566-590, São Carlos – SP – Brazil
Tel: +55 16 2739595 Fax: +55 16 2739601
E-mail: rslima@sc.usp.br

Antônio Nélson RODRIGUES DA SILVA
Associate Professor
Department of Transportation,
São Carlos School of Engineering
University of São Paulo
Av. Trabalhador São-carlense, 400
13566-590, São Carlos – SP – Brazil
Tel: +55 16 2739595 Fax: +55 16 273 9601
E-mail: anelson@sc.usp.br

José Fernando Gomes MENDES
Associate Professor
Department of Civil Enginering
School of Engineering, University of Minho
4710-057, Braga - Portugal
Tel: +351 253 604720 Fax: +351 253 604721
E-mail: jmendes@civil.uminho.pt

**Abstract:** The objective of this paper is to discuss challenges and opportunities met during the development of a SDSS (Spatial Decision Support System) for integrated management of health and education facilities at the local level in Brazil. The goal of the proposed system is to seek for an optimal arrangement of health and education facilities in medium-sized cities, in order to reduce both facilities construction costs and user's transportation costs that ought to be produced during a time span of two to four decades. Some of the operational difficulties observed during the early implementation steps of the proposed SDSS are discussed in this paper. Apparently, they can be relevant in the practical application of similar systems. The described experience also suggests that the implementation of systems like the one proposed here can be an opportunity to drive a change in the way that local governments in developing countries deal with planning.

**Keywords:** Spatial Decision Support System, education facilities management, health facilities management, developing country, urban infrastructure

## 1. INTRODUCTION

The number of studies concerned with the definition and implementation of systems for supporting urban planning has been growing in recent years either with the name of Planning Support Systems (PSS) or Spatial Decision Support Systems (SDSS), as can be seen in the works of Batty (1995); Batty and Densham (1996); Clarke and Langley (1996); Klosterman (1997); Langley (1997); Stillwell and Langley (1999); Kammeier, (1999); and Klosterman (2001). These systems are more frequently found in industrialized countries than in developing countries, what can be explained in many cases by the absence of systematic urban planning at all in the latter. However, despite the impressive technological advances experienced worldwide in recent years, the practical implementation of the theoretical developments introduced in urban planning support systems is still a challenge even in developed countries. According to Kammeier (1999), notwithstanding all promising advances in the development of systems conceived to support both the planning and decision-making processes, he was not able to find any complete DSS in the real-world until the time he wrote his paper.

A search in the specialized literature shows a large number of studies dealing with the development and theoretical implementation of PSS and SDSS, as in Batty (1995); Márquez and Maheepala (1995); Malczewski *et al.* (1997); Mendiratta and Ravikumar (1997); Kammeier (1999); Galvão (2000); Balling *et al.* (2000); Jankowski *et al.* (2001); and Klosterman (2001). The practical implementation of some of these systems, however, could face many difficulties (predominantly operational, but also in many cases political) that have not always been taken into account in the original system design. In extreme cases, these troubles could eventually impede the practical adoption of the planned system. Even though, any attempt to put those systems in practice could bring significant benefits to public administrators and overall improvements for the planning process in several areas. These benefits can be produced by the very first steps of the process, such as the effort to organize some important public databases. These are the starting points of the present work, which has as the main objective the discussion of challenges and opportunities met during the development of a SDSS (Spatial Decision Support System) for integrated management of health and education facilities at the local level in Brazil.

The goal of the proposed system was to seek for an optimal arrangement of health and education facilities in a medium-sized city, in order to reduce both facilities construction costs and user's transportation costs that ought to be produced during a time span of two to four decades. This period is crucial for the proposed management strategy because in it is the likely point in time when population shall become stable in the country. In other words, spending money now to build new facilities or to expand the existing ones may in some cases become a meaningless investment, if the projected demand in the facility neighborhood is not going to grow any more, or even worse, if it is going to decrease.

Therefore, even looking to the education and health systems independently, investments in facilities need careful examination of the future demand growth and its location. But there are connections between them that must be taken into account. In order to consider those connections, the system design was thus based on a comprehensive and careful research of demographic models, database management systems (DBMS), spatial interaction models, multicriteria decision analysis (MCDA), location-allocation concepts and planning and decision support systems (PSS and DSS, respectively), looking for both traditional and innovative approaches and computer-based techniques (such as Artificial Neural Networks, Cellular Automata, etc.). The integration of those techniques to build the proposed system, which is conceived for Brazilian medium-sized cities, was made in a Geographic Information System environment.

The integration of the education and health systems is the key for adjusting short and medium-time demand projections, because users are frequently "clients" of both systems, although often in different periods of time. As a consequence, the birth of a baby in a hospital, which is part of the health system, is certainly an indication that the child will need a day-care center within a few months and a primary school within a few years. Keeping track of the child address since his/her birth gives a good indication of this demand location in the near future. In that way, it is possible to anticipate the size (i.e, number of clients) and location of a reasonable share of the near future demand. On the other hand, the health system can benefit of the data collected in schools, because they need to trace where the children are, in order to be sure they have at least the basic preventive assistance (e.g., the required vaccines).

