

# A spatial decision support system for the provision and monitoring of urban greenspace

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**A Spatial Decision Support System for the Provision  
and Monitoring of Urban Greenspace**

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Technische Universiteit Eindhoven, op gezag van de  
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## PREFACE

This book brings the result of my PhD research project developed over the last four years on a decision support system for the planning and design of urban greenspace that was sponsored by the EC. This book is not meant to be an innovative contribution to spatial decision support systems development or design. Many studies already do a good job of that. It is not meant to be an advanced technical treatment of innovative models for solving specific greenspace management problems either. There has been already substantial progress with a wide range of theoretical problems in urban modelling. Instead, this book describes how methodology, models, and tools that have been developed and evolved over time in the urban planning domain and information can be combined in an innovative way to provide a powerful framework, to explore and extract quantitative performance indicators to a specific urban planning problem: the greenspace problem.

The fundamental concern of this research is the yet intangibility of the benefits of recreational/aesthetical greenspace, as a contribution to individuals quality of life. The theory is that access to greenspaces encourages people to be more active, contributing to a better quality of life and public health. However, very little is known (or poor articulated) about the link between urban greenspace provision and human behaviour hence, the benefits of greenspaces appear intangible and sustainable funding often suffers in relation to other priorities in the urban context.

This research is focused on assisting greenspace administrators (planners and decision makers) in the planning, design and maintenance of recreational/aesthetical urban greenspace by providing information and a technological and theoretical framework to deal with the problem in a more structured and measurable manner.

Many people have had part in the development of this book. My special thanks goes to Professor Antonio Nelson Rodrigues da Silva who guided me to the start of my academic career, always supportive and encouraging me since we first met. Special thanks go also to Harry Timmermans, my first promoter, who gave me this opportunity, and taught me so much along these years. It is a great pleasure to have worked with such a brilliant, exquisite and extremely patient person. Many thanks to my co-promoter, Theo Arentze, who has assisted me, and cooperated in the development of this



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# CHAPTER 1

## 1. INTRODUCTION

The development of 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 neighbourhoods, attractive street scenes and greenspace within walking distance are increasingly seen as important contributors to the urban quality of life.

Many studies in the past ten years underline the importance of nature for people's well being. Greenspace clearly contributes to the quality of life and public health (Yuen, 1996). It has been recognised that people desire attractive cities that are clean, spacious and uncongested.

Under the premise of sustainability principles, greenspace provides a number of benefits towards the overall goal of urban sustainability. Some benefits are more tangible than others, such that a quantified impact of a particular landscaping technique can be estimated (Randall *et al.*, 2003). Increasing the area of greenspace in urban areas, particularly with respect to trees, provides significant air quality and energy-conservation benefits. Trees are net producers of oxygen and net consumers of carbon dioxide, and thus a benefit regarding global warming attributed to the increasing concentrations of CO<sub>2</sub> and other greenhouse gases in the atmosphere. In addition, trees act as atmosphere filters, reducing amounts of harmful airborne pollutants such as ground-level ozone, carbon monoxide and sulphur dioxide (Dwyer *et al.*, 1992). Energy benefits are gained through appropriately siting trees around structures. Building air-conditioning and heating costs, in the respective seasons, can be reduced significantly as shown by Heisler (1986).

In many cities, innovative urban design incorporating greenspace has attracted investment in commercial or residential developments that has revitalised decaying urban areas. Sociological studies do underline the importance of the natural environment in the choice of residential location and researchers have included open spaces, parks, and natural areas as factors associated with residential choice (e.g., Vogt and Marans, 2004).

Yet, if the need of a range of recreational opportunities, open spaces 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 the quality of life in the city will be compromised. That has been one of the reasons why recreational and leisure trip analysis has received increasingly more attention in the last few years (e.g., Lawson, 2000; Pozsgay and Bhat, 2001; Bhat and Gossen, 2002; Kemperman *et al.*, 2004). Thus, it seems that we are faced with a cycle that begins and ends with greenspace provision.

In terms of less tangible benefits, aesthetics aside, the inclusion of nature in the neighbourhoods will facilitate more frequent recreational opportunities and may emphasize the important connection between humans and their environment.

Regardless of these considerations and although the planning and design of greenspace is one of the domains of urban planning, the greenspace field is still lagging behind in terms of availability of models and methodologies to analyse and predict spatial choice behaviour when compared to other fields of urban planning, such as for instance transportation and retail planning. The yet intangibility of the benefits of greenspace, as a contribution to a better-built environment, is one of the concerns here.

A problem with the presumed intangibility of the benefits of greenspace is that expectations with respect to urban public space are poorly articulated. Projects have often been considered in isolation and public participation, when it occurred, has been limited to consultation exercises in relation to major single developments. Benefits appear intangible and so sustainable funding often suffers in relation to other priorities in the urban context.

There are surprisingly few published guidelines explaining how to assess the provision of greenspace on an intra-urban basis (e.g., Nicol and Blake, 2000; Herzele and Wiedemann, 2002). Very little is known about the link between urban greenspace provision and human behaviour. Projects in the field have often been considered in isolation, as a tentative to generalized qualitative and quantitative assessments of greenspace provision by ad-hoc experiments. However, as any other urban planning problem, the planning and monitoring of urban greenspace is “based on a generic problem solving process which begins with problem definition and description, involves various forms of analysis which might include simulation and modelling, moves to prediction and then to prescription or design which often involve the evaluation of alternative solutions to the problem. Decisions characterize 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” (Densham and Batty, 1996).

Our target in this research project therefore is to develop a spatial decision support system to assist greenspace authorities to strategically enhance the supply of recreational greenspace (squares, parks, green corridors, waterfronts, passive and active recreation areas) with the right type and variety of greenspace that optimises public welfare.

The viewpoint that we take is that urban greening strategies and actions consider particularities of the urban environment within its community that involves a group of individuals showing behavioural patterns as a response to the environment they live in, rather than conducting experiments and produce generalized quantitative and qualitative targets.

## **1.1 Aim and objectives**

This PhD project aims at developing a prototype Spatial Decision Support System to assist local/regional authorities in the planning, design and maintenance of urban greenspace. The aim of the system is to provide a framework that integrates methodologies, models and tools, to support the planning and decision-making process, and is available to end-users.

The system should be able to output measures of tangible benefits of greenspace provision (quantitative and qualitative measures) for different facets (or criteria) in the urban context. Only then can greenspace options and actions be balanced against each other. By action, we mean planning, design, and maintenance. Planning of greenspace is concerned with the physical arrangement (location and size) of greenspaces in the built environment. Design of greenspace is concerned with the selection of features (facilities and attributes) within the physical locations to meet aesthetic and functional criteria. Decisions on the type of vegetation, provision of public transportation and facilities such as playgrounds, sport fields, walking path, benches, picnic tables, garbage bins, toilet, etc that turn into different functional values of the greenspace to the community will be the focus given to the greenspace design problem. Aesthetic value is left as another research issue. Maintenance concerns recurrent, periodic or scheduled work necessary to repair, prevent damage or sustain existing features in the greenspaces. Maintenance includes every type of cleaning services (spring and fall clean-up, garbage bins, toilet, etc), repair and replacement works (playground, walking paths, sport facilities) and gardening (weeding, pruning, gardening, cultivation, fertilization, etc).

As any other urban planning problem, the planning, design and maintenance of urban greenspace, is an ill- or semi-structured complex spatial problem. Decision makers have difficulty to define the planning problem or fully articulate priorities. It turns out to be a decision problem

characterized by multiple and often conflicting objectives. In addition, having no single *analytical* process to solve this kind of decision problems, the decision making process is often perceived as an arduous task surrounded by uncertainties. Therefore, efforts are taken here in the direction of providing: (i) relevant information for the problem solving process; (ii) the right tools, models, methods and methodologies to gather and evaluate the relevant information so that uncertainties can be reduced; and, (iii) a framework to represent the decision making process in a structured way.

Decision Support Systems (DSS) can be viewed as a framework containing tools, models, methods and methodologies to support decision makers through a process of solving ill or semi-structured decision problems in a systematic way. Spatial decision support system (SDSS) is a subset of DSS designated to the same type of problems, but with a spatial dimension.

Solving decision problems can be divided into several steps: problem analysis, problem structuring, generating alternatives, evaluation, choice, and implementation (Mintzberg, 1976; Simon, 1977; Adams *et al.*, 1990; Buede, 1992; Liu and Stewart, 2003). Practitioners of decision analysis generally agree that problem analysis and structuring are the most important and difficult steps of the analysis (Adams *et al.*, 1990; Liu and Stewart, 2003). In agreement with Liu and Stewart (2003), the most critical and most time-consuming task in decision analysis is to clarify issues and relationships, and to identify quantitative and qualitative variables. Indeed, these authors go in line with Keeney's (1992) argumentation, which points out that a philosophical approach and methodological help is missing in most decision-making methodologies to understand and articulate values and to use them to identify decision opportunities and to create alternatives.

Following Keeney (1992) and Liu and Stewart (2003), this research project seeks for a robust philosophical approach and methodological help to support decision makers and planners solving the greenspace problem. We believe that by providing a broader point of view to observe the problem and the problem context, the decision makers can better understand and articulate values about elements of the problem, and integrate all the related elements. In other words, if decision makers and planners can evaluate greenspaces in the context of the built environment and human behaviour patterns, they can gain a better understanding and articulate values about public greenspaces.

Although urban planners use a variety of terms to refer to the built environment, it is important to make clear some of the terminologies that will be used in the remainder of this book. In agreement with Handy *et al.* (2002), we refer to "urban design" as the design of the city and the physical elements within it, including both their arrangement and their appearance, and that it is concerned with the function and appeal of the public space. "Land use system" refers to the distribution of activities across space, where

activities are grouped into relatively coarse categories, such as residential, commercial, office, industrial, agricultural and other activities. The “transportation system” includes the physical infrastructure of roads, sidewalks, bike paths, railroad, tracks, bridges, and so on, as well as the level of service provided using the system. The built environment comprises urban design, land use, and the transportation system, and encompasses patterns of human activities within the physical environment.

The link between the built environment and activities, in particular greenspace recreational activity, is then made using theoretical frameworks borrowed from geography, psychology and economics, approached at two levels: spatial and spatial-temporal. At the spatial level, greenspaces are considered in connection with the place where people live in a way that reflects their needs and preferences. Spatial behaviour is then related to the impact of socio-demographic and spatial attributes on spatial awareness, preference and choice. At the spatial-temporal level, a more elaborated conceptual framework of context-dependent and time-sensitive choice behaviour is adopted. Hence, it articulates the notion that spatial choice can be best understood by realizing that individuals need and/or wish to pursue particular activities, and that the set of activities needs to be organized in time and space. The need to conduct activities will vary over time and space. Some activities are mandatory and need to be conducted frequently and are more constrained in terms of their duration, timing and location. Other activities are discretionary and less constrained in terms of their time, location and duration.

Having presented the aims, objectives and the context of this research project, we can now address the research topics as follows:

- 1) Develop an effective decision support system for solving recreational urban greenspaces planning, design and maintenance problems;
- 2) Develop appropriate measures to articulate greenspace values in the context of the link between built environment and human behaviour.
- 3) Given conceptual framework, what kind of data is available and/or collectable.

The first research topic is concerned with the complexity of the system. It is related to the structural and practical aspects of the system concept, architecture and design; as well, the limits of technologies for building SDSS. Although the focus of this project research is not in contributing innovations to the SDSS field, we do intend to develop a framework to represent the decision making process in a simple and transparent way. The



two last research topics are mutually dependent, that is, the development of measures is influenced by the availability of data and vice-versa.

## 1.2 Research fields

Many fields potentially contribute to this research project. Methodologies developed in information system, economics, decision analysis, spatial sciences and operations research are relevant for this purpose. These include techniques for modelling spatial behaviour, transportation analysis, multicriteria evaluation, etc. Geographic Information System (GIS) technology can strongly contribute to data handling problems and to the development of a graphic map-based user interface.

Last, but not least, this research has the objective of contributing to the state-of-art in the greenspace domain within the DSS perspective, by improving the match between fundamental and applied research.

