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A Spatial Decision Support System for Provision and Monitoring of Urban Green Space

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Abstract: A spatial decision support system for the planning, design and maintenance of urban green space is presented. The objective of the system under development is to assist local authorities and green space administrators to strategically enhance the supply of urban greening with the right type and variety of green space that maximizes public welfare. The system is being developed starting from a modelling perspective and GIS functionalities are added conform the needed analysis and subroutines within the system. The system has been written in the C++ Borland Builder 5 programming environment. GIS capabilities and dynamic mapping are added using MapObjects 2.0.

1. INTRODUCTION

The development urban quality of life indicators has recently gained much attention in the field of urban planning. In addition to social viewpoints such as employment, education and safety, environmental aspects, such as healthy air, quiet neighborhoods, attractive street scenes and green space within walking distance, are receiving increasingly more weight.

Many studies in the past ten years underline the importance of nature for people's well being. Green space clearly contributes to the quality of life and public health (Yuen, 1996). It has been recognised that people want attractive cities that are clean, spacious and uncongested. However, it is particularly the reality of urban overflow that stresses the urgent need for urban greening. Yet, if the need of a range of recreational opportunities, open space and sites of cultural interest are not strategically accommodated in the built environment, longer-distance leisure and recreational trips will drastically grow and as a consequence air quality, noise and other aspects contributing to quality of life in the city will be compromised. Thus, we are faced with a cycle that begins and ends with green space provision. That has been one of the reasons why recreational and leisure trip analysis has received increasingly more attention in the last few years (Lawson, 2000; Pozsgay & Bhat, 2001; Bhat & Gossen, 2002; Kemperman *et al*, 2002, 2003).

Although the planning and design of green space is one of the domains of urban planning, it is still lagging behind in terms of models and methodologies to analyse and predict spatial choice behaviour when compared to other fields of urban planning, as for instance transportation and retail planning. Apparently, the yet intangibility of the benefits of green space as a contribution to a better-built environment is one of the contributing factors here.

A problem with the presumed intangibility of the benefits of green space is that expectations in relation to urban public space are poorly articulated. Very little is known about the link between urban green space provision and human behaviours. Projects in the field have often been considered in isolation, tentative to generalize qualitative and quantitative assessment of green space provision by ad-hoc experiments. However, as any other urban planning problem, provision and monitoring of urban green space is based on a generic problem solving process which begins with problem definition and description, involves many forms of analysis which might include simulation and modelling, moves to prediction and then again to prescription or design which often involves the evaluation of alternative solutions to the problem. Decision characterizes every stage of this process while the process of implementation of the chosen plan or policy involves this sequence once again. The process takes place across many scales and is clearly iterative or cyclic in form.

Our target in this research therefore is to develop a spatial decision support system to assist green space administrators to strategically enhance the supply of urban greening with the right type and variety of green space that maximizes public welfare. The viewpoint that we take is that urban greening strategies and actions consider particularities of the urban environment within its society that involves a group of individuals showing behavior patterns as a response to the environment they live in, rather than conducting experiments and generalized quantitative and qualitative targets. Our challenge is to support the planners and decision makers with methodology, models and tools to assist them in structuring the decision making process in a more integrative and participatory way.

1.1 SDSS and Integrated Urban Models

Urban models provide an abstract world in which theories relating to urban processes may be investigated to gain a better understanding of such processes. They can also be used as a tool to evaluate the effect of various policy decisions on an urban system or subsystem. Wagener (1996) and Yates and Bishop (1998) recognize nine such subsystems within an urban system: urban networks, land use, workplace infrastructures, housing infrastructures, population, employment, goods transport, travel and the overall urban environment. Integrated urban models are built to investigate the interrelationship between subsystems and its change with time. Integrative models require integrative solutions, approaching different disciplines such as economics, geography, psychology, sociology, transport engineering. It is at the spatial level that the abstract representation of the urban environment will dictate how realistically these models suit investigations of urban processes. Hence, a key element in urban modelling is the representation of the space, i.e. spatial modelling.

