Chapter 10
GRAS: A Spatial Decision Support System for Green Space Planning

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10.1 Introduction

Green space is defined here as a vegetated public area in an urban setting that provides an open environment. Urban green spaces provide a number of benefits towards the overall goal of urban sustainability. Some of these benefits are more tangible than others (e.g. Heisler 1986; Randall *et al.* 2004). However, very little is known about the link between urban green space provision and human behaviour. There are surprisingly few published guidelines explaining how to assess the provision of green spaces on an intra-urban basis (e.g. Nicol and Blake 2000; Herzele and Wiedemann 2002). Projects on this field are in a premature stage, with current approaches just starting to explore the elaboration and application of choice experiments and contingent valuation techniques to explain the influence of green space on people's lives (Lawson 2000; Pozsgay and Bhat 2001; Bhat and Gossen 2002; Kemperman *et al.* 2005; Maat and de Vries 2006; Jim and Chen 2006). These are, however, isolated studies or *ad hoc* experiments rather than models or tools that can be explicitly used to support decisions on green space provision for public welfare.

Urban green spaces normally occupy large pieces of land, involve high maintenance costs and do not bring any direct monetary benefit. When the benefits of green spaces are indirect and intangible, sustainable funding will suffer in relation to other priorities in the urban context. With that in mind, we have developed a prototype Spatial Decision Support System (SDSS) to assist authorities to strategically enhance the supply of recreational green spaces (squares, parks, green corridors, waterfronts, *et cetera*) with the right type and variety of green spaces that optimise public welfare. The system has been given the acronym *GRAS*, the Dutch word for *grass*, which stands for GReenspace Assessment System. *GRAS*

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is a prototype SDSS proposed to underpin the planning, design and maintenance of recreational urban green space. By planning, we mean the process of forecasting or influencing the physical arrangement (location and size) of green spaces in the built environment. Green space design is related to the selection of features (facilities and attributes) within the physical locations to meet functional criteria. Examples of design considerations include the type of vegetation, provision of public transportation and facilities such as playgrounds, sport fields, picnic tables, toilets, *et cetera*. Maintenance encompasses the recurrent, periodic or scheduled work necessary to repair, prevent damage or sustain existing features in green spaces.

GRAS is a fully integrated, GIS scenario-based, microsimulation, multi-criteria evaluation system. The GIS-based scenario tool supports users in applying strategic thinking to the search for viable future options in green space portfolio within the built environment. A range of static to dynamic modelling methods is employed within the system to represent individuals' behaviours. In principle, these models operate on a '100 per cent sample' (i.e. the entire population) of individuals, which are synthesized from census data. Under the umbrella of the *Spatial Models Component,* spatial choice models traditionally used in the urban planning field can be applied. The *Spatial-Temporal Models Component* comprises an activity-based microsimulation model, the so-called *Aurora* (Joh *et al.* 2001; Joh 2004), which predicts space-time behaviour patterns at the individual level. It is based on the premise that the use of certain green space is not only a function of the attributes of the green space, socio-demographics and distance/travel time, but varies also as function of other activities that need to be conducted during the day and week and dynamic space-time constraints. Thus, this model provides considerably more detail than the traditional spatial choice models within the *Spatial Models Component*. A multi-criteria tool allows the comparison of current and future scenarios in light of multiple and possibly conflicting criteria.

GRAS's capabilities in supporting the planning, design and maintenance of urban green spaces were tested in a case study for the city of Eindhoven, Southern Netherlands. *GRAS*'s models and tools were used to identify and diagnose potential weaknesses and/or problems in the overall green space portfolio of the city. Based on a preliminary analysis/assessment of the current green space portfolio and planners' aspiration levels and goals for a future green space portfolio, changes were suggested and incorporated in the development of two new scenarios. These alternative green space scenarios were then evaluated and compared against each other using a range of performance indicators derived by the system. This exercise demonstrated *GRAS* to be a robust framework, capable of supporting every stage of the decision making process in green space planning and monitoring.

Although the main focus of this chapter is on the design of *GRAS* (i.e. the overall description of the program architecture, components, modules, interface and data infrastructure), we dedicate a section at the end of this chapter to outline the practical issues related to the system's application.

10.2 *GRAS* Architecture and Design

The traditional approach in developing SDSS or GIS-based DSS (Sprague 1980) for the urban planning domain uses a standard GIS package as a *DSS Generator* that is utilised to quickly and easily build the *Specific DSS* (Batty and Densham 1996; Keenan 1997; Yates and Bishop 1998; Wegener 2001; Booty *et al.* 2001; Geertman 2002; Randall *et al.* 2004; Yeh and Qiao 2005). Unlike the traditional approach, in this project we followed a more rigorous and flexible approach that used *DSS Tools* to develop the *Specific DSS*.