## 1.3 Outline

In line with the project aims and objectives, a Spatial Decision Support System has been developed. This GIS-based tool has been given the acronym GRAS, the Dutch word for *grass*, which stands for Greenspace Assessment System.

The full integration approach was used to develop the system. That is, starting from the modelling perspective, GIS functionalities were added by emulating the needed analysis and display functions by subroutines within the models. The program was written in Borland Builder C++ 5 and GIS functionalities were added using MapObjects 2.0 ActiveX Control.

In particular, the system incorporates the following components:

- 1) A geo-referenced database module;
- 2) A scenario management module;
- 3) The population synthesizer model;
- 4) The spatial models component;
- 5) The spatial-temporal models component;
- 6) The Multicriteria Evaluation Module; and
- 7) The Thematic Map Visualization Module.

In short, GRAS is a micro-simulation scenario-based multicriteria evaluation system. A range from static to dynamic modelling methods is employed within the system to represent individuals' behaviours. In

principle, these models operate on a “100% sample” (i.e., the entire population) of individuals, which are synthesized from census data. Under the umbrella of the *Spatial Models Component* are the traditional spatial choice models used in the urban planning field since long, related to the intensity of use and the impact of socio-demographic and spatial attributes on spatial awareness, preference and choice, explained in detail in Chapter 4. The *Spatial-Temporal Models Component* comprises an activity-based model, the so-called Aurora (Joh *et al.*, 2001; Joh, 2004), which is a micro-simulation model to predict space-time behaviour patterns at the individual level.

While most of these components are relatively new to greenspace planning, the model on space-time behaviour is quite innovative in its own right across different fields of application and spatial behaviour. It is based on the condition that the use of certain greenspace is not only a function of the attributes of the greenspace, 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 considerable more detail than traditional spatial choice models.

This study is organized in two parts. Part I is concerned with the system conceptual development and practical implementation. This part consists of three chapters. Chapter 2 reviews the relevant literature for the development of this research project in the DSS field. Practical work on DSS started in the late 1960s resulting in a conceptual framework that has been evolving since the early 70's. For the field of urban planning, the basic concept of DSS is then reviewed and a technological framework for developing the system is proposed. Making the link to Spatial Decision Support System, the spatial dimension of the DSS is discussed and presented by means of current spatial technologies available and used. Finally, examples of SDSS that has been developed and reported relevant to this research are presented. Chapter 3 describes the greenspace field in the context of urban planning in the Netherlands, and the impact of greenspace/spatial planning policies to the planning, design and maintenance of urban greenspaces on the regional/local scale. Hence, we narrow down the greenspace problem to the regional/local scope to refine systems requirements. The city of Eindhoven, a medium-sized city in the Southeast of the Netherlands, is taken as an example to refine system requirements and later, as a real case study to test the system. In Chapter 4, we articulate the requirements to develop a Spatial Decision Support System for the provision and monitoring of urban greenspaces in order to embody the system's conceptual framework. We also describe how the system is able to support the decision-maker/planners to structure the three phases of the decision making process, that is identification,

development and selection by means of a flexible environment to accommodate different decision process styles. The system's architecture and design are then described followed by the system's models, components and relationships. Chapter 5 is dedicated to a more detail description of the decision models and tools in the system.

Part II is concerned with system application. For that purpose, GRAS is prepared and set up with the required data to support the decision making process related to the planning, design and maintenance of urban greenspace in the region of Eindhoven. Hence, Chapter 6 specifies data requirements, data collection and methodologies for that specific application and Chapter 7 describes a real case study, applying GRAS to support the local authorities of the city of Eindhoven with their greenspace planning, design and maintenance decision problem.

Finally, Chapter 8 concludes this book with a summary of the major conclusions and a discussion of the potentials and limitations of the system and of possible future research avenues to improve systems performance.

## **PART I: SYSTEM DEVELOPMENT**



## CHAPTER 2

### 2. DECISION SUPPORT SYSTEMS: A LITERATURE REVIEW

*We believe that human beings cannot gather information without in some way simultaneously developing alternatives. They cannot avoid evaluating these alternatives immediately, and in doing this they are forced to a decision. This is a package of operations and the succession of these packages over time constitutes the total decision-making process (Witte, 1972, p.180).*

The Decision Support Systems (DSS) field presents a body of research that has been evolving since the 1970's. In despite of the criticism of having a body of research constituted by atheoretical studies driven by advances in computer technology, the DSS field seems to be well established. Hence, this chapter reports a collection of theoretical and practical developments in the Decision Support Systems field that are relevant to the development of the SDSS proposed in this research project.

This chapter is organized as follows. First, a brief introduction to Decision Support Systems characteristics, and the identification of decision problems to which DSS may provide a great contribution is given. Next, in order to build efficient decision support systems, we present some of the classic frameworks proposed in the literature to structure decision making processes in a Decision Support System. Narrowing down our Decision Support Systems review to the urban planning domain, the importance of the spatial dimension of the problem is recognized. The introduction of the spatial dimension leads our investigation to a specific branch of the DSS field, the Spatial Decision Support Systems (SDSS) branch. A technological framework to build SDSS is then described (and later used in the development of this research project), followed by a discussion of some of the spatial technologies available nowadays to add the spatial dimension to

decision support systems. Because of the proliferation of DSS in so many forms and different fields of application, we present a framework to categorize DSS, which will be helpful for the identification of SDSS examples that would contribute to the development of this research project. Finally, in order to position the state-of-art of (spatial) decision support systems in the urban planning domain and specifically in the greenspace field, we present a collection of domain/problem-specific (S)DSS examples reported in the literature.

## **2.1 Decision support systems and problem characteristics**

In the late 1960s and early 1970s, few firms and scholars began to develop Decision Support Systems (DSS), which became characterized as interactive computer-based systems that help decision makers utilize data and models to solve ill- or semi-structured problems.

Decision support systems were first introduced in business management aiming at improving the effectiveness of management information system because of competition pressures and changes in the economic environment. Scott Morton (1971) was one of the pioneers in articulating concepts related to DSS under the term Management Decision Systems. Alter (1980) expanded the framework about management DSS and provided a first concrete descriptive foundation of DSS. The books “Building Effective Decision Support Systems” by Ralph Sprague and Eric Carlson’s (1982) and “Decision Support Systems: Putting Theory into Practice” by Sprague and Watson (1989) were important milestones, providing a practical and understandable overview for building DSS.

Although there is not a generally agreement on an exact definition of a DSS, there seems to be a consensus that these types of systems are problem specific driven (sometimes domain specific) and developed to support ill-defined or ill-structured problem solving.

Problem structuredness is related to uncertainties, whether regarding objectives of the decision maker and/or the cause and effect relationships in the problem. Ill-defined problems occur when the problem is not well understood and ill-structured problems occur when the problem is understood but possible actions and possible developments are typically uncertain. Such problems cannot be solved by a series of fixed decision rules, i.e. they are “unprogrammable”. Thus, the decision process is characterized by complexity and open-endedness. The organization usually begins with little understanding of the decision situation it faces or the route to its solution, or has only a vague idea of what that solution might be and how it will be evaluated when it is developed.

As a first articulation of the concepts involved in DSS, Scott Morton (1971) identifies 8 characteristics attributable to problems which DSS may provide great contribution to the decision making process:

1. Large database.
2. High requirements for data manipulation.
3. Managerial judgment required.
4. Complex interrelationships.
5. Multidimensionality.
6. Different functional groups involved.
7. Economic significance, high payoff from good solutions.
8. Dynamic environment.

In a similar vein, Sprague and Carlson (1982) and Sprague and Watson (1989) argued that the characteristics of the problem hold more promise to understand DSS and its potential than definitions or collection of examples. However, the authors observed and pointed out some common characteristics in those DSS, which are:

1. They tend to be aimed at the less well structured, underspecified problems that upper level managers typically face;
2. They attempt to combine the use of models or analytic techniques with traditional data access and retrieval functions;
3. They specifically focus on features which make them easy to use by noncomputer people in an interactive mode; and
4. They emphasize flexibility and adaptability to accommodate changes in the environment and the decision making approach of the user.

During the past few years significant developments in the field of decision support system have been made thanks to rapid changes in computer technology. Nowadays, DSS are a well established area of applied research and one of the long-standing conclusions from reading DSS case studies is that what is called DSS can “take on many different forms and can be used in many different ways” (Alter, 1980).

The proliferation and evolving of DSS in many different fields of applications followed by brief and sketchy articles in the formal literature create difficulties in conducting theoretical research in the DSS field. Nonetheless, this chapter will discuss some previous research that has direct relevance to the development of Spatial Decision Support System (SDSS) in the urban planning context. It should be emphasized here that this chapter is not meant to be a detailed review of DSS in general. In particular, we will



review previously proposed frameworks to describe and structure the decision-making process and to conceptualise and develop the SDSS addressed in this thesis. This discussion serves to give a theoretical background to the present research project.

## 2.2 The decision making process

Decision-making takes place in the context of problems that neither the actors involved in the decision process nor the relevant theory are able to fully structure. As an alternative to deal more efficiently with those problems, attention is given to the decision making process. By supporting decision makers through a process to explore what would be the consequence of possible actions, a decision problem would be reduced to a choice problem. In other words, uncertainties inherent to decision-making would be reduced.

A number of frameworks has been proposed in the literature to describe the decision making process as a tentative way to structure it (Dewey, 1910; Witte, 1972; Simon, 1965; Morton, 1971; Mintzberg *et al.*, 1976). Perhaps the best known is Simon's "Intelligence, Design, Choice" stages (Simon, 1965).

Scott Morton (1971) developed a framework portraying the decision making process with somewhat greater discrimination than Simon's intelligence-design-choice trichotomy. In Simon's model, the decision-making process is divided into three major parts: (1) Intelligence, or the search for problems (analysis); (2) Design, or the invention of solutions; and (3) Choice, or the selection of a course of action. In Scott Morton's model, each of these major phases has three sub-phases: (a) Generation of input data; (b) Manipulation of the data; and (c) Selection for the following phase.

Witte (1972) investigated whether distinct phases in the decision making process do exist and whether they follow a simple sequence of phases as suggested in the literature (Dewey, 1910; Simon 1965). The sequence of five phases ("phase theorem"), from problem recognition through gathering information and development of alternatives and evaluation of alternatives, to choice, was however not supported for his whole sample. He found that the decision process consisted of a plurality of sub-decisions and when he tested the phase theorem in terms of the sub-decisions, he again found no support for the sequence. Therefore, he did recognize a number of operations that occur at different points in time. His conclusion is that "...human beings cannot gather information without in some way simultaneously developing alternatives. They cannot avoid evaluating immediately these alternatives, and in doing so, they are forced to a decision. This is a package of operations

and the succession of these packages over time constitute the total decision making process”.

Mintzberg *et al.*, (1976) developed a framework to describe the decision process resembling Simon’s trichotomy and based on Witte’s basic conclusions. It consists of 12 basic elements of the decision process described in 3 central phases (identification, development and selection), 3 sets of supporting routines, and 6 sets of dynamic factors. The general model of the decision process proposed by the authors is represented in Figure 2.1. The model can be used to illustrate the structure of decision processes.

Obviously, decision processes involve development of alternative solutions after problem recognition. Hence, at  $X_2$ , there is a branch off the main line into the search (and screen) routine to find a ready-made solution or into the design routine to develop a custom made-solution. The three modes of the evaluation-choice program are shown at  $X_3$ . At  $X_4$ , the model contains a branch from the evaluation choice routine back to the development phase at  $X_9$  to initiate another search or design cycle. Modified solutions first follow one or more search cycles to find a ready-made solution, and then a series of design cycles to modify it. In addition to nested development, nested selection also occurs frequently; hence, at  $X_4$  and  $X_8$  there is a loop from the evaluation-choice routine back to itself.

Any decision process may or may not involve formal diagnosis or authorization. Therefore, the model shows branches at  $X_1$  and  $X_5$ , which take the process off the main line and return it there when completed. In addition, authorization may be tiered; hence, the loop at  $X_6$  and  $X_7$ , and authorization to proceed may be sought after recognition or during development, resulting in a branch from the authorization routine at  $X_6$  back to development at  $X_9$ . There is also evidence that the decision process may branch from selection at  $X_4$  or  $X_6$  all the way back to diagnosis to allow for consideration of whole decision situation.