Therefore, the main system elements for the first periods of time are the exact location of both demand and supply, and location-allocation models, which in that case are based on Artificial Neural Networks. In the long run, however, this kind of data is not enough for demand projections, because migration flows become very important in the total demand size and location. In addition, it is interesting for the health system to know not only the demand location in the distant future, but also their composition in terms of age, since after population stabilization follows the trend of a much older population. In that level of the system, Cellular Automata models and spatial interaction models become the key elements for predicting, respectively, the size and location of the demand by age and the flows to the facilities. In that way, the system can manage the demand for both education and health systems at the operational, tactic, and strategic levels. However, there are many challenges and difficulties (e.g., data limitations, political and administrative discontinuity, and lack of software, hardware and "peopleware") for such a system design and implementation in a developing country. They are examined in this paper, along with the system description.

After this introduction, the next section of this paper brings a brief literature review about the use of systems designed for supporting urban planning and urban management (PSS, DSS, and SDDS). Next, in section 3, the specific target problem of the SDSS discussed here is presented, followed by an introduction of the system bases (section 4) and of the steps for its implementation (section 5). While some of the opportunities produced by the system are also discussed in section 5, some of the challenges and barriers to its implementation are presented in section 6. Finally, section 7 contains the concluding remarks, which are followed by the references.

## 2. PLANNING SUPPORT SYSTEMS

Despite the impressive development of hardware and software in the recent past and the wide adoption of computers in most planning offices, most planning problems cannot be solved simply by automating procedures. Batty (1995) stressed, however, the supporting role played by computers in the decision-making process. Thus, it is necessary to create systems for supporting the decision-making process that incorporate both issues suitable for automation and those that cannot be improved by such treatment. The infrastructure, the operation and the management of planning systems constitute a complex and demanding field, in which several actors and interests are involved, large amounts of resources are applied, and a variety of political options are open to discussion and decision. It seems obvious, though, that suitable planning support methodologies could significantly improve the performance of those systems.

According to Klosterman (2001), the recognition that the technological development is not a barrier for planning suggests that a better use of computer databases and planning methods shall not start with the selection of a technology, but rather with the choice of a planning conception. While no single technology alone can supply all subsidies needed by planners to carry out their activities, several distinct technologies can be applied together to provide resources and capabilities that no single tool can offer. For Klosterman (2001), this is the idea that has motivated many authors to adopt Harris' (1989) concept of Planning Support Systems as a platform (or model) to combine several methods and computational models in an integrated system for supporting the planning function. The name Planning Support System is nowadays broadly accepted, because it incorporates a larger range of concepts than the Spatial Decision Support Systems (Kammeier, 1999).

For some authors, however, the terms PSS and SDSS are confusing because many characteristics are present in both systems. For these authors, the PSS, the DSS, and the SDSS should all be designed to supply interactive, integrative and participatory procedures for the treatment of nonroutinary and poorly structured decision processes. However, due to the fact that the PSS is a planning system, particular attention has to be given to problems that: affect large number of people, have several issues and interests involved, and include strategic questions. This does not happen with the DSS and SDSS, which are in general designed to support more specific or short-term policy-making processes. This characteristic stresses the fact that PSS shall not be seen as a new, radical form of technology that will replace all software tools currently available. On the contrary, it has to assume the form of an information framework capable of integrating the vast range of current (and future) information technologies that can be useful for planning purposes. In addition, it shall not be seen as a "black box", i.e., a collection of computational models that can automatically generate the best solution when fed up with certain data. It has to be just the opposite. It must provide the basic information infrastructure needed for planning and that can facilitate the integration among planners and of planners with other actors (Klosterman, 2001).

According to Kammeier (1999), the new logic of computation for planning must be driven essentially by answers to policies and problems and not to data requirements or model characteristics. This is nothing but the same principle mentioned by Lee (1973) thirty years ago: "starting a model with a problem that needs solving rather than a methodology that needs applying". In conceptual terms, a PSS can be divided in four stages: (1) strategy formulation; (2) spatial analysis; (3) detailed evaluation of the selected projects or alternatives; and (4) political decision for implementation based on the three preceding PSS stages (Kammeier, 1999). Furthermore, according to the same author, depending on user's needs a modest initial structure could be developed to become a large and functional PSS through the addition of some computational tools for substantially enhancing the analysis methods required.

If it may be true that the real computer revolution did not yet take place in industrialized countries (Klosterman, 2001), this is certainly a fact in many developing countries. Moreover, the latter also suffer with a deficiency of planning methodologies and decision support systems for managing their social and economic development processes in order to distribute the usually scarce resources in a proper way. In that particular aspect, Planning Support Systems can play an important role in developing countries, as we tried to stress with the system introduced here.

## 3. PROBLEM IDENTIFICACION

The issue of planning health and education facilities distribution is essentially a location problem of discrete elements. The criteria for such a location are usually based on the accessibility measurement and coverage of the population (demand) in relation to health and education facilities (supply). This is unquestionably a relevant topic in Brazil, where even today the distribution of these facilities does not follow very precise methods in most urban areas. The allocation of the demand is as important as the location of new health and education units, because the correct use of the existing infrastructure may avoid or postpone the need of building new facilities. Thus, the problem is essentially an evaluation of location alternatives in a continuous or discrete solution space and subsequent allocation of the demand to the chosen alternatives. For that reason, it is named location-allocation problem.