GRAS is a GIS windows-based application, written in Borland Builder C++ 5 (Borland™) and GIS functionalities were added using MapObjects 2.0 ActiveX Control (ESRI™). Rather than embedding less elaborate models within a comprehensive GIS, we embedded a limited range of GIS functions within a more elaborate modelling framework. Although the chosen approach has disadvantages, such as requiring advanced programming skills when changes in the system are required, this development method offers a number of advantages, such as: (i) overcoming limitations and overheads of standard GIS software packages; (ii) flexibility to include the domain analytical/simulation models desired; and (iii) full integration, where the users only intervene in the system to control the modelling process, not to conduct basic operations needed for data modelling and interchanges.

Three major components can be identified in *GRAS*: the Database Management System (DBMS); the Model Based Management System (MBMS); and the component for managing the interface between the user and the system, i.e. the Dialogue Generation and Management System (DGMS). The DGMS is left for future discussion. For now, it suffices to say that the DGMS was built upon a graphical user interface (GUI) to allow easy and intuitive manipulation of the system. The main user interface for *GRAS* (Fig. 10.1) is a GIS-based map window with icons, a pull-down menu and pop-up windows that can be manipulated by a computer mouse (and, to some extent, via a keyboard) to gather user's actions with the goal to act on the data (i.e. visualize a map, consult and process the data) and on the models (i.e. set parameters and run models to produce new information). The first two components are described in detail in the next sub-sections.

10.2.1 Data and the Database Management System

In line with trends in urban planning towards more disaggregated and realistic models, the type of models proposed for green space provision and monitoring require a fundamentally new organization of more detailed data based on a micro view of the urban environment. Spatial modelling in the straightjacket of the zonal systems is too aggregated to predict impacts on small-scale planning, for instance neighbourhood-scale planning (Wegener 2001).

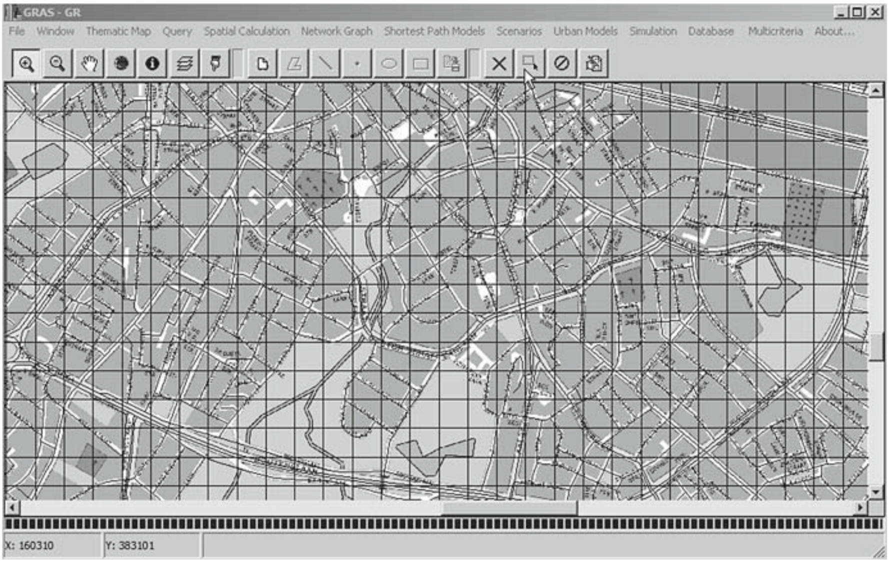

Fig. 10.1 *GRAS* main user interface

The move from macro to micro in complex spatial systems requires efficient data structures to overcome long data processing time and/or poor system performance (still an issue even with new technologies). The solution adopted to deal with such issues is to represent the study area as a cell system. Cells provide a stable representation of space, and are generally computationally more efficient to work with than zones, and, if defined on a sufficiently fine scale, will largely avoid the aggregation bias problems. On the other hand, they are very artificial constructs and their use can (perhaps) lead to an overlaid abstracted representation of space and spatial processes. In the limit, as the cell size goes to zero, cells become individual points in space and the spatial representation becomes fully continuous (Miller *et al.* 2004). A fully continuous representation of spatial distributions and processes is not a practical possibility at this time, at least for *GRAS*-type models. Hence, we use a cell system of 100 m × 100 m to represent urban space. Spatially aggregate data of land use, green spaces, work establishments, urban zoning system/sociodemographics and postcode addresses must be disaggregated and combined into a singular spatial source defined as cells. This unique cell vector-based layer contains the baseline data of *GRAS*. Although the cell size is an arbitrary value that can be easily changed, we strongly recommend the dimension suggested. The cell resolution was experimentally adopted as the optimum size given limitations of memory and speed of personal computer technology and model sensibility and accuracy given spatial resolution.