All of these branches also represent the comprehension cycles for example cycling within evaluation-choice at  $X_4$  and  $X_8$  and the failure recycles, from the evaluation choice routines at  $X_4$  or the authorization routine at  $X_6$  back to redevelopment at  $X_9$  to modify an unacceptable solution or develop a new one, or back to the evaluation-choice routine at  $X_8$  to modify criteria.

This sub-section shows that whilst the decision processes are immensely complex and dynamic, it is possible to conceptually structure them. Although structuring the decision making process seems much more problem domain dependent and ad hoc, the frameworks proposed in the literature offer substantial support during this phase.

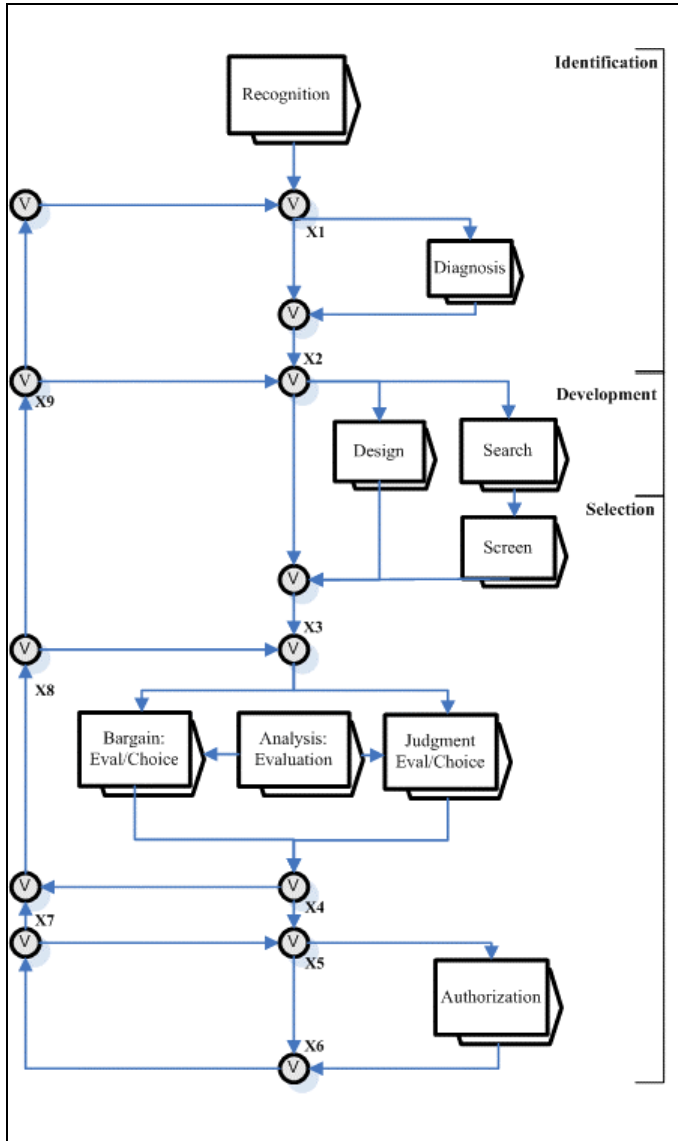


Figure 2-1. A general model of the decision process (Source: Adapted from Mintzberg *et al.*, 1976).

The importance of structuring the decision-making process can be explained by taking two points of view: the developer point of view and the user point of view. First, taking the developer point of view, the structure of the decision making process reflects the early stage of DSS development, that is, the DSS design. In short, because there is no solid base in the Information System literature or DSS literature to design DSS, it turns out to be an elusive task of how to select contingent models, to determine the influence of users culture on the choice of models and to establish how rigor is maintained in light of the flexibility in choosing methods. Therefore, by structuring the problem solving process (or decision making process), we are actually breaking the main problem into smaller and simpler sub-problems to find out interactions and dependencies among them. In other words, choices related to the type of models, tools, methods and the technology that will constitute the framework are not possible if dependencies, interaction and flexibilities in the problem solving process are not known.

On the other hand, taking the users point of view, by developing a framework that forces the user to deal with the problem in a structured and systematic manner, will break the complexity of the process into a set of actions and dynamic factors towards an effective and transparent problem solving process.

### **2.3 Urban planning and spatial decision making**

Many DSS applications in urban planning are concerned with geographic data. Spatial Decision Support System can be seen as an important subset of DSS whose fast growth has been facilitated by technical developments and availability of appropriate inexpensive technologies for manipulating spatial data.

Spatial technologies, of which Geographic Information Systems (GIS) are central, involve any kind of software that is essentially data driven with an explicit spatial or geographical dimension. Hence, data are georeferenced in a form that they can be stored, manipulated, retrieved and spatially displayed (Batty and Densham, 1996).

GIS software could be regarded as an *analysis information system* in Alter's framework (Alter, 1980), the database component being the critical component of such a system. As Longley and Clarke (1995) outlined, one can think of a GIS as a database management system with an additional, geographical shell that accounts for the special properties of spatial data in storing, retrieving, manipulating and reporting data.

While GIS may contain the information relevant to a decision, they are usually general-purpose systems, not focused on a particular class of

decision domain. Common to all definitions of DSS is that they must support a particular type of decision. This characteristic distinguishes DSS from general-purpose management information systems (MIS). Therefore, additional processing or integration functionalities with particular problem-domain models are needed to fully support decisions. Bring this into the urban planning context, better data and computers would not alone lead to improvements and or advances in the planning activity. What is also required is to fully explore the rich information base created from data processing inputted into relevant urban models. GIS lacks in the problem domain analytical or spatial modelling capabilities, even though they are relevant to examine whether the organisation of spatial information is appropriate for spatial models.

Is important to make clear that we do not frame DSS as an evolutionary advancement beyond Electronic Data Processing (EDP) and MIS, respectively and certainly, it has not been evolving to replace them either. To be more precise, DSS draws on models and data processing systems and interacts with the other parts of the overall information system to support the decision-making activities in an organization.

Keenan (1997) pointed out three categories of decision makers for whom SDSS can make a difference. The first group is in fields such as routing and location analysis, where the spatial component of such decisions is clear. The second group includes those problems where the importance of both spatial data and modelling is somewhat neglected at present, i.e. in disciplines such as marketing. The third and most important for this study is the group within the traditional areas of GIS applications that is in disciplines such as geology, forestry and urban planning.

Monitoring and evaluating urban developments is an essential ingredient of urban planning. Decision-makers use spatial urban models to investigate and gain a better understanding of urban processes. Spatial urban models provide an abstract world, and can be used as a tool to evaluate the effect of various decisions on an urban system or subsystem. Wegener and Spiekermann (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. Some spatial urban models deal only with one spatial subsystem, whereas others deal with interactions between different spatial subsystems. Integrated urban models is an approach in which two or more urban models are combined to investigate the interrelationship between subsystems and its change with time.

Integrative models, as defined above, represent a multidimensional concept that requires integrative solutions approaching different disciplines such as economics, geography, psychology, sociology, and transport

engineering. The need for an integrative solution is becoming more urgent because of the interconnectedness of economics, social, and environmental problems. Regardless conceptual formalisation, the spatial level or the representation of real-world physical attributes of urban model is the dimension that will however mostly dictate how realistically models suit the investigations of urban processes. In other words, it is at the spatial level that the abstract representation of the urban environment will dictate how realistically models suit investigations of urban processes. Hence, a key element in urban modelling is the representation of space and spatial modelling.

In summary, to facilitate the decision-making process in the urban planning domain, an integrated urban modelling environment must provide a variety of modelling techniques. The components of such an environment 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 operates on item (1) and produces new information (description, explanation), relevant for the decision making process, that is not in the database yet; and
- 3) A user interface that supports the visualization of the data sets and the output of models.

Existing Geographic Information Systems (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 GIS software to provide decision support within the GIS field.

A major research program involves the use and adaptation of GIS to modelling and linking various types of predictive and prescriptive models in formal terms. Strategies for such linking range from weak to strong coupling (Batty, 1994). Models can be linked to GIS simply through the import and export of data – weak coupling – while much stronger coupling exists where models are embedded within GIS or GIS functions within models.

Having defined the scope of SDSS and the problem domain to which it would improve the effectiveness, a framework for system development is derived in the next section.

## 2.4 Building SDSS

Since 1975, issues concerning the development of computer support for decision makers have generated a growing body of research. This body of research has been criticized by some for being a collection of a-theoretical studies driven by a technology push rather than by a managerial pull. The danger in an a-theoretical approach to a field of study is that, while interesting facts may be collected, no unifying themes or predictable patterns emerge (Eierman *et al.*, 1995). Trying to follow a theoretical approach, this section develops a description of SDSS as a special branch of DSS theory by analysing existing literature to provide guidelines for selecting among alternative strategies and actions for developing a SDSS.

### 2.4.1 Technological framework

The theoretical background to the development of SDSS is inspired by Sprague (1980). In Sprague's framework, a DSS may be built from three technological levels of hardware/software. At the most fundamental level of technology are the *DSS tools*, which are individual software components that can be combined to form a DSS. These would include programming languages, programming libraries and small specialized applications. At a higher level in the framework are *DSS Generators*, from which a specific DSS can be quickly and easily built. Indeed, a DSS Generator may be built from lower level tools to become a "package" of related hardware and software providing a set of capabilities to build specific DSS. *Specific DSS* are the systems developed to the end user or decision maker. It will allow the decision maker or a group of them to deal with specific sets of related problems.

*DSS Tools* can be used to develop a *Specific DSS* application directly. This is the approach to develop most traditional applications with tools, such as a general purpose language, data access software, subroutine packages, etc. The difficulty with this approach to develop a DSS is the constant change, whether in response to changes in the program environment as consequences of fast changes in computing technology or in response to the way users want to approach the problem. Therefore, a serious complication is the need to involve the user directly in the change and modification of the *Specific DSS*.

On the other hand, the development and use of *DSS Generators* promises the creation of a "platform" or starting area from which *Specific DSS* can be constantly developed and modified with the cooperation of the user, without heavy consumption of time and effort.

In building a DSS, the decision regarding the appropriate mix of *DSS tools* and the use of a *Generator* is an important component of the process. Sometimes, specific generators have been designed for certain classes of problems. In other situations, general-purpose software such as spreadsheet software or DBMS packages have been regarded as generators. The various generators have strengths and weaknesses in terms of their provision of the key components of a DSS: an interface, a database, and models. Important to realize is that the DSS solution actually constructed is strongly influenced by how suitable the generator is to cover required strengths in the specific DSS.

There is evidence that GIS software is suitable for use as a generator for a SDSS (Batty and Densham, 1996; Keenan, 1997; Bishop and Yates, 1998; Wegener, 2001; Booty *et al.*, 2001; Geertman, 2002; Yeh and Qiao, 2003 and many others). GIS provides a sophisticated interface for spatial information, database support that is designed to allow for the effective storage of spatial data and links between the interfaces and database to allow the user to easily query spatial data. Thus, the main advantage of using a GIS component in a decision support system is the data organisation and the simplicity in capturing 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 spatial data from different sources and non-spatial flat tables, based in one common spatial framework. Nevertheless, for the full range of potential uses of spatial data in decision-making, a GIS is not a complete DSS because of the almost complete absence of problem specific models or support for the organization of such models.

A large number of models and modelling techniques have been developed to support decision makers in the urban planning domain. As noted before, these models are drawn from well-established disciplines such as economics, geography, sociology, statistics and transport engineering, and in most cases do not require the use of spatial data. However, real world problems need to have a spatial component in at least one aspect of the decision-making. The models may operate on non-spatial (attribute) data, but the data set to be used for the modelling process may be created by spatial operations.