The aim of the SDSS under development is to search for an optimal spatial distribution of health and education facilities in medium-sized Brazilian cities that can minimize travel costs of the demand. The problem has to be tackled in two distinct moments:

- At the present time, by trying to optimize the distribution of the current demand in relation to the existing facilities;
- In the future, by trying to find the best alternatives for the location of new facilities and also by trying to optimize the distribution of the future demand in relation to the new and existing facilities.

A careful search in the literature shows that the following elements can support the development of models for dealing with the problems above introduced:

- Location models, particularly those focusing on discrete infrastructure elements;

- Traditional demand models, for the optimization of the spatial distribution of demand;
- Artificial Neural Networks and Cellular Automata models, for predicting, respectively, the likely demand flows to the facilities and the future size and location of the health and education demand;
- Multicriteria analysis, for the evaluation of distinct alternatives, particularly when combining several criteria in the development of evaluation scenarios;
- Geographic Information Systems, as an environment for the development of spatial analysis models.

The association of these elements is essential for the development of a system as the one schematically depicted in Figure 1, in which two planning dimensions can be distinguished. The first one is the *social* dimension, in that case limited to two levels: health and education. Each of these levels can be further subdivided in order to focus on specific health and education problems. In the case of the system here described, the focus is on the spatial distribution of health and education demand and supply. The other dimension represented in Figure 1 is the *temporal* dimension, which is divided in three levels: the present, the near future, and the distant future. That division is strongly influenced by the sort of analyses that has to be conducted in each phase, which change according to the available data. The combination of the subdivisions in the two dimensions result in the six squares numbered from I to VI, which are associated to the system planning and management steps. These numbers will be used when presenting details of these steps in section 5 of this paper. Before that, however, another important issue for the implementation of the system is discussed in section 4, as follows.

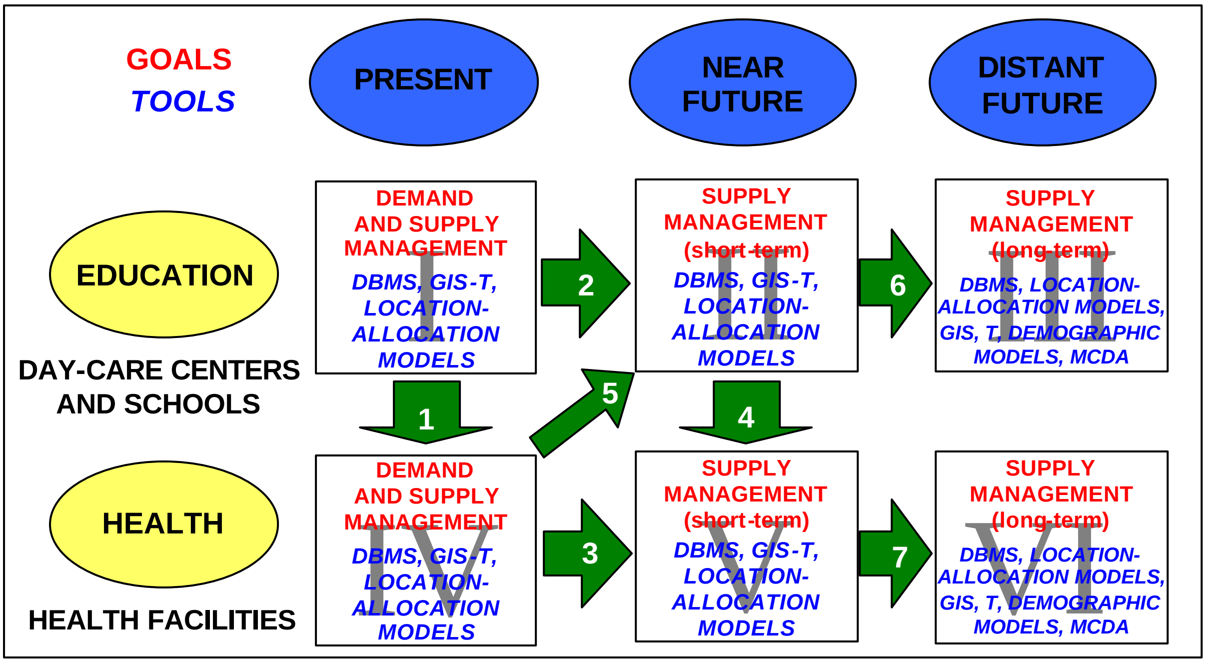


Figure 1 System framework

## 4. THE BASES OF THE SYSTEM

The efforts to build up the bases of the system must be directed to two main aspects: the search for institutional support; and the identification, delimitation or construction of databases. The challenge in the former aspect is in making it solid, permanent and comprehensive. The importance of the latter aspect is evident, since all subsequent analyses depend on accurate and reliable data.