There are many ways for classifying spatial models, but here we give special attention to its classification according to their resolution and extent of space, time and attributes. In our project, we build an integrated urban model where spatial representation of subsystems such as road network, land use, green space infrastructure, population and workplace infrastructure subsystems are integrated and disaggregated in a microscopic representation of the urban environment. Models based on a theory of human behavior and high spatial resolution of urban land use imply more realistic prediction of how the urban context is likely to change under different planning actions.

There seems to be a consensus that integrated urban modelling for decision-making or Decision Support Systems must provide support to a particular type of decision. The components of such a system should include:

1) A database management system that includes tools to support the collection and storage of data, the transformation between data models, the translation of a data structure for a given model, and the ability to retrieve data from storage;
2) A model management system that provides a set of tools and models that operating on (1) produce new information (description, explanation, description), relevant for the decision making process, that is not in the database yet; and
3) A user interface that support the visualization of the data sets and the output of models.

Existing Geographic Information System (GIS) provide some of these components. Indeed, the typical forms of data organisation of urban planning models are very similar to those of existing GIS. That might explain the increasing interest in the use of the GIS software to provide decision support within the GIS field. While an increasing number of GIS-based applications are described as being Decision Support System (DSS), these descriptions suffer from a lack of agreement on what a DSS actually constitutes. This misunderstanding comes from the fact that GIS assist in the collection or organization of data used by decision makers, but it lacks support for the use of problem specific models, i.e. they are usually general-purpose systems, not focused on a particular decision.

Spatial Decision Support System (SDSS) can therefore be seen as an important subset of DSS. It could be seen as a GIS based system for decision-making. The value of SDSS will be determined by how well they support the need for a spatial component in decision-making. However, the main advantage of using a GIS component in a decision support system anyway is the data organisation and the simplicity in captures data entry, data manipulation and visualization. Another important advantage is the possibility to co-process data stored in different data models. For instance, in conjunction with appropriate spatial models and techniques, it is possible to co-process green space data, network data and individual flat data based in one common spatial framework.

Nowadays there is a wide spectrum of urban planning models using GIS; however, in only few of them GIS play a role beyond database or mapping functions. Approaches such as "modelling with GIS" use standard GIS packages that support system-dependent macro-language and models to support the decision process are coded. However, the range of models that can be defined is limited.

In order to get rid of all the overhead and limitations of a particular GIS software package, the system here described is being developed primarily from a modelling perspective and GIS functionalities are added conform the needed analysis and subroutines within the system. Also, system's interface is built on the GIS component giving its powerful capabilities for providing graphical and tabular friendly user interface. The uniqueness of the tool lies in combining GIS technology and an integrated urban planning model for a specific decision problem using disaggregated data from different data sources of relevant urban subsystem.

Therefore, the system offers a friendly spatial oriented user interface where the user can change actual urban scenarios (green space portfolio within the overall urban system - network, land use, individuals, etc) and building alternative scenarios. Models based on observed behaviour predict the impact of such scenarios on spatial behaviour and a set of performance indicators. Tools and models for evaluating and comparing different scenarios are also part of the SDSS.

2. SYSTEM ARCHITECTURE

Figure 1a illustrates the development frame of the SDSS. MapObjects is a set of ActiveX objects used to implement mapping functionalities in the application. With this developer site tool it is possible to add dynamic mapping and Geographic Information System (GIS) capabilities to a windows application. The urban models and tools of the SDSS were written in the C++ Borland Builder 5 programming environment.