In summary, there are many advantages of information storage following the cell structure, such as:

- much higher spatial resolution: 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;

- avoiding of serious methodological difficulties such as the modifiable areal unit problem and problems of spatial interpolation between incompatible zone systems (Openshaw 1984; Fotheringham and Wong 1991; Wegener 2001); and
- facilitation of data flow within the urban models improving computing time (processing time) and decreasing required computing power.

Technically, the DBMS is a database model built with Borland Database Engine and embedded with GIS functionalities from MapObjects (ESRI). Embedding GIS capabilities to the objects and relational tables of Borland, spatial and non-spatial data from different sources can be efficiently stored, retrieved, manipulated and processed. The full integration of these two technologies makes the DBMS the heart of the spatial and operational information system, allowing for communication and intermediate storage among models without user intervention.

10.2.2 The Model Based Management System (MBMS)

The MBMS is an integrated model environment built with a range of models designed and implemented to support the evaluation and assessment of the urban green space provision and monitoring. It incorporates various procedures that enable users and planners to easily create alternative scenarios and make decisions based on a number of analytical models for green space assessment. After opening the MBMS 'box', tools and models illustrated in Fig. 10.2 are found. The arrows in the figure represent the communication mechanism and data flow between models.

Models implemented within the system were developed using a conceptual framework of individual behaviour patterns within the urban built environment (Pelizaro 2005). Such a conceptual framework is a state-of-the-art modelling approach for urban planning and monitoring processes and implies that planners can predict the likely impact of their possible future plans and actions by observing and predicting individual behaviour in the urban environment in constant change. The MBMS has seven major fully-integrated modules, described hereafter.

10.2.2.1 The Scenario Management Module

As an instrument for strategic thinking and option search, scenarios are means to represent the future. Xiang and Clarke (2003) argue that scenario development tools are likely to contribute to an effective decision-making process if they perform well the two functions of bridging and stretching. A scenario bridges the process of modelling with that of planning. It is a cognitive apparatus that stretches people's thinking and broadens their views in planning. The authors claim that a scenario development tool may best perform the bridging and stretching functions if it (i) stimulates surprising and plausible scenarios creation, (ii) presents the information used in a

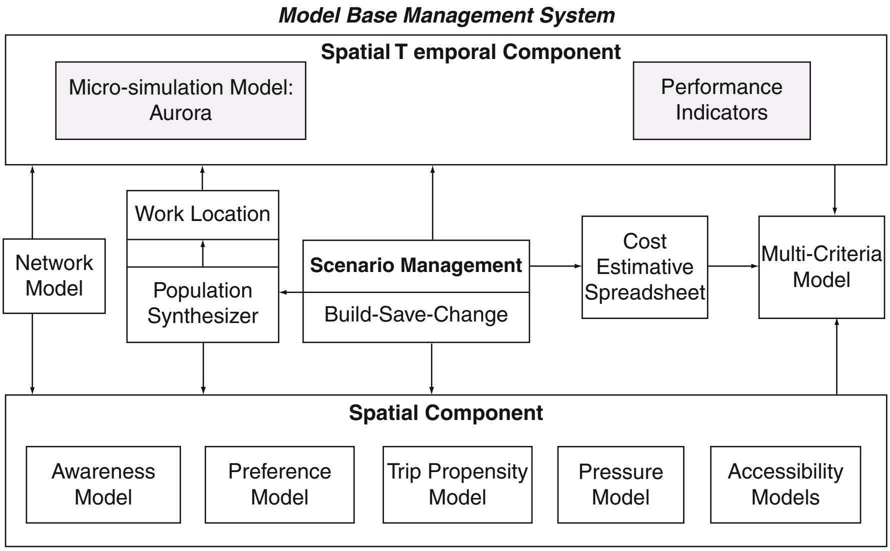

Fig. 10.2 Tools and models within *GRAS*' model based management system

vivid way and (iii) has a cognitively ergonomic design, that is, effectiveandsafe. Although we will not explore these issues here, it is worthwhile to mention that we have incorporated Xiang and Clarke's credentials in the design and implementation of the scenario tool in *GRAS* (Pelizaro 2005).

GRAS is operated around the concept of scenarios. A scenario is defined in terms of an appropriate description that represents the urban space/system in terms of land-use configuration, the transportation network, green space amenities, the zone system (socio-demographics) and work facilities. At the starting point, the user, having certain aspiration levels or goal states for the area being monitored, can modify the actual urban space. As suggested before (Arampatzis *et al.* 2004), this actual state, or 'status quo' or yet 'zero state' scenario, corresponds to the baseline situation, which is used as the basis for the creation of a new scenario.