### 4.1 The Institutional Basis

The first step for structuring the SDSS is the search for institutional support. Only a solid institutional foundation makes possible to build the operational foundation of the system, which is based on demand and supply data. The availability and access to data is often a crucial factor for the development of projects of this nature. These databases are quite often stored in public agencies. Therefore, the involvement of the local government, particularly of the high level administration staff (i.e., the mayor and direct assistants in charge of the municipal education, health, and planning secretaries) is central for the project development.

### 4.2 The Operational Basis

Although one can say that the operational foundation of the system is, in general terms, formed by data used to characterize demand and supply of the services under consideration, these data can have different origins. They can also be available at different levels of spatial aggregation and therefore they can mirror distinct aspects of the demand and supply. As each one of these levels can be important for the proposed system, the search for data as disaggregate as possible must guide the data search process. It must be remembered that further aggregation is always mathematically feasible, while the opposite is not. Furthermore, as the purpose of the system is to individually locate the demand, a georeferenced address database is very important not only for operational analyses, but also for analyses at the tactic and strategic levels.

The ideal condition for bringing a reliable address database to the system occurs when it already exists (preferentially stored in a GIS environment) and it is maintained by a planning agency (usually public), although shared and updated by the different agencies that make use of it. Unfortunately, in medium-sized Brazilian cities this is an unlikely situation. If that is the case, the construction of the address database from the beginning is a very important and unavoidable step of the process. Nevertheless, it is always important to look for alternatives (like that one proposed by Lima *et al.*, 2001) before starting the time and money-consuming process of building a new address database from scratch. Those authors found an interesting alternative to deal with this problem in the city of São Carlos, where the municipal agency in charge of water distribution and sewage disposal has an excellent address recording system based on geographic coordinates of land parcels.

It is important to notice that up to this point no sophisticated tool is really required for the operational tasks of data acquisition and formatting for use in the system. Even though, these phases can take a long time. Furthermore, they can be the most important phases of the project, considering that all analyses carried out in the subsequent phases are strongly influenced by the way demand and supply data are gathered, stored and maintained.

### 4.3 Demographic Data

Notwithstanding the importance of the mentioned databases for the municipal administration, they are not always available. Even when they are available, though, it is very difficult to find them in perfect conditions for immediate application. In some extreme cases, the alternative is to work only with demographic data for building the proposed system. The acquisition of demographic data does not happen only in that case, however, since they are always needed in the models used to predict the demand variation in the near and distant future.

The access to data showing the number of births in the city through time as well as the population growth rates makes possible to estimate the number of annual births from the present year until the project horizon year (for example, the year when population stabilization shall occur). These data are usually aggregated at the city level and they are, in the case of the municipalities located in the state of São Paulo, reliable and easy to get. The state planning agency responsible for the database (SEADE - State Data Analysis System Foundation) makes available annual information starting in the end of the 19th century.

Another important source of demographic data is the Brazilian Census Bureau. The main products distributed by that federal agency are the decennial census data, which are usually aggregated at the census tract level in urban areas. The use of these periodic and reliable datasets in combination with some simplified hypotheses makes possible to build projections of the spatial distribution of births and of certain specific age groups throughout the city under analysis. This is essential for the implementation of the proposed system. Although simplified hypotheses can always bring some degree of distortion of the results in absolute terms, they are useful for first estimates. These preliminary estimates can then be gradually improved when more precise data becomes available.

There is one kind of information that shall not be aggregated for the purpose of this SDSS. It is the location of the health and education facilities (the supply side). Furthermore, for the first operational stages of the system (stages I and IV) this is an essential information that cannot be estimated. Its exact number and location is mandatory for the all operational analyses.

### 4.4 Description of Demand and Supply

Once the institutional and operational bases are assured and the required (or available) demographic data are obtained, the next step is to describe the demand and supply as disaggregate as possible. In general, that description produces increasingly aggregate estimates along the years until the project horizon year. Conversely, the accuracy of the spatial distribution of these estimates decreases through time.

After the estimation of the project horizon year $n$ and of the annual number of births, it is necessary to know the spatial distribution patterns of births and how these patterns change along the years. Indeed, the actual birth figures are the main data of the system because they are used in all project stages. For stages I and IV (i.e., present time), the ideal situation is to know the exact addresses of every single baby just born (from the records of the health subsystem) and of every student actually registered in the education levels that are considered in the SDSS. For stages II and III (education) and V and VI (health) the proposition is to combine current georeferenced data with demographic data to obtain future estimates. These projections can be partially based on artificial intelligence models (such as Artificial Neural Networks) and dynamic urban simulation models (such as Cellular Automata).

The basic modeling conception is to use data of the latest available decennial demographic census, which are aggregated at the census tract level, to estimate the number of births in each of these urban subdivisions. The absolute birth figures can then be transformed in percentages of the total number of births in the whole city, in order to allow comparisons of values of different moments in time. This is the basis for estimating the spatial distribution of births in the city through time. In the system proposed here, the actual number of births and the addresses of these babies are also registered. That information can then be used to continuously improve the estimates as the number of records increase.