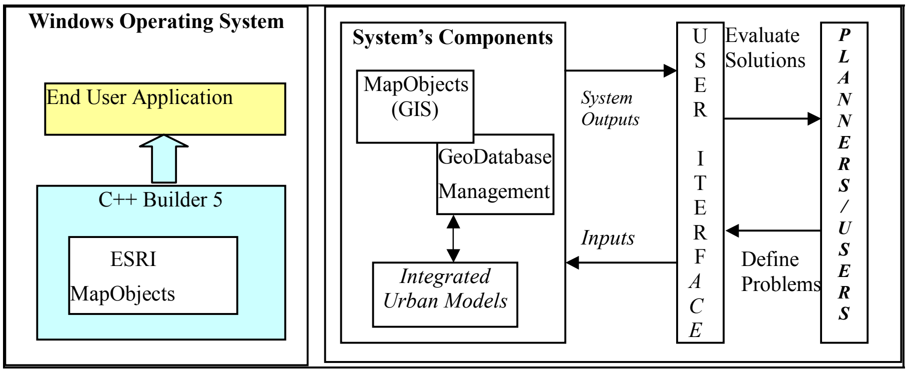

Figure 1. a) Development Environment; b) System's Architecture

Figure1b gives a simplified view of the system architecture. The GIS component is the heart of the SDSS and is used for data organisation of urban planning models. The main advantages of data organisation in GIS are the ease of data capture or data entry, data manipulation and visualization. Another advantage is the possibility to co-process data stored in different data sources (polygon based, line based, point based, etc.) and intermediate storage between the various sub models in the Integrated Urban Model Component**.**

The Database Management better defined as *Cell-Based Database Management System,* is the intermediate data organisation component of the SDSS that passes data to the urban models. This intermediate component holds information combined from different data sources into 100 m^2 (100 x 100m) cells, i.e. spatially aggregate data from land use coverage, green space infrastructure, urban zoning system and socio-demographics were disaggregated and combined into a singular spatial source defined as cells of

100 m^2 units. There are many advantages of information storage following the cell structure, such as:

1) Much higher spatial resolution: disaggregating the zonal system, spatial dimension of most urban models, avoid assumptions that attributes are uniformly distributed throughout a zone. Spatial interactions between zones are established via networks linked only to the centroid of the zones. When zones are divided into cells interactions are established between cells via networks linked to the centroid of the cells.
2) Avoiding of serious methodological difficulties such as the 'modifiable areal unit problem' and problems of spatial interpolation between incompatible zone systems (Wegener, 2001).
3) Facilitation of data flow within the urban models improving computing time (processing time) and decreasing required computing power.

2.1 Integrated Urban Models

The Integrated Urban Model component consist of a range of models designed and implemented to support the evaluation and assessment of the urban green space provision and monitoring. The type of spatial planning models proposed in this research is based on theories about human behaviour and representation of individual patterns within the urban environment. It is of vital importance for cities to not only know what is going on but also why, i.e., to understand the interest and motives of the relevant actors.

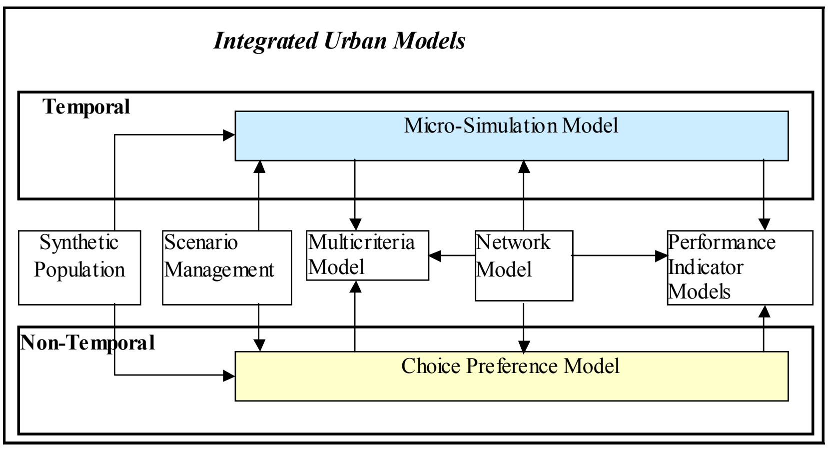

Figure 2. Urban Model Components

This modelling approach is part of the urban planning and monitoring process to understand present individual behaviour in order to predict likely future plans and actions, in particular individuals likely responses to statutory green space planning instruments. Figure 2 shows the tools and models within the integrated urban models component, described in the next section.