The creation of a new scenario is carried out through interactive procedures supervised by the scenario management tool under the concept of 'themes'. In practice, the scenario development process involves a simple operation of changing the cell(s) attributes (data / information) of a cell-based map describing the urban space (which could be the baseline data or a scenario created previously), using the scenario themes strategy illustrated in Fig. 10.3a. Indeed, the target urban space to be modified in a new scenario is selected by the user on the map-based user interface, using the computer mouse. Then, the edit box window shown in Fig. 10.3a prompts, introducing the concept of scenario themes for data editing. For instance, suppose the user wishes to create a new scenario where a particular green space will be redesigned. The user then enables the scenario development tool by simply clicking on the appropriate icon of *GRAS*'s user interface. Then, the user selects any cell on the map that belongs to the green space to be modified. The window shown in

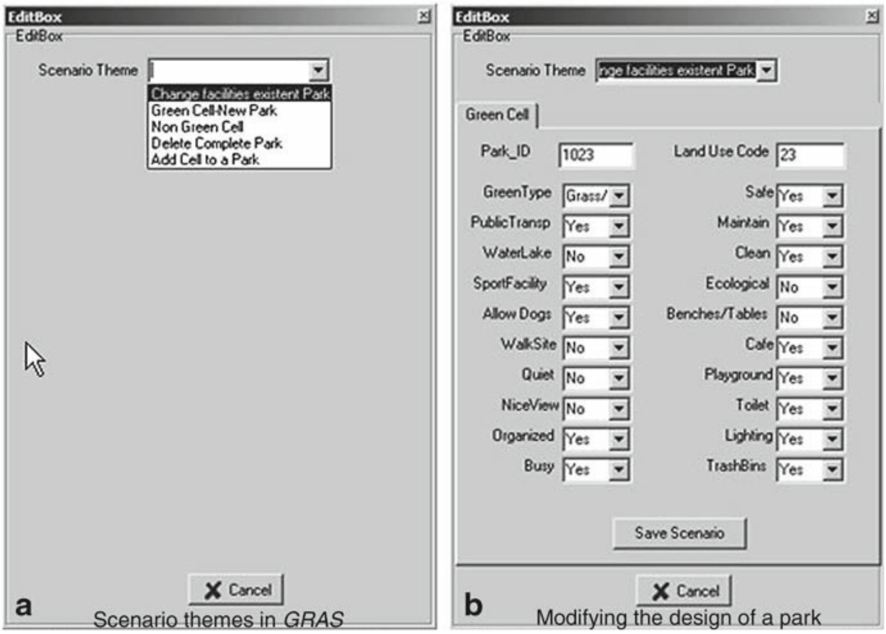

Fig. 10.3 Scenario management tool and scenario themes in *GRAS*

Fig. 10.3a prompts the user to choose the appropriate theme listed in the drop down box (in this case, 'change facilities of a green space'). The system refreshes the scenario edit box window as shown in Fig. 10.3b, displays the current description of the green space to be modified and sets the database to the edit mode. Yet through this interface window, the green space design can be modified by adding or removing the functional attributes as listed in Fig. 10.3b.

An important function of the concept around scenario themes is to restrict data access in order to guarantee data consistency. By ergonomically designing a scenario theme interface, only relevant data are made editable to users. As described in the example above, when the user redesigns an existing green space, only the data describing that green space attributes and facilities are made editable to the user. There are five themes on which to compose scenarios:

- Change the facilities of a green space: allows users to modify green space features (design), which will impact on individuals' perceptions/values.
- Green cell – new park: allows users to create a new green space on the area specified by the user on the map interface.
- Non-green cell: allows users to remove a parcel of land from an existing green space. The interface will then prompt the user to redefine the land-use and socio-demographic attributes for that parcel of land within the scenario being developed.
- Delete complete park: the selected green space (map user interface) is replaced with a new development, which is specified by the user in terms of land-use and socio-demographics attributes.

- Extend the area of a green space: increases the green space area with surrounded parcels of land specified by the user on the map interface.

10.2.2.2 The Population Synthesizer

The scenario population is defined by means of the Population Synthesizer. In *GRAS*, significant efforts were made towards adopting a disaggregated approach to system modelling, in which behaviour is the sum of individuals' behaviour of an urban system. The 'synthetic population model' takes care of creating a population imitation of the study area with demographics closely matching those of the real population. The information on the individual level used by the different models within *GRAS* is: age; gender; employment status in number of working hours; and household composition: with/without child(ren).

Following earlier work (Beckman *et al.* 1996; Bradley *et al.* 2001; Arentze and Timmermans 2000) the synthetic population model uses iterative proportional fitting (IPF) to extend a given sample of the population consistent with known statistics of the target population. To create a synthetic population, the Population Synthesizer requires the following types of data source: census tract data of the study area on the cell level and demographic data of a representative sample of the real population on the individual level.

The Population Synthesizer user interface allows creation of the entire population or only a percentage or even subgroups of the entire population, using age, gender, household composition and work status constraints (or a combination of these possibilities). The possibility of reproducing only segments of the population provides extra system capability to support decisions to benefit a particular group(s) of the target population.