## 5. STEPS FOR THE SDSS IMPLEMENTATION

After the acquisition of a georeferenced address database and its association to demand and supply data, the implementation of the SDSS represented in Figure 1 can finally start. The mere description of the system implementation steps highlights several opportunities that it offers, as can be seen next.

### 5.1 Phase I: Education – Present Time

The first phase of the SDSS deals with the education subsystem and it consists in the evaluation of the current situation through a predominantly operational approach. The goal here is to improve the distribution of students by simply allocating them to closer facilities. Investments in this phase, if any, shall be preferably directed to increase the capacity of the existing facilities and not to the construction of new facilities. In this phase, the main tools applied are location-allocation models, which are fed with georeferenced data of the students and schools. These models look for students' distribution patterns that can minimize the displacement costs of the students given the actual distribution of schools. In summary, assuming the existence of a reliable address database in a GIS environment, the tasks carried out in this first phase are: to evaluate the actual distribution of students, to identify the schools they attend, and to estimate the corresponding individual and total displacement costs. The displacement cost assumed here is the shortest distance through the road network connecting every student house to his (or her) school. The location-allocation models search for new spatial distributions that can minimize these costs for each education level considered (in that case, day care centers and EMEIs, which in Portuguese stands for *Escolas Municipais de Educação Infantil*, or Municipal Schools for Child Education). In that process, mathematical location models (e.g., such as those dealing with the p-median and p-center problems) are associated to performance measures that try to characterize accessibility or equity levels of the demand.

The definition of goals for the demand re-distribution can follow distinct criteria. A first criterion considers the re-distribution of students in the entire city given the current capacity of the schools. In addition, certain limits for accessibility and equity values can be set. The models can be used, for example, to search for a spatial distribution of students that does not have any single student traveling more than a certain predefined distance. Different scenarios can be built, each one of them showing more than one performance measure, such as: average, maximum and total travel costs, percentage of students that have to be relocated from one school to another, etc. These values are very important for the decision-making process, since the administrator using the system can make judgments based on objective measures. Investments for expanding the capacity of the system shall be carefully examined in this phase because there is no information about the demand variation through time and therefore they can become a useless supply in the future. The goal of this phase is to improve the overall accessibility level of the users while seeking for an optimal use of the existing education facilities.

### 5.2 Phase II: Education – Near Future

The phase of education demand management for the near future requires an essentially tactic approach, in which the system must look for alternatives to improve even further demand coverage. Also in this phase, investments must be not very high and their focus must be mainly in medium-term improvements of the system. That includes the construction of new facilities in regions of the city where they are clearly needed because the demand allocation of phase I is not sufficient to solve the problem. This phase also asks for an operational approach similar to what is done in phase I, but the objective now is only to manage the system. Therefore, a large demand re-distribution is not supposed to happen any more.

Another point to consider in this phase is the anticipation of future needs. It is important to estimate, for example, the number of students that will attend every particular school in the years to come or the best schools to allocate the children leaving the day-care centers. In short, the demand and supply changes that will take place in the near future must be foreseen, year by year, and their impacts to the entire system must be estimated in advance. In the case of most medium-sized Brazilian cities, large demand fluctuations are not supposed to happen any more. However, it is important to follow the changes that happen during the life of the users in order to always assign every child to the best (in this case, closest) school. This is particularly true when the children are changing to a higher education level (from day-care centers to EMEIs, for example). A positive aspect of this phase is that many actions of tactic planning are well accepted by public administration, mainly because they can be achieved into the government period of four years.

In practical terms, it is important to know the size and location of the demand for day-care centers and EMEIs. One of the operational approaches to estimate that demand is to look only at birth data in the city, therefore ignoring the migration flows coming into the city and leaving it as well. The subjacent assumption in this case is that the number of children born in another city and who are attending the day-care centers of the city under consideration equals the number of children who moved out to another city (or died) after their birth in the studied city. Although this assumption can be acceptable at a macroscopic level (i.e., for the entire city), it seems too weak to be accepted in the case of migration flows occurring within the city. It is very difficult to predict the internal migration flows in a city because there is no data available describing how these changes actually take place throughout time.

So, the estimation of the total demand is done based on the annual birth estimates per census tract. In the case of day-care centers, for instance, the demand size is given by the number of births in a certain year plus the births in the three preceding years (i.e., less than one, one, two, and three years-old children). As already mentioned, no migration flows are taken into account. The obtained sum is, however, only the potential demand because not all children in that age group (0-3 years-old) are going to public day-care centers. Some of them remain at home while some others attend private day-care centers. As the proportion of the demand that is really going to use the system is very difficult to predict, the system is designed to leave this as an option for the decision-maker. He/she can adjust the figures according to his/her individual knowledge of the situation in the city. The system can then be used to evaluate the impacts of different choices. In the case of the EMEIs, the procedure for estimating the demand is similar to what was described above, but the children to compute are those who were born 4 to 6 years before the year under consideration.

For each tested hypothesis the system calculates the total number of children attending day-care centers or EMEIs. Assuming that the demand values estimated for each year follow the same spatial distribution pattern actually found in the current georeferenced demand data (available in phase I), it is then possible to plan the supply side for accommodating the demand in the whole city. Several scenarios can be built and the location-allocation models can be used once again to evaluate the impacts of different supply options on travel costs. Once again, changes in the supply side must be carefully examined in the distant future, in order to avoid investments in facilities that can become idle in just a few years.