3. SYSTEM DESCRIPTION

The SDSS works in two different modes: non-temporal and temporal. In the first mode, green spaces are conceptualized in terms of their attributes and facilities that may or may not induce some utility for socio-demographics segments of the population. The results provide information on preferences for different green space attributes and location and the effects of these preferences on their use. In the space-temporal, or activity based approach, besides individual's preferences for certain types of green space, individuals and households needs or desires to pursue other activities in space and time are also considered. The results provide extra information about the frequency and timing of use of green space.

Performance Indicators Models, such as Accessibility (based on different concepts), Awareness, Maximum Utility, Choice preferences and probabilities of visit, will inform the user about the critical urban areas in terms of green activities. Multicriteria Models will guide users through conflicting criteria situations of funding allocation/public welfare. Problems can be formulated at different levels (from regional to local/district) by querying data from the region or zone of interest. A thematic map tool shows the spatial distribution of one or more specific data themes for standard geographic areas. The map may be qualitative in nature (e.g., predominant green space types) or quantitative (e.g., output from data models).

In the next sub-sections a detailed description of each approach and its respective models and sub models are given.

3.1 Non-Temporal approach

In the context of transportation demand analysis, choice models (referred to as disaggregate models) have played an important role in the last 25 years. In particular, random Utility or Discrete Choice theory has been identified as central to many state-of-art urban models (Wegener, 1994; Bishop, 1998). These models assume that demand is the result of several decisions of each individual in the population under consideration. The decisions are modeled as a choice among a finite set of alternatives.

In order to develop models that capture how individuals are making choices, we have to make specific assumptions about who is the individual and what are his/her characteristics; the alternatives or the possible options of the decision-maker; the attributes of each potential alternative that the decision maker is taking into account to make his/her decision; and the decision rule, describing the process used by the decision-maker to reach his/her choice.

The prediction of green space choice behavior model constitutes a major challenge to modelers because analyzing the choice of an individual requires the knowledge of what has been chosen, but also of what has not been chosen. Therefore, assumptions must be made about the characteristics or attributes of the individual that are likely to explain their choice; options (or alternatives) that were considered by the individual to perform the choice. The set containing these alternatives, called choice set, must be characterized by a finite number of alternatives that can be explicitly listed. Each alternative in the choice set must be characterized by a set of attributes. Similarly to the characterization of the individual, the analyst has to identify the attributes of each alternative that are likely to affect the choice of the individual. There is no automatic process to perform this identification. The knowledge of the actual application and the data availability plays an important role in the process.

3.1.1 Choice Model

Discrete Choice (i.e. when individuals have to select an option from a finite set of alternative) modelling methods are casted in the theoretical framework of random utility theory. The implicit assumption throughout these models is that we possess revealed- or stated-preferences cross-sectional data. Choice experiments were applied as a mechanism to analyze preferences of individuals in relation to urban green space characteristics and attributes. In this case, the responses were analysed using the well-known multinomial logit model of the following form:

$$p_i = \frac{\exp(\beta_{i0} + \sum_k \beta_{ik} X_{ik})}{\sum_{i'} \exp(\beta_{i'0} + \sum_k \beta_{'ik} X_{i'k})}$$

The beta-parameters represent the influence of the attribute levels on the overall utility of an urban park. The range in estimated parameters for a particular attribute is taken as a measure of the relative importance of that attribute. If all estimated parameters for a particular attribute are the same, the attribute levels do not discriminate and hence are not important. Details of this experiment can be found in Ponjé & Timmermans, 2003.

The estimated utility parameters are available in tabular format in the system database. The user applying one of 3 different rules, as shown in Figure3, can define the choice set.