The coupling of spatial models with GIS can be made in four different manners: isolated applications, loose coupling, tight coupling and full integration (Nyerges, 1992). The difference between them is the linkage between these two components, i.e. the increasing intensity of coupling. Models can be linked to GIS simply through the import and export of data – weak coupling – while much stronger coupling exists when models are embedded within GIS or GIS functions within models (Batty and Densham,



1996). In loose coupling applications, models are external to GIS offering independent and flexible development and testing advantages. On the other hand, planners spend lots of time converting data and moving files between packages. Hence, this integration strategy fails to provide: (i) a consistent user interface; (ii) a consistent data structure; (iii) support for the development and modification of models; and (iv) user interaction during a simulated event. In more tightly coupled systems, GIS users have access to models through software “hooks” and/or built in macro-languages. This integration strategy can provide access to a consistent user interface and data structure (Bennett, 1997). Consequently, embedding the spatial model into the GIS has the advantage that all functions and data resources of the GIS can be used.

Until recently, there was a wide spectrum of urban planning models using GIS but in only few of them GIS plays a role beyond database or mapping functions. Specific modelling languages, such as STELLA (High Performance System, Inc., Hanover, NH) or SWARM (PCRaster Environment Software, Utrecht, NL) offer tools for combining spatial models with GIS functions; however the range of models that can be defined is limited.

Nowadays, system-dependent macro-language and models are standard capability of the component-based software architecture of some GIS products to allow the user to code the decision process. Approaches such as “modelling with GIS” are using strong coupling to link a GIS with a large number of external analysis and modelling routines under a common graphical user interface. The growth and evolution of commercial desktop GIS packages such as *MapInfo* and *ArcView* provide formal links and macro languages, which enable their functionality to be extended directly through new programming or indirectly through links to other software. There are many examples of extended functionalities which link GIS to analysis and modelling and we will illustrate few varieties here.

Batty and Xie (1994) use strong coupling to link ARC/INFO with a large number of external analyses and modelling routines under a common graphical interface. They note however that in their application the GIS is essentially a storage and display medium.

Batty and Densham (1996) present an example extend GIS to embrace predictive modelling. The application aims at modelling urban population density where the process consists of data analysis, model calibration, and prediction as a set of relations embedded within GIS. It uses the GIS component (ARC/INFO) as a display medium and as the organising frame for the sequence of analysis and modelling operations, which are accessed as links to the outside world through system macros. Once again, GIS acts as the framework and most of its relational functions are never actually used.

Densham (1991) has developed a program called LADSS (Location-Allocation Decision Support System) which link heuristic optimisation techniques for matching the supply of various facilities such as school, shopping centres, or hospitals to the demands for these same facilities by the affected population. Various optimisation functions can be optimised but typically these involve functions which minimise distances, travel time or travel cost between the demand and supply points. Developing such models within GIS provides very powerful visualisation facilities for display and manipulation, giving immediate intuitive evaluation capabilities, which a wide range of non-technical users and decision makers can relate to.

Yates and Bishop (1998) propose a methodology for the integration of separately developed software packages. The authors argue that an integrated urban modelling environment must provide access to a variety of modelling techniques that can be applied to data sets stored in a variety of data models (and underlying data structure). The component of such an environment should include a database management system, represented by GIS, a model management system that could be one or more of several systems built to support modelling activities, such as statistical packages (e.g., SAS, SPSS, LIMDEP, SPLUS, etc.), system dynamics packages (e.g., STELLA, VENSIM and EXTEND, etc.) and linear and nonlinear program solvers (e.g., LPSOLVE, CPLEX, etc.). In general, these software systems are, and have been, developed independently with their own specifications, interfaces, data models and data types. The integration methodology proposed consists of four separate components: the protocol for communication, a message queuing system, wrapping software and implementation techniques. This process addresses specific issues and computational skills to enable communication and sharing of procedures between the different systems. Besides, the authors are not concerned with the provision of a user interface. To provide a drag-and-drop type interface linking models to data sets for instance, issues related to providing a universal language for integration is addressed. The users need to have a profound knowledge of computer programming to design a well-defined interface to coordinate with the data structure held by the GIS. This is often a time consuming and exhaustive task. Another issue that was let beyond the scope in the methodology is security. This includes concepts relating to the rights to use the data and software, and auditing of such use. Yet most of these software systems were not designed explicitly to integrate with geoprocessing technologies and, thus, possess limitations for the representation of geographical systems. Most importantly, these software packages do not explicitly support spatial data structures and, thus, they do not provide strong support for the development of spatially distributed models. The dynamic modelling language introduced by Wesseling *et al.*

(1996) is an important step toward meeting this need. However, the use of this package is limited to raster representation of space.

Even though considerable effort has been made in the development of GIS-based decision support systems to embed various models into the system, issues of model sharing and reusing among different applications have not been fully addressed.

To overcome these limitations in traditional approaches and following a more object-oriented approach, recent work by Raper and Living (1995), Bennett (1997) and Hopkins (1999) represents a greater methodological advancement in spatial decision support systems. Their research attempts to design a type of spatial modelling systems within which model objects can be defined, constructed and calibrated based on object-oriented methods. For instance, Bennett (1997) proposes a framework for the integration of simulation models of spatial processes with GIS technology. The author uses an object-oriented approach to provide the: (i) extensibility needed to create new geographical models, (ii) semantic power needed to construct complex objects that capture the spatial states, processes, and relations of geographical systems, and (iii) flexibility needed to develop simulations models that can adapt to the changing states of geographical systems.

However, Yeh and Qiao (2003) argue that the efforts described above do not provide appropriate tools to communicate with existing GIS products that have developed flexible functions for spatial data manipulation, analysis and presentation, and hence, substantial effort is required to build several GIS functions into these modelling systems. Furthermore, they do not have appropriate procedures to represent analytical models or model objects, to support model reuse and sharing among different applications, and to facilitate intelligent model selections in a complex problem solving process. Contributing to this direction, the authors propose an alternative approach aiming at designing Model-Objects, an object-oriented model management component that can be fully integrated or linked with GIS, relational database management systems (RDBMS) and other techniques to perform model reusing and development functions. It is similar to ESRI MapObjects GIS and ActiveX controls in Visual C++ that can be embedded into a number of application systems to perform specific tasks. Procedures for model generalization, representation and decomposition are developed according to object-oriented concepts and methods. These procedures can be adopted to decompose urban planning models into a set of model components and elements, and these model components can be used as the “building blocks” of the model library.

A more radical approach in building SDSS is starting from the modelling perspective and GIS functionalities are added conform the needed analysis and subroutines within the system. In short, rather than embedding less

elaborate models within a comprehensive GIS, it is possible to embed a limited range of GIS functions within a more elaborate modelling framework. As Wegener (2001) noticed before, the benefits of this strategy are substantial as one gets rid of all the overhead and limitations of a particular general-purpose GIS software package. However, the contribution of these applications will be determined by how well they support the need for a spatial component in decision-making.

For instance, Batty and Densham (1996) presented an application developing purpose-built GIS type functions within a specific modelling package to modelling urban population density. In short, they embedded a limited range of GIS functions within a more elaborate modelling framework. The interactive modelling process comprised less than 3000 FORTRAN statements and as the user is so close to both graphics and the model, changes to the visualisation can be made at will. The problem of course lies with the absence of interactive functions such as zoom and the way these are controlled with pointer devices such as mouse. Nevertheless, the system has to be so closely tailored to the study area in question that even changing the problem's size – from 8 to say 80 zones – caused major changes in the visualization, which necessitates reprogramming.

Perhaps, one of the most successful examples up to date using full-integration approach is a commercial decision support system shell for Windows called RAISON (Regional Analysis by Intelligent Systems ON microcomputers), which has evolved over the past decade at the National Water Research Institute of Environment Canada (Booty, *et al.*, 2001). The promises hold by this “environmental decision support system” is that by having a modular framework such as that used in the RAISON DSS, the components required for a particular application can be easily added or modified. By providing the user with a simple development language and libraries of special development functions, the system can easily be modified to fit a wide range of applications. The system consists of the following modules: (i) database: Microsoft Access 2.0 as standard; (ii) spreadsheet; (iii) GIS: handling vector and raster maps, and support a number of map projection; (iv) Models: can be incorporated in the system in different ways (for a example see Lam *et al.*, 2002); (v) Uncertainties Analysis; (vi) Neural network; (vii) Expert System: rule-based system with fuzzy logic; (viii) Optimisation: linear programming and genetic algorithm methods are available; (ix) Visualization: graphs, maps and tabular functions are available or can be customized within the system.

In this research project, we followed a more rigorous approach than traditionally, in that “*DSS Tools*” were used, to develop the “*Specific DSS*”, the SDSS so-called GRAS (Greenspace Assessment System). Although the chosen approach has disadvantages, such as a minimum of programming

skills when changes in the system are required, the development efforts may be very well justified by a number of advantages, such as: (i) overcoming limitations and overhead of standard GIS software packages; (ii) flexibility to include the domain analytical 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 modelling and data interchanges.

Before we present the *DSS tools* that are used to develop GRAS, we discuss in the next subsection the most popular spatial technologies used by researchers and practitioners to develop SDSS nowadays and how they can (or cannot) be embedded/linked with other technologies or applications to develop a SDSS.

#### 2.4.2 Current spatial technologies

The developments in GIS software since 1990 have been facilitating the use of off-the-shelf software as the basis for the SDSS. An example of this type of software is the *ArcView* package from ESRI. This software is primarily designed to allow the user to view and query spatial data. *ArcView* has its own macro language, Avenue, which can interact with SQL database servers, and the ability to use platform specific links with other software. An optional network analysis package is available for *ArcView* allowing its use for a variety of applications, which need this functionality, for example transportation modelling. It is intended that the full *ArcInfo* package will be required for some GIS operations. The software is available for Windows, Macintosh and UNIX operational systems. These characteristics make *ArcView* a potential generator for many types of SDSS software.

Another widely used desktop mapping product is *MapInfo*. It is a potential candidate to become a SDSS generator given its simple, efficient and friendly user interface to manage spatial data. The *MapInfo* package provides some functionalities in the form of a library that can be plugged in. In addition, *MapInfo* has its own language (Mapbasic) to add modelling functionalities, which is likely to be developed to become increasingly similar to other programming tools, such as Microsoft Visual Basic.

*TransCad* is a PC based GIS designed specifically for managing transportation data and to facilitate the use of transportation models. It is an excellent example of a potential DSS generator in the transportation domain as it provides a number of features, which specifically support transportation modelling. These include provision for a road network layer with the ability to store relevant network characteristics such as turn penalties. Relevant data may be stored in matrix form. The developer has the option of adding additional modelling functionality using Caliper Script macro language or of

adding some of the GIS functionalities of *TransCad* to another application by means of the Geographic Information System Developers Kit (GDK) supplied. Applications developed using this toolbox can communicate with external software using DDE (Dynamic Data Exchange), OLE (Object Linking and Embedding) and ODBC (Open Database Connectivity) standards. Dynamic data exchange (DDE), object linking and embedding (OLE) and open database connectivity (ODBC) are techniques to allow data pass from different software and applications.

Keenan (1997) argues that, in order to be used as a DSS generator, GIS software must allow easy automatic interchange of data between the GIS modules and modelling techniques operating on non-spatial elements of the data. In other words, to be used as a SDSS generator, GIS software must make data available in a format that is appropriate for modelling techniques drawn from other disciplines.

Technically speaking, Open Database Connectivity is an open standard interface used to access databases. With ODBC, applications can access databases from multiple database vendors. Because it is a standard applied across DBMS and applications, theoretically, communications between different platforms and DBMSs are transparent using this interface.

Putting this in a simple manner, DDE is a method used by Windows and OS/2 to transfer data between different applications. When two or more programs that support DDE are running simultaneously, they can exchange information, data and commands. Following fast computer technology progresses, DDE capability is enhanced with Object Linking and Embedding (OLE) technology, a more robust method that enable objects to be created with one application and then link or embed them in a second application. The OLE technology has been superseded, once again, by ActiveX controls. ActiveX Control can be seen, however, as a set of rules for how applications should share information. Indeed, ActiveX technology is a loosely defined set of technologies developed by Microsoft that provides a tool for linking desktop applications.

Without missing the point here, the use of these types of technologies offers two possibilities for SDSS developments:

- 1) PC based GIS software may be used for the main interface and database facilities. Domain models or additional modelling might be incorporated in OCX (the OLE control extension) using ActiveX controls or applets for interface requirements;
- 2) Alternatively, in the other way around, the main application might be developed in programming language environment (e.g., C++, C, Java, etc. programming language environments) and OCX type applets or ActiveX controls used to provide some element of GIS functionality.