### 5.3 Phase III: Education – Distant Future

The analyses of this phase, in which long term actions and heavier investments must be planned, ask for a strategic approach. As the planning period is 20 to 40 years ahead of the present (it depends when the population stabilization occurs), there is no need to work with disaggregate demand data. Data aggregated at the census tract level are good enough for the estimates to be done in this phase. In addition, demand models are key elements of the system in that stage. The evolution of the demand will be strongly dependent on the evolution of the whole urban population. If the predictions of population stabilization within 20 to 30 years are really confirmed, this must substantially change the demand profile. The population will gradually grow older, what means that the size of the demand considered in the proposed SDSS must decrease. This is particularly relevant if the supply side is expanded from now until the moment when the demand starts to decrease. Of course, the expansion of the supply is not only driven by the population growth, but also by other (e.g. physical) changes in the city that can require the construction of new facilities. This process is obviously distinct for different cities: some of them grow faster than others, some can even experience a decrease either in the total population or in certain age groups. If the knowledge of these trends is important, equally important is the knowledge of the spatial distribution of the population (and of the demand) within the city along the years.

Due to all those factors, traditional demand models can produce poor results for long-run estimates, mainly when a spatial variable is part of the problem. The accuracy of spatial data is negatively influenced by the several assumptions adopted to adjust the available data to what would be needed for running the traditional demand models. This is the reason why we decided to incorporate a dynamic urban simulation model based on Cellular Automata in the system for predicting the spatial distribution of the demand through time. The data used to feed these models come once again from the decennial census. Although they are aggregated at the census tract level they can be used to identify, in the future, distinct growth patterns of the demand for schools occurring in particular regions of the city.

The knowledge of the projected spatial distribution of the demand is a key element for the analysis of the supply in a distant future. Once again, location-allocation models are used to define where the demand must be allocated and if any existing educational facilities must be closed or new ones must be opened. In the latter case, the location of the new units is also an outcome of the analysis, which is always carried out with the aim of reducing users' travel distances. The particularity here is that trips are now supposed to start at the centroids of the census tracts, which is the aggregation level adopted for the analyses in this phase. The facilities, however, are still precisely located. According to Lima *et al.* (2001), this is not a problem in the studied context. In a comparative evaluation conducted by those authors, this aggregation resulted in distance values in average 5 % higher than if they were calculated with the exact location of all users.

### 5.4 Phases IV, V and VI: Health

Most of the inputs needed for phases IV, V, and VI of Figure 1 are obtained through a general description of the demand and supply of the health services at the municipal level. Furthermore, a substantial part of the methodology, data, problems and tools needed to solve them are similar to what was applied in the education subsystem. As a consequence, only the points that significantly differ from what was applied in phases I, II, and III are discussed in this topic.

In the case of the health subsystem, the approach is somehow different from what was used in the education subsystem, since the users of the former do not necessarily have to daily visit the supply points. Furthermore, the definition of several groups of target users according to their ages has implications on the analyses to be conducted, since different age groups demand different services. Thus, which seemed to be a more realistic approach for the first system design was to work only with the age groups that are concurrently users of both health and education subsystems. There are many advantages of such an integrated planning approach, but one of the most visible benefits is the possibility of sharing common databases. It means that many of the analyses to be carried out in phases IV, V, and VI can rely on the same demand data collected for phases I, II, and II. This is particularly true in the case of the databases containing the addresses of the just born babies and of the students actually registered in the education subsystem. These data are the basic inputs for running the steps IV to VI when looking at the age group of children from 0 to 6 years old. In this age group the focus of the health system is on immunization and pediatric routine medical care.

Thus, the identification of the demand for health-care facilities has to be done for all children from 0 to 6 years old. This is done by weighing the annual population estimates by the frequency of regular visits to health-care units in each age subgroup (e.g., less than one year old, between one and two years old, etc.). The annual estimates are then obtained until the year *n*, what gives a good perspective of the changes in the size and spatial distribution of the demand over time. In the case of the spatial distribution of health demand, the simplified hypotheses and the models used for future demand prediction are the same ones previously used for education, since the population is assumed to be the same for both services.

If these particularities are taken into account, the other activities of phases IV, V, and VI (Figure 1) are in general similar to what was respectively done in phases I, II, and III. In the case of the location-allocation models, however, the capacity of the health facilities is no longer a constraint, since users do not have to visit them everyday. In phase IV, the objective of the process is to maximize the accessibility of the overall system by trying to allocate the children to the closest health-care facilities. An optimal spatial demand distribution linked to an efficient system for scheduling vaccination and medical visits can avoid peaks in the service and therefore long waiting times for the users. Nevertheless, the optimal distribution of the demand is based on the assumption that the supply side is correctly set. This aspect can also be evaluated by measuring the system coverage with a model criterion (such as maximum coverage) and GIS tools. This allows the identification of areas of the city that are not served by the health system. Consequently, these are candidate locations for new facilities. The steps for evaluating the system coverage are also important in phase V, when the alternatives for opening new units shall be examined in more detail. Several distances can then be tested in the definition of the maximum coverage of the system, in order to evaluate the consequences of different values for the number of health facilities.