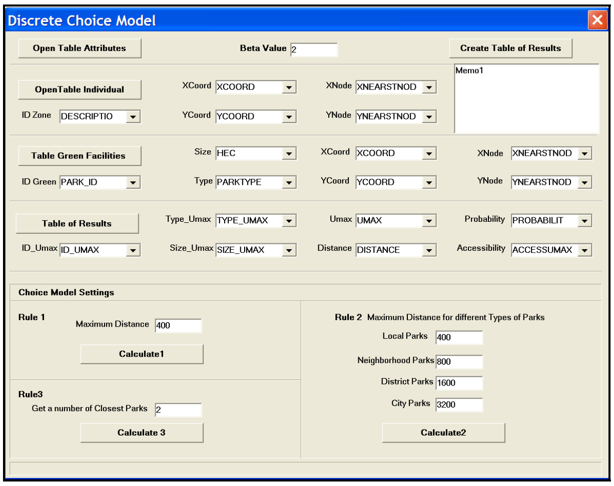

Figure 3. SDSS Choice Model User Interface

Applying Rule 1, the user defines an action radius in meters and the system will find the choice set for each individual by searching in the space the green facilities that are located within such distance from the individual (using the network model, i.e. network distances). Applying Rule 2, the user can define different action radius area by different green space category. Finally, Rule 3 defines individual choice set as the two closest parks. Whatever the rule chosen, the model calculates utilities of the parks in the choice set (applying the linear equation of utility, and using the parameters estimated in the experiment and the green space attributes information organized in the database management system). Thus, in order to predict if an alternative will be chosen, according to the model, the value of its utility must be contrasted with those of alternative options and transformed into a probability value between 0 and 1.

The disadvantage of this model is that it only considers individual preferences without considering individuals and households need or wish to pursue other activities in time and space. Time pressure is a reality and has big influence on people’s life nowadays, ruling their activity patterns. Thus, is very import to understand where people are in time and space, and what kind of activity pattern they develop to be able to predict the changes in their activity pattern by changes in the urban system. The temporal approach tries to overcome these limitations of the non-temporal approach.

3.2 Temporal approach: Aurora

In the temporal approach, the concept used for modelling human behaviour and their demand for urban green space is based on the Activity Based Approach. The Activity based approach places primary emphasis on activity participation, looking at constraints imposed by the spatial distribution of opportunities for (green related) activity participation and temporal considerations on individual activity participation decisions. Activity-based models typically describe which activities people pursue, at what location, at what times and how these activities are scheduled, given the location and attributes of destinations, the state of the transportation network, aspects of the institutional context, and their personal and household characteristics. Thus, activity-based approach views observed behavior as a manifestation of people's preferences under spatial and temporal constraints.

It is important to notice that such approach is a new challenge and a big step in the direction of integrating the overall planning of the urban environment, that is, the whole urban environment is contributing in an integrative manner to establish the patterns of human behaviour.

The activity-based micro-simulation model named Aurora (Joh, 2003) will be integrated in the SDSS in order to simulate individual activity patterns. By understanding green activity patterns planners can optimise the combination of green space type and attributes that provides the highest level of benefits to green space users.

A time-use survey entails the collection of data regarding all activities (in-home and out-of-home) pursued by individual over the course of a day (or multiple days). The examination of both in-home and out-of-home activities, given special attention to recreational activities within space-time prism facilitates an understanding of how individuals (considering their socio-demographic characteristics and household composition) switch their recreational activities in response to green space facilities location (as function of distance) and attractiveness (as function of attributes and size). This in turn, translates to an understating of when green space visits are generated or suppressed.

The outcomes of this model allow one to monitoring green space provision by generating:

1) Frequency of green space attendance as function of available time and green space attractiveness;
2) Average duration of green activities;

3) Start time distribution: start times in green activities across the day;
4) Duration of activities by green space;
5) Transport mode;
6) Frequency that the green activities are been combined with other activities (trip chain).
7) Location choices.

3.3 Common tools and modules

Whatever the system's approach chosen by the decision maker during the decision maker process, Population Synthesizer, Performance Indicators, Scenario Management, Network and Multicriteria Models are common components necessary to prepare, assess or evaluate data and information.

3.3.1 Population synthesizer model

Given that the system is conceptualized on theories of human behavior at the Individual level, a synthetic population that represents every individual in the region under study is a required element. Aurora and the Choice Model use and produce information at the individual level to estimate individual green space preferences and predict activity patterns. The *Synthetic Population Model* takes care of creating a population imitation of the study area with demographics closely matching the real population. Following earlier work in this area (Beckman *et al.* 1996), Iterative Proportional Fitting (IPF) is used for constructing the synthetic population and making the sample consistent with known statistics of the target population. This model outputs individual's age, gender, presence of children in the house – or not and employment status in terms of the number of working hours.