10.2.2.3 The Network

The Network model plays an important role in the system. It estimates distances using information about the road network and Dijkstra's shortest path algorithm. Distances related to the movements of individuals in space and time will be given by this model and passed on to others system's models when required. Models within the 'Spatial Component' assume that individuals move in space looking for the shortest distance. In these cases, the shortest path is given by the shortest distance. On the dynamic level (spatio-temporal models), it is assumed that people seek to minimise travel times by choosing a route to a given destination. Hence, the shortest path is given by the minimum travel time.

10.2.2.4 The Spatial Models Component

The 'Spatial Models Component' consists of a family of discrete choice models to describe individuals' green space choice behaviour and a model to calculate spatial accessibility measures to urban green spaces. This component can be also called a '*Static Component'* in the sense that models do not consider the movements of the individuals in space and time. Individuals' green space choice set is restricted by some accessibility measure from each individual's doorstep. We estimated three discrete choice models with different degrees of complexity (and behavioural realism) capturing different aspects of the theoretical framework described in Pelizaro (2005). From these three discrete choice models, we derived four models to assess/evaluate green spaces: (i) an awareness model; (ii) a preference model; (iii) a trip making propensity model; and (iv) a pressure model.

The Awareness Model

The concept of awareness is defined here as the probability that individuals know a certain spatial choice alternative, i.e. green space. The model developed by Ponjé *et al.* (2005) and embedded in *GRAS* assumes that the awareness level of an urban green space is a function of (i) a set of relevant attributes of the green space, (ii) a set of relevant characteristics of individuals, and (iii) some measure of accessibility. The model estimates an average awareness level for each green space within the study area that is the sum of individuals' awareness of each particular green space. This quantitative measure will inform decision makers/planners on the most/least known green space in the study area. This measure could be used, for instance, as an indicator of maintenance budget management or improvement priorities.

The Preference Model

This model assumes choices are based on the utility individuals derive from green spaces, which allows them to rank green spaces in terms of preference. A preference scale was observed from actual individual stated choices or preferences under experimental conditions (Ponjé and Timmermans 2003). Based on that, utility and level of preference for a green space can be predicted as the accumulation of each individual's utility/preference for that green space. Figure 10.4 illustrates the user interface of this model in *GRAS*.

Notice there are three rules to define the choice set across individuals. Rule 1 defines the choice set for individual i located in cell z, as those green spaces $j \in J_i$, for which the distance d (calculated by the shortest path algorithm using the road network) between z and j is smaller than or equal to a threshold distance defined by the user via the user interface ('Maximum Distance fill-in-the-blank box'). Rule 2 uses the same principle, but allows the user to define different distance criteria for different types of green space, suggesting that individuals are willing to travel further to reach larger/more attractive green spaces. Rule 3, on the other hand, uses variable r defined by the user to delineate the choice set, where r is a constant that counts the number of alternative green spaces. In this rule, the closest r green spaces to the individual's doorstep are assumed to make up an individual's choice set.