In the case of the long-run planning procedures carried out in phase VI, they are similar to what is applied in phase III. They therefore include the strategic options of opening or closing facilities while taking into consideration long-term demand fluctuations. Obviously, the policies for matching the supply and demand of health and education systems are similar and they must be coherent with one another. However, the decision of opening or closing a health-care unit is easier than in the case of a school or a day-care center, because the former are usually smaller than the latter. Even though, the same tools used in phase III (multicriteria analysis and CA) can be applied in phase VI.

## 6. THE REAL-WORLD CHALLENGES

With the system conceptual framework defined as presented in the previous item, a practical application was launched in the year 2000 in the city of São Carlos, state of São Paulo, Brazil. That medium-sized Brazilian city was selected because there is a close link between the local government and the university where the system is under development. This link could help, at least in theory, to surpass eventual institutional barriers. However, many of the system needs or inputs were often not easily found in the real world. Every single step faced some challenges and the need of surrogates for some required data became common throughout the process. A summary of the main difficulties found along the development can be seen in Table 1.

Table 1 System requirements and real-world responses to them

| SYSTEM NEEDS | REAL-WORLD RESPONSES |
|---|---|
| **THE BASES OF THE SYSTEM** | |
| **INSTITUCIONAL BASIS**. | |
| Association with local government. | Political problems.<br>Difficulties for convincing local government partners about the advantages of the system implementation.<br>Slow and discontinuous data acquisition process |
| **OPERATIONAL BASIS** | |
| Georeferenced GIS maps of the city.<br>Georeferenced address database (needed for the identification of the actual spatial distribution of the demand).<br>Demand and supply data with geographical reference and at different levels of spatial aggregation. | Lack of an organized and up-to-date georeferenced address database.<br>The process of demand georeferencing is very difficult due to data inconsistencies.<br>Demand data are very difficult to obtain.<br>Data available usually in hardcopy format (rarely in digital format). |
| **DEMOGRAPHIC DATA** | |
| Historical records of total population, number of births, and population per age group in the studied city.<br>Recent census tracts data. | Census data were not georeferenced until recently. |
| **DESCRIPTION OF DEMAND AND SUPPLY** | |
| Tools and data to estimate when the population stabilization will occur and the annual number and spatial distribution of births until there. | Difficulties for identifying the exact location of the existing demand.<br>Likely imprecision of the methods available to generate the annual demand estimates. |
| **PHASE I** | |
| Data that form the operational basis of the system, population densities (actual and target, if any), demand and attractiveness of the supply units. | Troubles to georeference the student’s addresses and absence of information about the workplace location of parents (in the case of day-care centers).<br>Difficulties to incorporate attractiveness factors and alternative transportation modes in the calculation of the travel costs.<br>Difficulties for considering the unsatisfied demand in the modeling process, since in general there is no data about it. |

Table 1 System requirements and real-world responses to them (cont.)

| SYSTEM NEEDS | REAL-WORLD RESPONSES |
|---|---|
| **PHASE II** | |
| Data that form the operational basis of the system, projected population densities (actual and target, if any), candidate points for the location of new schools and day-care centers. | Likely imprecision of the projected demand due to the assumptions needed to estimate its future size and spatial distribution.<br>Unawareness of migration flows (within the city and between cities). |
| **PHASE III** | |
| The same as in Phase II, in addition to urban expansion trends. Crucial factor for this phase is the perspective of population stabilization. | Traditional demand models are not good for long run projections |
| **PHASES IV, V, AND VI** | |
| Data that form the operational basis of the system, demographic data and projections (inputs of Phases I, II and III).<br>Definition of a model criterion (e.g., maximum distance) for measuring the coverage of health-care facilities. | Difficulties to incorporate attractiveness factors to health care facilities in the calculation of transportation costs and the unsatisfied demand in the model.<br>Difficulties and models simplifications similar to Phases I, II, and II. |

## 7. CONCLUDING REMARKS

The objective of this paper was to discuss some of the challenges and opportunities met during the development and early implementation stages of a SDSS (Spatial Decision Support System) for integrated management of health and education facilities at the local level in Brazil. The goal of the proposed system is to seek for an optimal arrangement of health and education facilities in a medium-sized city, in order to reduce both facilities construction costs and user's transportation costs that ought to be produced during a time span of two to four decades.

One of the points observed during the first implementation steps of the proposed SDSS was that operational difficulties, which were not even imagined when building the theoretical framework of the system, could be highly relevant in its practical application. Problems that might have a simple solution from a technical point of view (i.e., the available technology could in theory easily solve them) many times became painful in practice. One of the main causes of these problems was the absence of databases with a minimum level of organization. In same cases, this can be so critical that the whole project can fail due to the lack of reliable databases. On the other hand, the implementation of systems like the one proposed here can be an opportunity to drive a change in the way that local governments in developing countries deal with planning. If this sort of change takes place, even considering that the entire operational foundation has to be built before the implementation of the SDSS itself, the effort is certainly rewarded. Unquestionably, the first elements that will be improved in the process will be the public databases.