A number of GIS related tools of this sort exist (the GIS ActiveX Controls), for example Sylvan maps (Sylvan, 1995) or MapObjects from ESRI, the market leader in GIS software.

There is no strong evidence in the literature which of the two technological approaches to follow. The choice might very well depend on ad hoc trial, developer skills and/or preferences, system's requirements, and trade offs between budget and deadline.

To develop GRAS we chose the second approach. It seemed to be the most efficient and effective approach given the relatively large number of urban modelling required within the system compared to the small subset of GIS functionalities required by the subset of routines within the models. Therefore, the SDSS was developed in C++ programming environment, more specifically the CBuilder<sup>5</sup>, and GIS functionalities were added using the MapObjects<sup>2</sup> 2.0 ActiveX Component. Before we illustrate some important examples of spatial decision support systems to situate the state-of-the-art of SDSS within the urban planning domain, a framework to categorize DSS is described. This framework is a key element to classify and describe comprehensively the examples mentioned above. The intention is that by using such a framework we can articulate clearly and comprehensively the aspects of decision support systems developed lately to support and inform decision-makers in the urban planning field.

## **2.5 Categorizing DSS: a Framework**

Decision Support Systems vary in many ways: some focus on data, some on models and some on communication. DSS also differ in scope, some DSS are intended for one "primary" user and used "stand-alone" for analysis and others are intended for many users in an organization (Power, 2001). DSS is a complex subject with an evolving body of research.

The absence of a well-defined theoretical body of research in DSS and the proliferation of practical developments in so many different fields of application creates also problems of terminologies and in communicating about DSS when conducting research. The solution we found therefore is to provide a framework that will be used in the remainder of this book to describe the proposed or existing DSS under different dimensions in a comprehensive, useful and parsimonious manner.

For a number of years, Alter's framework (Alter, 1980) has been consolidated by the categorization of DSS into 3 classes:

<sup>1</sup> Borland CBuilder5 is a trademark product of Borland Software Corporation.

<sup>2</sup> MapObjects is a trademark product of Environment Systems Research Institute (ESRI)

- Data-oriented or Data-driven: file drawer systems, data analysis systems and analysis information systems types.
- Model-oriented or Model-driven: accounting and financial models, prediction models and optimisation models types.
- Intelligent or Knowledge-driven: rule-based models type.

Because DSS is becoming more common and more diverse than when Alter conducted his research and proposed his framework, Power (2001) proposed an expanded DSS categorisation framework. His framework focuses on one major dimension with 5 generic types of DSS and 3 secondary dimensions. The primary dimension is the dominant technology component or driver of the decision support system; the secondary dimensions are the target users, the specific purpose of the system and the primary deployment technology. Some DSS are best classified as hybrid systems driven by more than one major DSS component. The generic types of Decision Support System are:

- 1) *Data-Driven DSS*: it emphasizes access to and manipulation of large databases of structured data. Simple file systems accessed by query and retrieval tools provide the most elementary level of functionality. Data warehouse systems that allow the manipulation of data by computerized tools tailored to a specific task and setting or by more general tools and operators provide additional functionality. Online Analytical Processing (OLAP) provides the highest level of functionality. These systems include file drawer and management reporting systems, data warehousing and analysis systems, Business Intelligent Systems, Executive Information System (EIS) and Spatial Decision Support Systems.
- 2) *Model-Driven DSS*: emphasizes access to and manipulation of models. Simple statistical and analytical tools provide the most elementary level of functionality. It uses data and parameters provided by decision makers to aid them in analysing a situation, but they are not usually data intensive. Some OLAP systems that allow complex analysis of data may be classified as hybrid DSS systems providing modelling, data retrieval and data summarization functionality. This category includes systems that use accounting and financial models, representation models, and optimisation models.
- 3) *Knowledge-Driven DSS*: it can suggest or recommend actions to decision-makers. These DSS are person-computer systems with specialized problem-solving expertise. The “expertise” consists of knowledge about a particular domain, understanding of problems within that domain, and “skills” at solving some of these problems. A related



concept is Data Mining, which refers to a class of analytical applications that search for hidden patterns in a database. Data Mining tools can be used to create hybrid DSS that have major data and Knowledge components. Tools used for building Knowledge-Driven DSS are sometimes called Intelligent Decision Support methods.

- 4) *Document-Driven DSS*: also called Knowledge Management System, it is evolving to help decision-makers retrieve and manage unstructured documents and Web pages. A Document-Driven DSS integrates a variety of storage and processing technologies to provide complete document retrieval and analysis. Examples are policies and procedures, product specifications, catalogues, and corporate historical documents, including minutes of meetings, corporate records, and important correspondence. A search engine is a powerful decision-aiding tool associated with a Document-Driven DSS.
- 5) *Communications-Driven and Group DSS*: it includes communication, collaboration and decision support technologies that do not fit within those DSS types identified by Alter. A Group DSS is a hybrid DSS that emphasizes both the use of communications and decision models. It is an interactive computer-based system intended to facilitate the solution of problems by decision-makers working together as a group.”

In what concerns to “target users”, we can call DSS targeted for external users an *Inter-Organizational DSS*. With the rapid growth of the Internet, Companies can make a Data-Driven DSS available to suppliers or a Model-Driven DSS available to costumers to design a product or choose a product. Most DSS are *Intra-Organization DSS* that are designed for use by individuals as “stand-alone DSS” or for use by a group of people.

DSS can be *Functional-Specific DSS* or *General Purpose DSS*. Functional-Specific DSS may be customised in-house using a more general-purpose development package or specially designed to support functional areas or specific decision tasks. On the other hand, General-Purpose DSS software helps support broad tasks like decision analysis or planning.

Finally, the deployment technology may be a mainframe computer, a client/server LAN, a desktop stand-alone or a Web-Based architecture.

## 2.6 Examples of SDSS

In this section, we present, in the context of the framework proposed in the section before, some examples of (spatial) decision support systems proposed to support decision makers engaged with decision problems in the urban planning domain. The intention is to identify the category(ies) of

(S)DSS that has been developed and applied in our field of research in order to position and identify the state-of-art in such a field. This section is divided in two subsections. The first subsection presents a overview of general SDSS proposed for different problems in the urban planning domain and, the second, presents SDSS examples proposed for greenspace-specific problems.

#### *Urban planning domain SDSS*

Before discussing these, it is relevant to mention that another ramification of DSS is gaining strength in the literature: Planning Support Systems (PSS). Although some researchers do not recognize any difference between a Spatial Decision Support System and a Planning Support System, there is a remarkable acknowledgement in the literature that each of these terminologies possesses certain distinguishing characteristics. Geertman and Stillwell (2003), argue that, although PSS have much in common with SDSS, PSS generally must pay attention to long-range problems and strategic issues and may even be designed explicitly to facilitate group interaction and discussion. SDSS, on the other hand, are designed to support short-term policy-making by isolated individuals or business organizations. However, the PSS and SDSS are by no means mutually exclusive and have much in common, reason why we also include examples of PSS in this section.

By far, the majority of DSS and PSS in the urban planning domain have been developed to address land use /suitability or transportation problems. A widely known example of PSS is the “*What if?*” tool, a commercial interactive GIS-based planning support system. As its name suggests, the tool does not attempt to predict future conditions exactly. Instead, it is a policy-oriented planning tool that can be used to determine *what* would happen *if* clearly defined policy choices are made and assumptions concerning the future prove to be correct. Policy choices that can be considered in the model include the staged expansion of public infrastructure and the implementation of alternatives land use plans or zoning ordinances. The system was developed with Microsoft’s Visual Basic and ESRI MapObjects GIS component software. It incorporates many of the design concepts in the first California Urban Features (CFU) model (Landis, 1994; Landis, 1995) and similar models such as the San Diego Association of Governments Sophisticated Allocation Process (SOAP) model (San Diego Association of Governments 1994). The disadvantage of the tool is its lack of a firm theoretical basis. The model does not include measures of spatial interaction, i.e., accessibility to employment, shopping and recreational opportunities which is the key component of most urban models. It does not

model the behaviour of actors either (Klosterman, 1999). *What if?* is a model-driven, functional specific and intra-organization stand-alone DSS.

Arentze (1999) developed a loose coupling SDSS for retail and service planning. The system is meant to be useful for planning in the context of local/regional government (public sector) as well as in the context of retail/service companies (private sector), dedicated to solve single site location and multi-facility location problems.

SPARTACUS<sup>3</sup> (System for Planning and Research in Towns and Cities for Urban Sustainability) has been developed by a consortium of partners from Finland, Spain, the UK and Germany. SPARTACUS is a hybrid data- and model-driven, function-specific (or task specific), intra-organizational stand-alone system dedicated to assess urban sustainability policies. It is based on a land use transport interaction modelling framework, so-called MEPLAN, combined with a set of urban sustainability indicators. System's components are: (i) a GIS-based Raster component to calculate indicator values that must be treated in a spatially disaggregated way; (ii) MEPLAN database and presentation module; and (iii) The USE-IT (Urban Sustainability Evaluation and Interpretation Tool) module, an independent decision support tool allowing the user to define indicators, give weights and value functions for the indicators in order to calculate sustainability indices and to view results in tables or in graphical forms. USE-IT is interfaced with the RASTER and MEPLUS modules.

Arampatzis *et al.* (2004) present a general purpose prototype GIS-based DSS for evaluating urban transportation policies. The objective of this hybrid data-driven and model-driven, intra-organizational and stand-alone tool is to assist transport administrators enhance the efficiency of the transportation supply while improving environmental and energy indicators. The authors use a tightly coupled strategy to embed MapInfo GIS (ESRI) with traffic, emission and energy consumption simulation models. Therefore, MapInfo serves as a central repository for the basic data, as a intermediate storage space for each scenario parameters, as well as for providing the user interface.

*TourPlan* is a function-specific, data-driven, intra-organizational and stand-alone prototype decision support system designed for tourism planning in small island states (SIS). The tool combines GIS inputs for identifying sites suitable for tourism development and Multi Criteria Analysis (MCA) techniques for evaluating sets of choice alternatives. *TourPlan* shares a generic design architecture with two other model-driven DSS, one named *AccessPlan* developed to deal with planning health facility locations and resource allocation, and the other named *EduPlan*, which was developed to support school location planning and to evaluate school performance in

<sup>3</sup> <http://www.vtt.fi/rte/projects/yki4/spartacus.htm>

satisfying operating objectives (Feick and Hall, 1999). The three spatial decision support systems are written in Microsoft Visual Basic and Visual C++ and uses tightly coupled approach to integrate the GIS component. This GIS component combines two elements, named *winR+* and *ZonPlan*. These five tools<sup>4</sup> were developed under the umbrella of a project funded by the International Development Research Centre (IDRC) of Canada as well as other agencies culminating in the release of the tools in 1998.

Lazzari and Salvaneschi (1998) presented a function-specific, knowledge-driven, intra-organisational and client/server LAN spatial decision support system for landslide hazard monitoring in the region of Valtellina (Northern Italy), named EDYNET. Several monitoring sub-systems check hydrogeological and climate aspects of the site (slope stability, geology, rainfall); the sensors are connected to remote data acquisition units, and their signals are transmitted via radio to a central acquisition system. EDYNET supports the data interpretation and analysis by means of artificial intelligence techniques and spatial representation using a GIS component. The application was developed using Visual Basic and Prolog2 programming language, MapInfo GIS (ESRI) and Access (database). Basically, Visual Basic uses Prolog2 as a DLL (Dynamic Link Library), while shares data with MapInfo via OLE (Object Linking and Embedding).

ASSESS (A System for Selecting Suitable Sites) is a spatial decision support system that has been used extensively for multi-criteria decision analysis in a policy environment in Australia (Hill *et al.*, 2004). It is a general purpose, data-driven, intra-organization and stand-alone system written in the Arc Macro Language (AML) within the ArcInfo<sup>5</sup> GIS. Indeed, ASSESS performs a simple multi-criteria analysis on input data layers selected by the user. Rating layers may be added or combined by the user to create an integrated suitability or relative value map. The process does not involve optimisation of any sort.