3.3.2 Network model

This component plays an important role in the system. It calculates distances using information of the road network and a shortest path algorithm to calculate minimum distance routes. There are some basic routines within this model such as:

- *Find Closest Node in The Network:* find X and Y coordinates of the closest node in for every cell from the Cell Based Database and store de distance to enter in the network;
- *Find Closest Green Facility:* finds the closest green space for every cell and calculates de shortest path (Figure 4);

- *Find Path Origin->Destine:* Shortest Path Routines using 2 different layers or data sources.

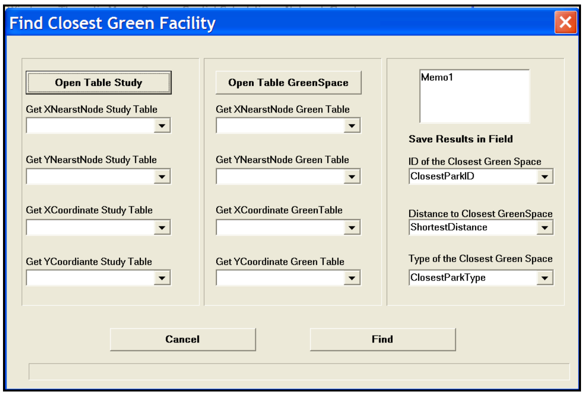

Figure 4. Basic routine within Network Model

3.3.3 Performance Indicators

3.3.3.1 Accessibility

There are 9 different equations implemented to calculate Accessibility within the system.

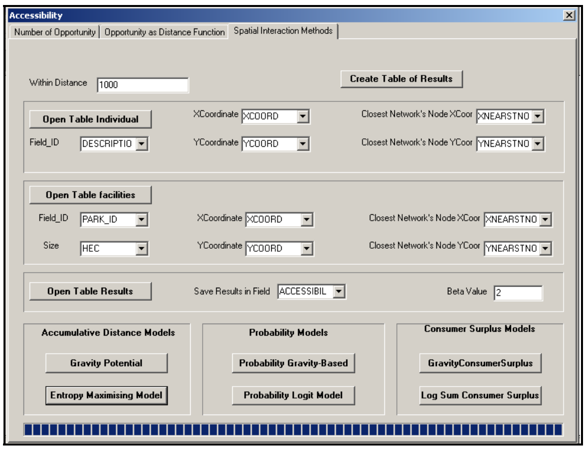

Figure 5. Accessibility Model Window

Six of them are based on Spatial Interaction Methods (Talen and Anselin 1998, Dalvi 1978, Coelho and Wilson 1976) two of them measure number of opportunities as function of distance (Ingrim 1971) and one measure is only counting the number of opportunities (Wachs and Kumagai 1973) i.e. the number of green space within certain distance defined by the decision maker.

3.3.3.2 Awareness

The concept awareness level is defined as the relative strength of the familiarity of an individual in the study area with a green space. We assume that the awareness level of an urban green space is a function of (a) a set of relevant attributes of the green space, (b) a set of relevant characteristics of individuals, and (c) some measure of accessibility. For a more detail explanation of models concept and estimation see Ponje *et al.* (2003).

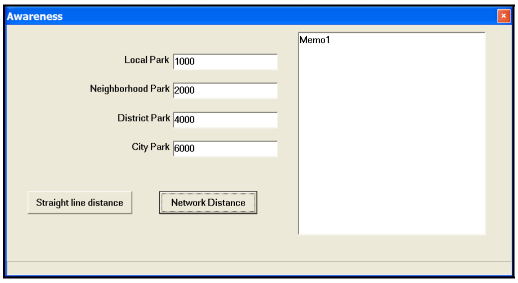

Figure 6. Awareness Window

3.3.3.3 Scenario Management

Decision scenarios are apparatus for means-oriented plan formation and evaluation. It allows the planners to make changes in a virtual urban environment and evaluate the impact caused by those changes.