In the sequence, the creation of databases following minimum standards and shared by more than one public agency could remove several obstacles to urban planning and urban management. In the particular case of the students database management a simple routine that matches the address being typed during the student registration with a dataset containing a list of streets in the city could avoid several problems when georeferencing students' addresses. In addition, the process could help to update the streets database. Finally, it is essential to stress the need of institutional support for the full implementation of a system as the one discussed here. The local government has to be an active partner. That means not only the mayor, but also the high-level staff in charge of education, health, and planning activities. Only with such an involvement it is possible to think about building the operational foundation of the system, which depends essentially on reliable data of demand and supply.

## ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Brazilian agencies CAPES (Post-Graduate Federal Agency), FAPESP (Foundation for the Promotion of Science of the State of São Paulo), and CNPq (Brazilian National Council for Scientific and Technological Development), and to the Portuguese agency ICCTI (International Institute of Scientific and Technological Cooperation), which have been supporting our efforts for the development of this work in different ways and periods.

## REFERENCES

Balling, R.J.; Day, K.; Taber, J.; Wilson, S.A. (2000) Land-use / transportation planning for twin cities using genetic algorithm. **Proceedings 79th TRB Annual Meeting,** Washington, D.C., U.S.A.

Batty, M. (1995) Planning support systems and the new logic of computation, **Regional Development Dialogue, Vol. 16, No. 1,** 1-17.

Batty, M. and Densham, P.J. (1996) **Decision support, GIS, and urban planning**. Centre for Advanced Spatial Analysis (CASA), University College London, England, http://www.geog.ucl.ac.uk/~pdensham/SDSS/s_t_paper.html

Clarke, G.P. and Langley, R. (1996) A review of the potential of GIS and spatial modeling in the new education market. **Environmental and Planning C: Government and Policy, Vol. 14, No. 3**, 301-323.

Galvão, R.D. (2000) **Sistemas de apoio à decisão espacial para problemas de localização e distribuição**. Projeto integrado de pesquisa, Programa de Engenharia de Produção, Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia da Universidade Federal do Rio de Janeiro. http://www.po.ufrj.br/projeto/.

Harris, B. (1989) Beyond geographic information systems: computers and the planning professional. **Journal of the American Planning Association, Vol .55, No. 1,** p.85-90.

Jankowski, P.; Andrienko, N.; Andrienko, G. (2001) Map-centred exploratory approach to multiple criteria spatial decision making. **International Journal of Geographical Information Science, Vol. 15, No. 2,** 101-127.

Kammeier, H.D. (1999) New tools for spatial analysis and planning as components of an incremental planning-support system. **Environmental and Planning B: Planning and Design, Vol. 26, No. 3**, 365-380.

Klosterman, R.E. (1997) The "What-If?" collaborative planning support systems. In P.K. Sikdar, S.L Dhingra and K.V. Krishna Rao (eds.), **Computers in urban planning and urban management**. Narosa Publishing House, New Delhi, Vol. 2, 692-702.

Klosterman, R.E. (2001) Planning support systems: a new perspective on computer-aided planning. In R.K. Brail and R.E. Klosterman (eds.), **Planning support systems: integrating geographic information systems, models, and visualization tools**. ESRI Press, Redlands, California, 1-23.

Langley, R. (1997) **The use and development of geographical information systems (GIS) and spatial modeling for educational planning**. Unpublished PhD Thesis, University of Leeds, Leeds.

Lee, D. (1973) Requiem for large-scale models. **Journal of the American Institute of Planners, Vol. 39, No. 3,** p.163-178.

Lima, R.S.; Naruo, M.K., Rorato, R.J.; Silva, A.N.R. (2001) Influência da desagregação espacial da demanda por educação no cálculo das distâncias de deslocamento em uma cidade média. **Proceedings 20th Congresso Brasileiro de Cartografia and 8th Conferência Ibero-Americano de SIG**, Porto Alegre, RS, Brazil, 2001.

Malczewski, J.; Moreno-Sánchez, R.; Bojórquez-Tapia, L.A.; Ongay-Delhumeau, E. (1997) Multicreteria group decision-making model for environmental conflict analysis in the Cape Region, Mexico. **Journal of Environmental Planning and Management, Vol. 40, No. 3,** 349-374.

Marquez, L.O. and Maheepala, S. (1995) A decision support system for the integrated planning of urban development and utility services. **Proceedings 4th CUPUM World Conference,** University of Melbourne, Australia, Vol. 2, 127-138, 1995.

Mendiratta, P.; Ravikumar, K.V.R.K. (1997) GIS as a decision support system in urban planning: case study of regional park development in New Bombay. **Proceedings 5th CUPUM World Conference,** Indian Institute of Technology, India, Vol. 2, 794-801, 1997.

Stillwell, J.C.H. and Langley, R. (1999) Information and planning in the education sector. In J.C.H. Stillwell, S. Geertman and S. Openshaw (eds.), **Geographical Information and Planning.** Springer Verlag, Germany, Chapter 17, 316-333.