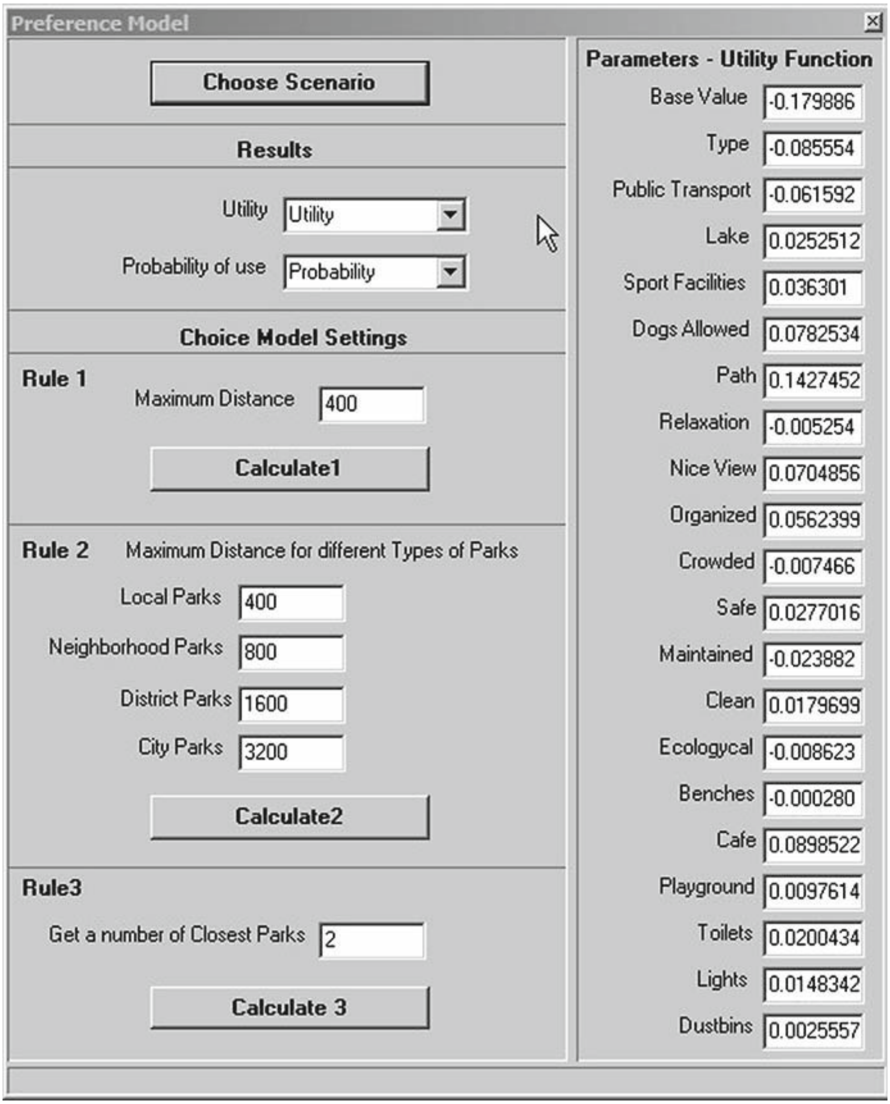

Fig. 10.4 Preference model user interface

The Trip Making Propensity Model

This model predicts the probability of green space usage, given the season of the year, the day of the week and the time of the day. To predict the allocation of trip frequencies across different types of urban green space, the model assumes that the choice of green spaces for recreational and leisure trips involves substitution. Therefore, besides individual socio-demographics and the specific attributes of each green space, the model tries to capture the effect of temporal variation (time of the day, day of the week and season of the year) on an individual's choice. For more information on the model calibration, see Kemperman *et al.* (2005). The individual's choice set is defined following the same approach as Rule 2 of the preference model. As output, green spaces are scored with the number of visits by individuals, given the season of the year, the day of the week and the time of the day.

The Pressure Model

The 'pressure' on green space usage is defined here as the number of individuals visiting a given green space per hectare of green space per day per season. Hence, the model focuses on informing administrators about the intensity of green space usage by season as an indicator of pressure. The frequencies with which individuals visit green spaces were estimated for the different seasons of the year using a survey data and the CHAID (Chi-square-Automatic-Interaction-Detection) technique (Pelizaro 2005). Then, the number of visits that an individual makes to each green space from the choice set is given by the number of visits that this individual makes to green spaces in a given season (result of the CHAID analysis) multiplied by the probability of visiting such a green space found by the trip propensity model. By repeating this procedure for each individual of the scenario population, an aggregate number of visits across the green spaces in the study area is derived. The aggregate number of visits to each green space is then divided by the number of days in the season and by the size of the green space (in hectare) resulting in a measure of green space pressure.

Accessibility Performance Measures

GRAS includes nine accessibility measures that refer to the level of access for green activity from any home within cell z to each of the green space locations j, given the distance dzj. Six of these measures are based on spatial interaction methods (Coelho and Wilson 1976; Dalvi 1978; Ben-Akiva and Lerman 1978; Martin and Williams 1992; Love and Lindquist 1995; Talen and Anselin 1998; Miller 1999). The so-called cumulative-opportunity measure evaluates accessibility with regard to the size of opportunities accessible within a certain travel distance from a given home location (Ingram 1971). The container measure counts the number of green spaces within a certain distance threshold defined by the user (Wachs and Kumagai 1973). The minimum distance measures the distance from home location to the closest green space facility. For all accessibility measures implemented, distance is calculated from an individual's doorstep to the green space entry point, using the road network.

10.2.2.5 The Spatial Temporal Component

The spatial temporal component is represented by an activity-based microsimulation model that predicts space-time behaviour patterns at the individual level.

This component is a simplified version of a model of activity (re)scheduling, named *Aurora* (Joh 2004). Our interest in applying the activity-based approach to the green space problem is to examine the participation of individuals in green activities. The ultimate goal is to understand and, thus, predict activity choice dynamics. This approach shifts the unit of analysis from green space facilities to individual green space activities participation. Spatial choice can then be viewed as, at least in principle, deciding which activities to conduct (activity participation choice), where (activity location or destination choice), when (choice of timing), for how long (duration choice) and the transport mode used (mode choice involved).

From an applied perspective, the problem of how individuals schedule their planned activities as a function of available time, transport mode, *et cetera*, is more relevant, especially, when the focus is on the examination of non-mandatory activities such as green space. Spatio-temporal constraints are critical in the sense that the temporal considerations on individual activity participation decisions (with more rigidity associated with work related activities compared to leisure activities) added to the spatial constraints imposed by the spatial distribution of opportunities for activity participation decisions may imply that an individual cannot be at a particular location at the right time to conduct a particular activity.