Although the DSS field has been evolving within computer technology advancements, the few examples above and many others (e.g., TranSims<sup>6</sup>, MEASURE<sup>7</sup>, Xplorah<sup>8</sup>, INDEX<sup>9</sup>) show that DSS is a well-established field of research. These same examples show also how certain fields in the urban planning domain, such as transportation and land use, are in a very mature stage in terms of models and methodologies for assessing and predicting the

<sup>4</sup> <http://www.fes.uwaterloo.ca/Tools/index.htm>

<sup>5</sup> ArcInfo is a trademark product of Environment Systems Research Institute (ESRI)

<sup>6</sup> <http://transims.tsasa.lanl.gov/>

<sup>7</sup> <http://www.epa.gov/ORD/NRMRL/pubs/600r98097/600R98097.pdf>

<sup>8</sup> <http://www.riks.nl/projects/Xplorah>

<sup>9</sup> <http://www.crit.com/index/index.html>

impact of decisions. Very sophisticated models and methodologies have been proposed, implemented, applied, validated and used.

### *The greenspace field*

Although the planning and design of greenspace is one of the domains of urban planning, there is surprisingly few published work articulating greenspace assessment, provision and/or management on an inter-urban basis.

In particular, very little is known about urban greenspace provision and human behaviour. The greenspace field is in a very premature stage where the state-of-art has just started to explore the development, elaboration and application of choice experiments techniques and multinomial logit models explain the influence of the greenspace in people's (quality of) life (e.g., Maat and De Vries, 2002; Kemperman *et al.*, 2004). But still, they are isolated studies or ad hoc experiments, rather than a model or tool explicitly used to support the decision making process. Therefore, monitoring and evaluating urban greenspaces still being controlled by statutory planning and regulation in many countries, rather than by observation and evaluation of individual responses to different planning actions.

One of the few examples of a "DSS" is GARP, an acronym for Greenspace Acquisition and Ranking Program. GARP is a computer-assisted decision strategy (CADS) that can be the basis of an orderly and rational local government program of acquisition land for open land and recreation. The idea is that open space acquisition programs using GARP can lead to an optimal spatial pattern of public open space. GARP evaluates land parcels on the basis of their human recreation potential. Fifteen criteria are used to rank parcels. Numerical values are assigned according to how well the parcels conform to each criterion and the importance of the criterion for active and passive recreational use (Thrall *et al.*, 1988).

Another example is the SDSS developed by Keisler and Sundell (1997) for the planning of national parks. The underlying assumption is that the value of an area depends primarily on what is found within its designated boundaries. The fundamental objectives are conservation and social use of park resources. The authors propose combining multi-attribute utility theory (MAUT) with geographic information (GMAUT) so that desirable, or appropriate, boundaries can be determined on the basis of the goals and objectives of the park. The tool combines two major approaches: suitability indices (e.g., suitability for natural habitat for particular species, recreation, historical value, or other uses) and site evaluation (to describe the attractiveness of the place in terms of a mix of subjective and objective measures). There are two major problems with this tool: methodological and

technical. The problem with the methodology is that it is labour-intensive. Separate subjective input for each evaluation can be costly and time-consuming when many alternatives must be evaluated. In addition, many subjective values may be difficult to measure. A second problem is related to the spatial component. The authors used a loosely coupled approach to integrate the GIS component to the methodology proposed for the management of the Glacier National Park. Consequently, spatial data had to be encoded and was not quantitatively linked with the achievements of fundamental objectives of decision makers and stakeholders. The overall conclusion of such applications was that the overall decision-making process was not very well supported and heartfelt disagreement was mixed up with more objective disagreements about scientific issues. In other words, values were not clear.

Randall and Baetz (2003) used a tightly coupled prototype GIS-based decision support tool for neighbourhood greening. The main objective of neighbourhood greening, under the umbrella of sustainability, was to encourage greenspace management that uses techniques that are well aligned with nature. Suggested neighbourhood greening techniques and approaches included neutralization of existing parks, increased foliage along streets and rights of way, less frequent cutting in grassy fields, introduction of native species, and the cessation of pesticides and herbicides applications. They created an *ArcView* (ESRI) based extension called “*Neighbourhood Greening*” (NG) incorporating concepts of neighbourhood greening features. The NG extension contains individual methodologies to carry out the following tasks: (i) quantify the benefits of alternative landscaping techniques; (ii) generate a street tree planning schedule; (iii) determine the best location(s) for neighbourhood greening features; and (iv) investigate neighbourhood greening features and create a map depicting a potential neighbourhood greening program. The objective of the tool is to provide government agencies, private groups, and individuals with a number of useful options in generating and evaluating plans for neighbourhood greening. Specific reference is made to how perceptions of safety may change with neutralization objectives, the need for such strategies to be evaluated and informed by public participation, and tools used in public consultation process (e.g., visualization tools).

Herzele and Wiedemann (2003) presented an integrated indicator designed for: (i) the monitoring of the urban greenspace provision against quantitative and qualitative targets; (ii) the comparison between cities and city parts; (iii) the assessment of the effects of future policy scenarios; (iv) the indication of location where action is required. The indicator development was guided by five principles: (1) citizen based; (2) functional levels; (3) preconditions for use; (4) variety of qualities; (5) multiple uses.

The parameters were derived from available research on public preferences and use of greenspaces in the Flanders Region (Belgium) for greenspace provision based on accessibility and attractiveness issues. The authors used GIS ArcView 3.2, Spatial Analyst 1.1 (ESRI) and Microsoft Access to measure accessibility for 4 cities in the Flanders Region. Although it considered barriers and crosswalks, distances are calculated using straight-line distances, rather than distances on the road network.

Bunch and Dudycha (2004) presented a loosely coupled prototype GIS-based decision support system for environmental management of the Coom River. The authors use GRASSLANDS (LAS) GIS software package to manage spatial database and a model to simulate hydraulics and water quality of the river named DESERT (Ivanov *et al.*, 1996).

Although significant advances were made in the theory of urban models (fuelled by a number of complementary issues such as the availability of a wide range of new data sources in public and private sector and the increasingly power and portability of computers), the application of such theoretical developments was not widespread over the urban planning domain. Whilst the land use and transportation field are following general trends towards advanced models, methodologies and techniques integrated in a computer environment, the greenspace field is still lagging behind.

The few examples of greenspace applications found in the literature and described above show the very premature stage of the field. Limitations are in every aspect: the spatial dimension of the problem solving process, methodological approach, lack of tools or models, lack of an integrated working environment to support the overall decision-making process. Although the SDSS developed in this project presents some similarities with many of the systems reviewed here, we intend to contribute by supporting every stage of the decision making process, that is the planning, design and maintenance of urban greenspace, by providing tools, models and methodologies coming together in an integrated and structured environment.

## 2.7 Conclusions and discussion

In this chapter, we reviewed the main issues regarding development of SDSS. The review has identified a number of key elements that are paramount to the positioning of this thesis. First, we have argued that the literature on DSS developments is still evolving from empirical research and hence there is no single method for developing DSS. Therefore, we identified a number of frameworks that can facilitate different stages of the development process, i.e. from problem structuring to system design and implementation. Secondly, the review of practical SDSS developments in the

field provided us with a background of what has been proposed in terms of tools, models and methodologies or a combination of them to solve similar problems. Finally, the examples of DSS for the greenspace field identified in the literature have shown that DSS for the greenspace field is still very limited.

The next chapter describes the greenspace field in The Netherlands to identify domain characteristics, problems and issues. With this perspective, we hope to be able to articulate more realistic system requirements, and fundamental elements for developing a successful system's concept and design.





## CHAPTER 3

### 3. THE GREENSPACE PROBLEM

The objective of this chapter is to position the greenspace problem in the context of local governance. The aim is to clarify current practices in the planning and design of greenspace, in order to develop a system that accommodates user (planners and decision makers) requirements. Hence, questions like how is greenspace planning conducted, what are the difficulties (technological and methodological) of the decision making process, what are the policies and guidelines that apply, and so on, must play a great role in the specification of the system.

Eindhoven, a medium-sized city in the Southeast of the Netherlands, is taken as reference in this study to identify issues in current practice. To that end, in the next section, we outline national (Dutch) spatial planning, focusing on the identification of policies, guidelines, responsibilities and main concerns left for the regional/local government for greenspace planning. Against this background, section 3.2 focuses on the current strategies and practices in the City of Eindhoven. This chapter concludes with a description of the main problems and difficulties dealt with by decision makers during the decision making process at the local level.

#### 3.1 The greenspace problem in the Netherlands

The Netherlands is a densely populated country where issues concerning space have to be considered carefully. According to the Ministry of Housing, Spatial Planning and Environmental Management (VROM)<sup>1</sup>, the total surface of the country is 41.546 square kilometres and at present, approximately sixteen million people live in the Netherlands with an average density of about 450 people per square kilometre. Moreover, 14% of its surface is taken up by housing, businesses and infrastructure, whereas some 70% is agricultural land. Nature reserves occupy approximately 13%. The increasing demand for land, houses, offices, factories, roads and railway

<sup>1</sup> <http://www.vrom.nl/international/>

systems make a careful spatial planning and environmental policy necessary. A wide range of actors with various interests operate in recreation, nature conservation, extensive agriculture, livestock farming, horticulture and spatial quality.

The Ministry of Housing, Spatial Planning and Environmental Management (VROM) is responsible for co-ordinating environmental policy at the government level in the Netherlands. Issues regarding spatial planning, environmental management and housing are mutually dependent and where possible preferably mutually supportive. VROM is primarily a policy making body that creates favourable circumstances for others. The “Fifth National Policy Document on Spatial Planning”<sup>2</sup>, entitled “Making Space, Sharing Space” is the policy document containing the national government’s spatial planning policy resolution for the next few decades.

The Fifth Report on Spatial Planning is aimed at solving the issue of space by intensifying and combining the use of space. It approaches the spatial (main) structure using criteria for spatial quality, applied to three spatial policy concepts as the structuring principle: the *contour policy*, *urban networks* and *water*. What is interesting for us here is the contour policy. The contour policy distinguishes the so-called “red” and “green” contours. According to the Fifth Report the active, primarily economically driven, functions of housing, work and infrastructure should be able to develop within the red contours indicated by the municipalities. The restrictive functions of environment, nature and open space/landscape are, as seen from the planning perspective, protected within the green contours indicated by the municipality. The areas in between are balance areas made up of many areas having landscape values. These areas form, at the same time, the missing areas for future extension of the red contours. That means that, besides the distinction between uses that has so strongly shaped the spatial development of the Netherlands, the suitability of places for different combinations of uses is becoming increasingly important.

After the presentation of the Fifth Report on Spatial Planning, the Environmental and Nature Policy Assessment Agencies (a collaboration of the National Institute of Public Health and the Environment (RIVM) and the Agricultural Research Department (DLO)) were asked to test the report against its effects so as to obtain insight into the possible economic, ecological and socio-cultural impacts. In order to predict the effects of the Fifth Report, the present situation is compared to a future planning variant, the so-called trend variant, developed by the Environmental and Nature Policy Assessment Agencies.

One of the important conclusions drawn by the Environmental and Nature Policy Assessment Agencies is the decrease in protection of

<sup>2</sup> [http://www2.vrom.nl/docs/internationaal/vijfdenota\\_engels.pdf](http://www2.vrom.nl/docs/internationaal/vijfdenota_engels.pdf)

landscape values and recreational quality (Egmond, 2001). The Fifth Report goals for stimulating recreational green in and around cities do not offer a powerful stimulus to break the current impasse in land acquisition for green areas. The increasing demand for green, along with the stagnating provision, causes the decline of recreational quality in and around cities.

Another conclusion is that valuable landscape is less protected within the Fifth Report. These areas, like the recreation green areas, are not incorporated in the green contour; therefore, they are not subject to heavy restrictions on building and development of commercial sites and infrastructure. The trend variant analysis shows that new buildings projects would encroach on 20% of the valuable landscape.