Figure 7 shows the system's interface and the construction of a new scenario. When the user presses the button OK from the *Scenario* box, the *EditBox* will pop up (Figure 8). In that dialog, the user can choose from five possible scenario themes, which are:

1) *Change the attributes of an existent Park* – if the cell under manipulation belong to a green space and the decision maker wants to test changes in the park design;
2) *Green Cell – New Park* – if the decision maker wants to build a new park out of that cell;
3) *Non Green Cell* – if the decision maker wants to reduce the area of a existent green space;
4) *Delete Complete Park*;
5) *Add Cell to a Park* – if the decision maker wants to increase the area of an existent green space.

Data Consistency is the main property of the Scenario Management. Its design ensures that data will not be inconsistently stored and consequently, it will not allow inconsistent data to be passed throughout other models and tools. After changes, evaluation models should be processed and the decision maker will take his/her decision on whether accept and implement those changes or not. If changes are accepted, the data form the scenario can be exported to the "main" file by using *Scenario->Implement Scenario* in the *Main Menu*.

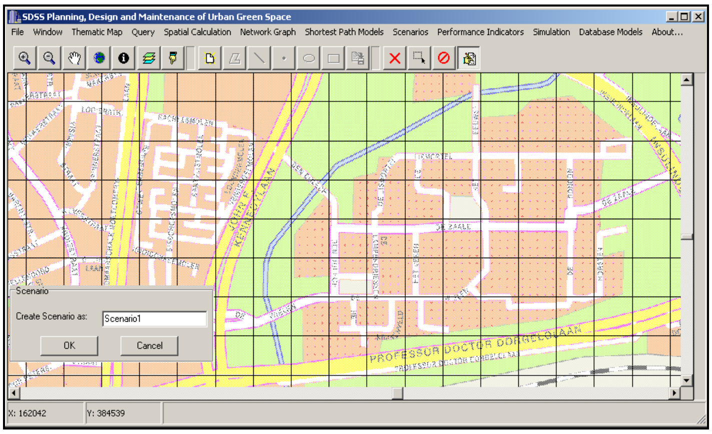

Figure 7. Create Scenario

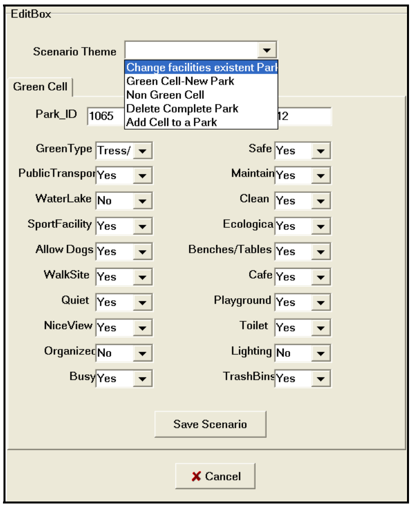

Figure 8. Edit Box Window

3.3.3.4 The Multicriteria Model

Multicriteria evaluation methods serve to investigate a number of choice possibilities in the light of multicriteria and conflicting priorities.The choice possibilities can be alternative plans or strategies, administrative zones or regions, potential green space areas, green space renewal neighbourhoods, and so forth. The hard core of this evaluation approach consist of a two-dimensional matrix, where one-dimensional expresses the various alternatives and the other dimension the criteria by which the alternatives must be evaluated.

4. CONCLUSION

The SDSS under development is designed to be a very flexible tool for the planning, design and maintenance of urban green space. It is a user-friendly tool, easy to be manipulate and has acceptable processing time giving the amount of data handled and calculations processed within the Models and Tool. It combines map-based visualization and models and techniques for qualitative and quantitative analysis and it support planners and decision makers (potential users) with a scenario builder tool to explore and guide future planning on green space provision.

Is important to note that knowledge and expertise are factors that should play the main role underneath any Decision Support Tool. By means of a support system we provide information structure and specialist models and tools, but the perception, judgment and decision still being a task of the decision maker, that by manipulating the system in a cyclic and iterative process will exanimate what might be the best planning and/or decision giving a particular scenario and problem definition.

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