We remind the reader here that this chapter is not meant to include a detailed review of the model conceptualisation and operation (see Arentze *et al.* 2005; Pelizaro 2005; Joh 2004). As our focus is on the system as a whole, we concentrate on the model's outputs and green space assessment measures that can be derived from this component. The output generated by *Aurora* is the schedule of activities for every individual of the (synthetic) population for a given urban built environment (scenario). Individuals' schedules of activities provide a good source to derive several urban design performance indicators, based on the individuals' behavioural patterns. From this model, as implemented in *GRAS*, we can derive three performance indicators.

The so-called 'quality of life' is represented by the average utility of individuals' schedule. This is directly related to quality of life in the sense that, if facilities (green spaces, work, *et cetera*) are not well distributed in space, individuals must travel further. Because travel generally has a negative utility value (consumes time and costs money), the overall schedule utility will decline. Moreover, there will be less time left for individuals to conduct activities. Since the utility derived by individuals for conducting an activity is an increasing function of the time spent, less time available will once again reduce the total schedule utility. Similarly, if facilities are not very attractive, individuals may choose to travel further or simply to not conduct the activity at all. Either way, this will have a negative impact on the schedule utility (not conducting an activity returns 'zero' utility).

The second performance indicator is the 'average travel time to green spaces' and the third, is the 'average duration of green activities'. Visit duration patterns can be quite informative to authorities, regarding issues of green space attractiveness (design aspects), spatial location or a combination of both. A short period of time spent in certain green space can be an indication of poor attractiveness or good location (little traveling required). Therefore the impacts should be analysed within the urban context.

10.2.2.6 The Cost Estimation Spreadsheet

This tool calculates costs related to green space provision and maintenance. It requires users to input, via the user interface, elements of costs related to particular features and services provision as shown in Fig. 10.5. Maintenance costs are estimated on an annual basis, while provision costs are estimated as a fixed amount of lifetime investment. Costs are estimated per hectare of green space, allowing green space administrators to fairly compare expenses among green spaces of different dimensions (size). Together with the set of spatial (-temporal) behaviour models implemented in *GRAS*, the assessment of green space costs will allow decision makers and planners to trade off green space costs and benefits on a more quantitative basis. Decisions on the planning and design of green spaces will affect costs of provision and maintenance. Scenarios can then be compared not only in terms of the green space benefits to the community, but also in terms of the costs associated to the implementation of actions.

10.2.2.7 The Multi-Criteria Model

Performance indicators derived from the models described above are often measured in different scales and dimensions. Therefore, the multi-criteria evaluation (MCE) technique is used to rescale these indicators into a common measurement unit, allowing for the comparison of different scenarios in the light of multiple criteria and conflicting priorities. In *GRAS*, the Weighted Linear Combination (WLC) method (Voogd 1983) is used to combine the evaluation scores and weights to arrive at an overall scenario score. The criteria weights are assigned by the user via the user interface. To convert the various criteria scores into a common measurement unit, the interval standardization method (Voogd 1983) is applied. Hence, the score of each criterion will range from 0 to 1.

10.3 *GRAS* Application

In order to make *GRAS* operational, extensive data collection and preparation is required. *GRAS* strongly depends on data: spatial and non-spatial data is required for (i) description/representation of the study area, and (ii) model calibration. In the case study developed to test the system, the data required for the representation of the study area (outlined in Section 10.2.1) was gathered relatively easily from several governmental institutions. One exception however, was the data related to green space attributes (e.g. picnic facilities, sport field, *et cetera*), which was not available

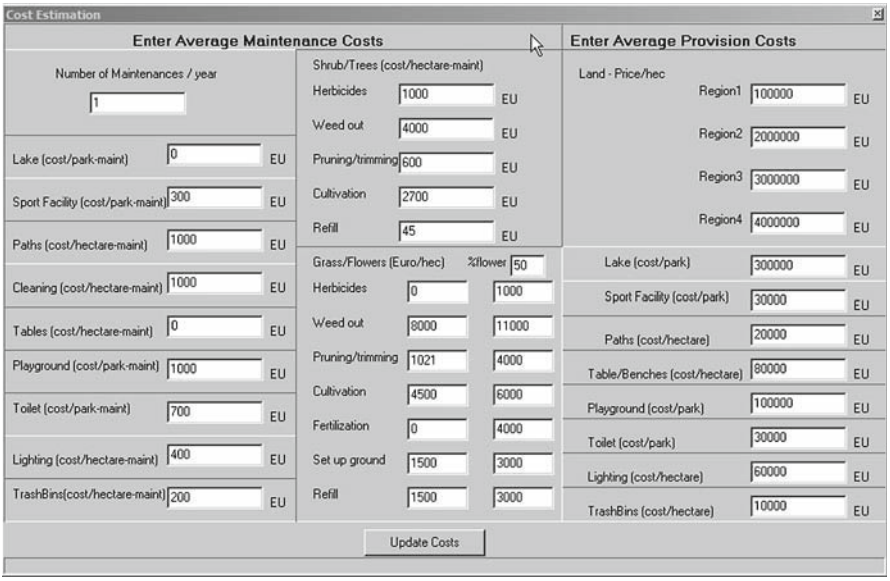

Fig. 10.5 Cost estimative spreadsheet user interface

and required additional fieldwork. The effort to gather this information and store it in a digital format was not trivial, considering the 1,600 green space areas within our study area.