On the other hand, nature quality improves. The general areas sought for green contours in the Fifth Report will result on large pieces of adjoining nature areas. Consequently, nature quality can be raised by extending the size of nature areas and by realising larger nature units. For instance, a large nature area increases the quality of habitat of certain animal species as opposed to several fragmented nature areas. Thus, greenspaces for environment protection in the Netherlands are well drawn and protected by national policy.

Nevertheless, greenspace for recreational and landscape purposes are left with a lot of freedom for regional and local planning and decision-making. By means of the Fifth Report, the central government of the Netherlands makes decisions on national issues. Provincial and municipal councils have their own decision-making power on regional and local levels. National policy obviously restricts the powers of local and regional governments. The principle however is to keep decision-making powers as close as possible to the local level, promoting public participation democracy.

On the one hand, leaving the decision-making process to the local level, once again, generates conflicting interests among the several actors in the urban context. Generally speaking, urban developments will be influenced by negotiation, persuasion and incentives among the several actors, such as local government, residents and developers. This is where spatial planning models became important. It is of vital importance for the city not only to understand the interests and preferences of individuals on greenspaces but also to predict their likely response to different greenspace alternative plans. This way of planning and monitoring will make a significant contribution to the field of greenspace, which benefits appear intangible and consequently, sustainable funding often suffers in relation to priorities of other fields within the urban planning domain.

On the other hand, engaging the residents' needs and preferences at a strategic level of greenspace planning and monitoring can be challenging calling for innovative approaches. When very little is known about people

and how they use greenspaces, their benefits in relation to individuals' quality of life remain poorly articulated and therefore, appear intangible.

Within this context, our propose in this research project therefore is to develop a prototype spatial decision support system to assist local authorities and decision makers in recreational urban greenspace planning, design and maintenance.

The viewpoint that we adopt is that urban greening strategies and actions should be carried out based on particularities of the built environment within its local community that constitutes a group of individuals showing behaviour patterns as a response to the environment where they live in.

In the next section, we present an example of how the greenspace field is administrated at the local level in the Netherlands.

## **3.2 The Greenspace field at the local level**

This section investigates issues related to greenspace (with recreational and landscape purposes), at the local level. Because greenspace (for recreational and landscape purposes) has a lot of freedom in the regional and local decision-making process in the Netherlands, very little can be found in the literature about greenspace administration practices on the local level. Hence, we take the City of Eindhoven as an example to investigate the local decision making process concerning greenspace. The intention is to understand the concepts, strategies and/or methodologies used, and the difficulties dealt with, at the local level of greenspace planning in order to capture important technological and methodological issues during the development of the system proposed in this research project. Moreover, this city will be later taken as a case study for the application and demonstration of GRAS.

This section is organised in three subsections. The first section describes the characteristics of greenspaces in Eindhoven, in terms of spatial distribution and patterns, and design strategies. The second subsection describes the strategy to improve greenspace in this city, as a reaction to the Fifth Report on Spatial Planning. Finally, we conclude this section with a discussion of the practice of greenspace planning and the uncertainties involved.

### **3.2.1 Spatial pattern and design of urban greenspace in Eindhoven**

The municipality of Eindhoven is the largest city in the Southern part of the Netherlands. There are slightly over 200,000 inhabitants living in a total area of 8800 ha. The city is divided into 108 neighbourhoods and approximately

40% of the city is green, considering public and private space. The area of public parks sums to an amount of 19%, which means that parks occupy approximately 1636 ha of the city's area (see Figure 3-1).

The provision of urban greenspace in Eindhoven is based on the concept of a park hierarchy, introduced in 1978 as a local policy instrument called "Structure plan"<sup>3</sup>. Although such policy instruments were heavily criticized in the 1980's, at present there is a revival, being an important tool for both municipal and provincial planning. In short, the structure plan for greenspaces consists of:

- "buurtpark" – local parks: small parks (size  $\leq 4,25$ ha, with playground). Every citizen should be able to reach this type of park travelling a maximum of 400 m.
- "wijkpark" – neighbourhood's parks (size  $> 4,25$  and size  $\leq 14$ ha). Every citizen should be able to reach this type of park travelling a maximum of 800 m.
- "stadsdeelparken" - district parks (size  $> 14$ ha and size  $\leq 135$ ha): parks for a great part of the city often with sport facilities. Every citizen should be able to reach this type of park travelling a maximum of 1600 m.
- "stadsparken"- city parks (size  $> 135$ ha): parks for the whole city, often a landscape with all sorts of recreational facilities. Every citizen should be able to reach this type of park travelling a maximum of 3200 m.

Figure 3-1 illustrates the distribution of park typology across the city and Table 3-1 gives complementary information. Eindhoven has a number of isolated (patchwork pattern) parks (local and neighbourhood) that function for its immediate neighbourhood. The Dommel River (arrow in the map of Figure 3-1) and one of its tributaries, the Tongelreep River, intersect the city providing a green environment (ribbon pattern), which widens towards the city's edge into larger park areas (wedge pattern).

On the outskirts of Eindhoven, we find green areas that surround the city (belt pattern), being basically forest and moorlands. Therefore, a transition from esthetical to nature green implies a shift from the city centre to the more peripheral areas of the city.

Regarding greening diversity, four types of greenspace are distinguished by the municipality:

1. Aesthetical green, especially in the city centre and in shopping centres;

<sup>3</sup> <http://www.map21ltd.com/COSTC11/nl-planning.htm>

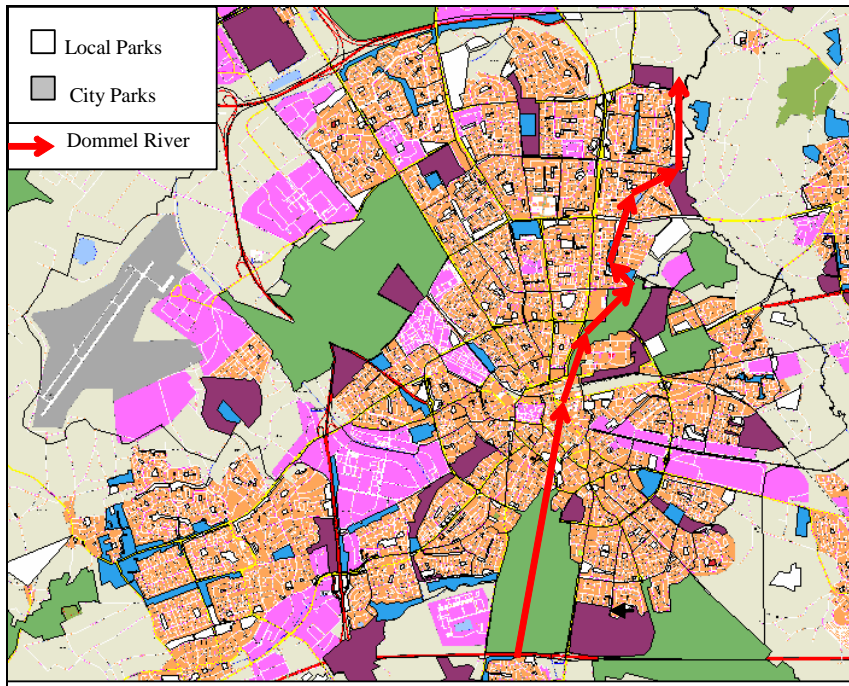


Figure 3-1. Spatial distribution of greenspaces in Eindhoven

2. Standard culture green, defined as non-authentic green that is intensively maintained;
3. Landscape green, defined as authentic green that is extensively maintained;
4. Nature green.

Table 3-2 reports the kinds and quantities of vegetation, found in the public space in Eindhoven (in the parks and streets).

Table 3-1. Total area of greenspaces sorted by type in Eindhoven City

Hierarchy	Unit	Area
City Parks	hectare	1291.46
District Parks	hectare	136.11
Neighbourhood Parks	hectare	109.78
Local Parks	hectare	98.64
Total	hectare	1635.99

Having given a description of the concept of greenspace in Eindhoven, in the next section we describe strategies and practices currently used in greenspace planning. In summary, these strategies can best be understood as a reaction to the focus on the concept of the compact city (high density urban development), as described in the section above.

### 3.2.2 Current greenspace strategies in Eindhoven

In line with the national policy document “Making Space, Sharing Space”, the City of Eindhoven has published their strategic visions about greenspace in the city, which is defined as a set of spaces and elements with an ecological, water management, recreational, aesthetical and/or spatially structuring meaning.

This vision highlights the desired developments of these spaces and elements in view of a sustainable, high-quality green spatial structure and the functions it supports.

The vision (Visie Groenbeleidsplan, October, 2000) is based on an analysis of the strengths and weaknesses of greenspace in the city. A strength of the city is a clear structure with elongated greenspaces (along the river Dommel that cross the city), zones separating the city from other towns and villages, and green arteries. Other strengths include the heritage value of some elements and the richness in types of trees. Threats relate to a tendency of decreasing variety in greenspace and a general decline in quality. Moreover, the supply of various types of recreational facilities leaves much to be desired.

The vision mentioned several spatial strategies to improve greenspace in the city:

Table 3-2. Greenspace diversity in Eindhoven (2001)

GREEN DIVERSITY	UNIT	QUANTITY
Flowerbeds	Ha	1
Roses	Ha	4
Hedges	Km	5
Grass	Ha	256
Rough grass	Ha	109
Bush	Ha	214
Wood	Ha	42
Water	Ha	23
Trees	N	8000



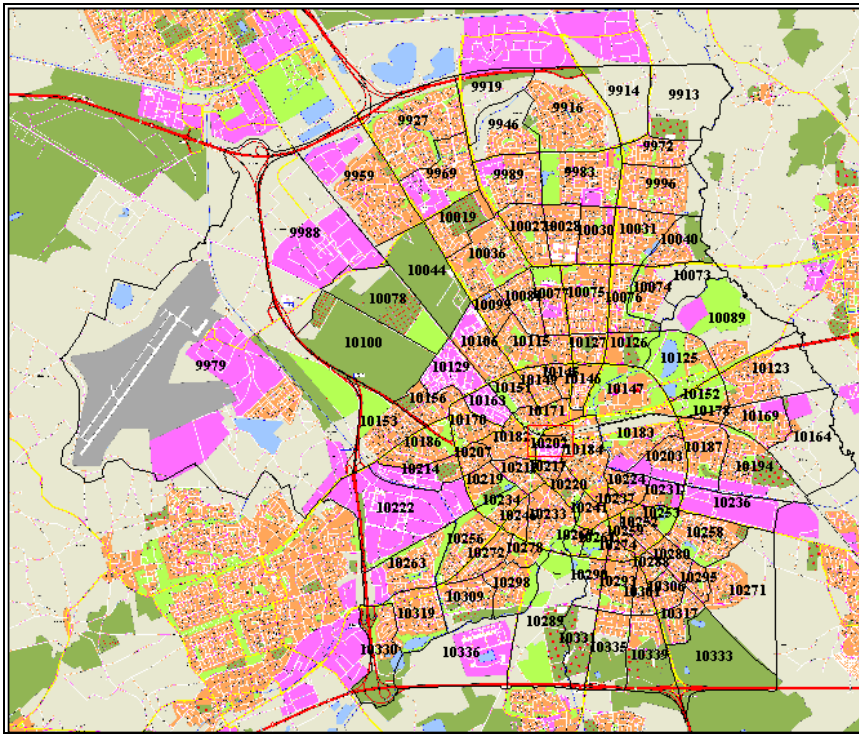


Figure 3-2. Neighbourhood Division in Eindhoven

1. Strategy 1: City-“red” dominates image. In this situation, greenspace only supports the primary work or residential function of the area. Green is important as a recreational function (neighbourhood park) or for water management. Examples are the city centre (Figure 3-1: neighbourhoods around 10202), Vaartbroek (Figure 3-1: 9996), de Hurk (Figure 3-1:10222).
2. Strategy 2: City-green dominates. These are major green areas in the city’s edges. Examples include Schutterbosch (10317), omgeving Parklaan (10152, 10178, 10331) Philips High Tech Campus (10336) and the airport area (northern of 9979).
3. Strategy 3: Integral development green-red. Residential functions and work will be developed in a more integral fashion with greenspaces. Examples are Bokt-Noord (9914) and area 9988.
4. Strategy 4: Multifunctional green. These areas include sport and recreational areas, relatively small nature areas, garden, etc. They

can be typically found at the edge of town. Examples are the Geneper Park (10289), and neighbourhoods 10335, 10339, 10044 and 10153.