A proper operational setting of the models within *GRAS* requires two sets of parameters to be estimated from empirical data. The first set is required for the static models and the second, for the activity-based model. Therefore, a multitude of survey and statistic procedures need to be performed, which can be highly complex in the case of the activity-based model. Data collection and model calibration are well documented elsewhere (Joh 2004; Pelizaro 2005).

To date, *GRAS* has been applied only once. A case study was developed in the city of Eindhoven, southern region of The Netherlands. In line with the local spatial planning strategy to improve green spaces in the city centre of Eindhoven, green space authorities were seeking answers to the following questions: (i) What would be the best available location to place a green space within the city centre area? (ii) What combination of facilities should it comprise to engender the best value perceived by the community; and (iii) Does perceived benefit pay off the economic investment (i.e. green space provision and maintenance costs)?

GRAS has shown to effectively support all phases of the decision-making process. First, *GRAS* models were used to evaluate/assess the current green space portfolio in the city centre of Eindhoven compared to the green space portfolio of the city of Eindhoven as a whole. This evaluation confirmed the speculation of a lack of green space within the city centre (measured as green space availability, i.e. area divided by the number of CBD's inhabitants). In addition, individuals living within the CBD were found to have relatively low measures of accessibility to green spaces and green spaces within the CBD were indeed under high usage pressure. The development of alternative solutions consisted of a search for suitable locations to build a green space and respective design (i.e. combination of facilities within the green space). The GIS-based user interface has shown to effectively support the location search process, although expert knowledge of the current urban design and expert judgement were essential to the development of possible scenarios.

On the design level, decision makers could simply include or remove facilities (or a combination of them) in the green space being created. Three different scenarios were created by variyng location and design. Models in *GRAS* were then used to assess each scenario based on 16 performance indicators derived in *GRAS*. Scenarios were then compared against each other by means of the multi-criteria analysis model.

Even though there is a lack of green space in the CBD, high costs associated to green space provision in the CBD would not compensate the small gain in individuals' perception. This conclusion surprised green space authorities who were already convinced that a new green space in the area would bring a great deal of benefit to the community. We have found that the small amount of land suitable/available to build a green space in the CBD and its high monetary value does not pay-off the small increase of individuals' perception of the green space portfolio.

10.4 Conclusion and Future Developments

In this chapter, the design of a prototype SDSS for the planning, design and maintenance of green space has been described. *GRAS* is a GIS, scenario-based, microsimulation, multi-criteria decision support system, with a range of domain-specific models inspired by a commonly accepted conceptual framework of spatial (-temporal) behaviour. The suggested system is capable of assisting every stage of the decision-making process, i.e. from the identification of a problem and the definition of (multiple) objective(s) to allowing the users to generate alternatives, and to the evaluation/assessment of alternatives. The system identifies interdependencies among planning, design and maintenance elements of the green space problem and integrates these three levels of decision effectively. *GRAS* was built using the full-integration approach, written in Borland C++ Builder 5 and GIS functionalities were embedded by MapObjects 2.0 ActiveX Control. As discussed in the chapter, the chosen approach provides a more flexible and elaborated development environment. One shortcoming, however, is that when available models in the system cannot fully meet users' needs, users may have difficulties in building and integrating other models themselves because *GRAS* does not provide procedures to enable models to be created and integrated.

GRAS data dependency is an important issue that deserves critical thought. The large amount of data and information needed to operate the system is not only a strength, but also a potential weakness. Obviously, the strength is related to the rich information provided for decision making. The weakness is the considerable effort required to collect the data to feed and calibrate the system and, later, to keep the database up to date.

An issue that needs to be addressed in future work is the further development of the *Aurora* model. Future elaborations may involve finer categorization of activities, especially related to recreation and leisure, which is relevant if the user wishes to have more detailed information about the kind of activities that can be conducted at the parks. The spatial representation in *GRAS* may also be a concern in future research. We did achieve a more disaggregated level of spatial representation than the traditional zone-based approach. Explorations indicated that the spatial representation of 100 m by 100 m cells is computationally efficient, but the cells sometimes appear rather artificial. The user interface can also be improved. To ensure optimal performance, usability testing must be addressed in future research.

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