5. Strategy 6: Nature. These areas are primarily meant for ecological purposes. An example is the Strabrechtse Heide (10333) and the De Wielewaal (10100).

Within the vision, there is also a plan to connect neighbourhoods, park areas and surrounding countryside through narrow but attractive green corridors (network pattern) to better articulate and improve the green structure. These design strategies include:

1. Strengthening of urban areas using green elements;
2. Maintaining or strengthening existing greening in the city;
3. Strengthening of the own identity of the green structure;
4. Articulating identity by natural elements;
5. Preserving cultural-historical values.

### **3.2.3 Discussion and Comments**

The local greenspace field in the Netherlands seems to be in a transitory stage. With the decentralisation of the decision making process and enlightened of norms and rules in the greenspace field, local authorities still are hesitating in using innovative approaches to deal with the greenspace planning, design and maintenance and bonding to retroactive norms and rules. This can be noticed with the revival of greenspace policies (the Structure Plan) that were criticized in the 1980's, and are currently applied in local and regional level to guide greenspace planning.

Although effort is being made in the direction of developing new strategies for the administration and development of greenspaces with a recreational purpose, such strategies are vague and lack a devised plan of actions.

As an effort to set priority actions, given the community needs and economic resources, greenspace authorities use information extracted from an annual survey questionnaire applied by the local government to assess the level of quality of life in the city. This survey addresses all kind of questions related to the level of satisfaction of individuals on the urban environment related to health care, housing, work, greenspaces, etc. Hence, only very general information on the level of satisfaction of individuals on urban greenspaces is available. Very little is known, however, about greenspace recreational needs, i.e. the extent to which existing greenspaces meet individuals needs; the relative importance of green space attributes and the

combination of green space types that maximize public welfare, including the economic benefits. This lack of information generates questions such as: (i) what is the group of individuals benefiting from each particular plan strategy? (ii) how much benefit will such a plan actually return to the community or a group of individuals? Could that be maximized? In other words, to diminish the uncertainties of the greenspace decision-making process information on the relative importance of greenspace attributes and the combination of greenspace types that maximize public welfare, including the economic benefits are required.

On the technological level, tools used to support decision makers are restricted to printed maps of the urban system (in different scales) in transparent sheets used for visual suitability analysis techniques. Information of major greenspaces attributes is stored in Excel tables. Information regarding costs (maintenance and provision) is maintained and controlled in another department. It is interesting to note that, although planning, design and maintenance of greenspaces are dependent on each other and part of the same decision making process, maintenance issues are treated in a separate stage of the process, i.e. after planning and design decisions have already been made. Hence, the maintenance sector will approve or reject plans based on budgets. This makes the process much more difficult and more time consuming, once interactions are restricted.

In summary, the greenspace decision making process in Eindhoven is carried out based on a set of strategic plans, bounded by economic resources and operationally guided by retroactive norms and rules when too many uncertainties emerge. The practical and operational process is carried out by simple visual suitability analysis using the transparent map technique and basic information on the level of satisfaction of neighbourhoods regarding greenspaces. In the end, the lack of information and technological support leaves too much space to decisions based on the argumentative power and decision-makers cognitive knowledge and intuition, rather than based on an analytical problem solving process to maximise public welfare.

### **3.3 Conclusion and discussion**

Decisions regarding recreational greenspace provision, design and maintenance in the Netherlands are made by the local competent authorities based on their own experiences and knowledge of the field, often without any (or obsolete) methodological or technical support. Unfortunately, very little is known about greenspace provision and individuals' needs and preferences.

Aiming at bringing the public interests into the greenspace decision making process, the national government moved to the local level the power and freedom of greenspace decision-making. Bringing public participation into the decision-making process requires innovative approaches to engage public interest towards clarification of greenspace values and benefits. Nevertheless, the greenspace decision-making process is still grounded on retroactive norms and decisions are made at the level of subjectivity and communication skills, bounded by resource availability. Methodologies, models and tools to predict the impact and/or benefits of different plans are hardly used.

Uncertainties are mostly related to the lack of information on greenspace use and values. As a consequence, formulation of plans, clarification of priorities and optimisation of resources are surrounded by uncertainties. In other words, the lack of information about population segments, their location and their needs and values with respect to greenspace makes the problem very complex when specifying action plans and priorities that aim at maximising public welfare. In addition, the lack of information of the relationship between users and greenspace functionalities creates a spectrum of uncertainties to decision makers when optimising the resources allocation among greenspaces in the city. As a consequence, the efficacy and effectiveness of greenspace provision may or may not be optimal.

Our challenge in this project is twofold: (i) provide information to decision makers to clarify issues regarding individual needs and preferences, and greenspace functional values; (ii) provide an integrated framework with a set of tools, models, and methodologies that, systematically operating on (i) produce new information needed to assess and evaluate the benefits of alternative plans and actions.

Decision support tools may be helpful in this regard, because (among other benefits) it provides an integrated framework with: (i) a database component to store, manipulate, and retrieve large data sets; (ii) a model component holding tools and models that operate in the database component; and (iii) the decision making process can be structured in a systematic way such that different plans and actions can be investigated and compared using the same principles.

Based on arguments above and on trends in the urban planning domain, we develop a prototype SDSS for the planning, design and maintenance of recreational urban greenspace, described in the next chapter.



## CHAPTER 4

### 4. THE GREENSPACE ASSESSMENT SYSTEM (GRAS)

This chapter reports in detail the overall design of the SDSS proposed in this research project, the so-called GRAS (GreenSpace Assessment System). Technically, GRAS can be characterized as a functional-specific, hybrid model-driven and data-driven, intra-organisation, and stand-alone desktop application. GRAS is a functional-specific tool because it is a framework especially designed to support to the planning, design and maintenance of recreational urban greenspace. It is model-driven because the system has a *Model Component* consisting of a set of spatial and spatio-temporal models that use parameters controlled and adjusted by the decision makers via the user interface to assist them in analysing a situation. It is also data-driven because these models access and manipulate large databases of structured spatial and non-spatial data. The spatial component overcomes a historical approach in the urban planning field where most models have dealt with the spatial data aspatially.

Conceptually, GRAS is a GIS-scenario-based micro-simulation multi-criteria decision support system, which operates at the individual level. In principle, models operate on a “100% sample” (i.e., the entire population) of individuals, which are synthesized from census data. A range from static to dynamic modelling methods is employed within the system to represent spatial and spatio-temporal behaviours of individuals related to greenspace. The idea is that by understanding the behavioural response of individuals to the actions of government, decision-makers and planners can provide the right greenspace portfolio within the built environment.

The following issues will be discussed. In Section 4.1, system requirements are explicitly articulated. Motivated by the requirements specification, a conceptual SDSS for the planning, design and maintenance of greenspaces is developed in Section 4.2. A conceptual model to structure the decision making process in the system is also proposed, followed by a description of the conceptual framework of the models proposed to evaluate greenspace problems (and derive greenspace performance indicators). Section 4.3 develops the system architecture and design. Following the old “black box” approach, the system’s components and relationships are

explored, i.e., starting with the view of the system as a black box, we successively “open” the boxes to describe the database system, the model-based system, the dialog management system, and their interconnections. Section 4.4 ends the chapter with some conclusions and discussions.

## **4.1 System Requirements Specification**

Potential users of the proposed Spatial Decision Support System for the planning, design and maintenance of recreational urban greenspace are local authorities engaged in these activities. In order to have a good understanding of the system performance requirements, greenspace decision makers and authorities were engaged in this phase of the project. System’s requirements were therefore delineated after several meetings arranged with local authorities. The intention was to bring inputs from practitioners into the system’s development process in order to diminish the gap between fundamental and applied research.

The need for a Spatial Decision Support System for the planning, design and maintenance of greenspace, with recreational and landscape purposes, was recognized in the context of local/regional level of governance. Several factors were identified, in different stages of the decision making process, that create a need for decision support.

In the problem diagnosis stage, the identification and analysis of problems is often difficult and surrounded by uncertainties. Analysis aimed at explaining observed system performance, i.e. how the existing greenspace portfolio is attending the needs/preferences of the community (or group of individuals) or accomplishing policies are not fully articulated, due to the lack of information about the causal relationship between the physical and behavioural system. Very little is known about:

- How different greenspace types (given by the size and attributes/design) are used and by whom;
- What are the needs/preferences of individuals for different greenspace types, given individuals’ socio-demographic characteristics, the spatial context, and the temporal conditions such as the season, day of the week and time of the day; and,
- Individuals’ green activities behaviour within spatial and spatio-temporal contexts.

In this sense, greenspace performance indicators such as accessibility, utility, social welfare, etc., are not properly (if not at all) investigated, creating several categories of uncertainties that complicate the decision

making in this stage. The outcome of this stage is a decision whether to develop intervention strategies.

Having identified a problem, decision makers may formulate a limited and potential set of alternative strategies to solve the problem, which characterises the next stage of the decision making process. Action alternatives, such as developing a new greenspace, reducing the size or completely removing greenspaces, changing the greenspaces design (by adding or removing facilities or attributes), may involve elements related to the physical planning and/or design and will have impact on maintenance costs. In many cases, a strategy requires a coherent set of actions to achieve a balanced configuration in the greenspace portfolio. For example, the reduction of a greenspace may require redesign of such a greenspace or, perhaps require the expansion of another “substitute” greenspace. In current practice, the generation of alternatives involve creative thinking of planners in combination with subjective judgements. Transparent map overlays are used to stimulate planners creativity thinking. By means of maps, greenspace authorities visualize the spatial elements of the problem, such as greenspace amenities, land use and transportation system, and the possible interaction between these spatial elements in the built environment. Spatial ingredients are then intuitively combined with the authorities’ knowledge of the study area during the decision making process. The uncertainty source of this stage is related to the lack of a computational procedure to combine GIS and spatial domain models and articulate the information-compilation process needed for the development of potential alternatives. As well, a tool, such as a scenario development toolkit, would support and stimulate decision-makers/planners in strategic thinking and option search, and representation of alternative future greenspace developments. The representation of the alternatives is especially relevant to the next stage of the decision making process, i.e. the analysis phase.

The analysis phase involves the assessment of feasibility and likely impacts of alternatives. Feasibility assessment involves a viability analysis of the alternatives. Viability analysis of greenspace developments is surrounded by uncertainties, given the nature of the investment. Greenspaces normally occupy large pieces of land, involve high maintenance costs and do not bring any direct monetary benefit. The benefits of greenspace are indirect and yet, still intangible. Hence, there is a need to develop models and methodologies to assess the benefits of greenspaces and predict their impact on the physical and behavioural system. In current practice, feasibility assessment is restricted by the available budget. The assessments of the impact of alternatives are restricted to simple calculations of the average amount of greenspace per inhabitants and/or the geographical area affected (in terms of the number of inhabitants), using a general rule to determine the catchments area by greenspace type. Maintenance issues are analysed by an independent sector of the greenspace field, which causes an



interruption in the decision making process because alternative plans need viability approval of the maintenance sector.

Finally, the choice of an alternative is based on ranking the alternatives in light of different criteria and objectives. Because decision problems may involve multiple and conflicting objectives, criteria may involve different scales and dimensions, and have different weights, a multicriteria evaluation technique is required.

In summary, there are four main issues being voiced in the Greenspace field. The first one is related to the lack of information on the social values attached to greenspace. Little is known about the demands, needs and preferences of greenspaces users, and especially, potential users. Not much is understood about greenspace infrastructure, human behaviour and activity patterns as a means to maximize the value functions of greenspaces.

The second is related to the lack of a conceptual framework for the identification and calculation of performance indicators for use in a variety of situations in greenspace planning, design and maintenance. Much of this involves data modelling and analysis to understand the spatial distribution or variations of greenspaces in the urban environment and the impact on individual behaviours.

The third issue is related to technological requirements. A Geographic Information System is an essential technological requirement to be integrated with domain models and embedded in a scenario-development toolkit. Although, technological disparity in the public sector of developed countries was recognized as an issue during the 80's and 90's, it seems that the problem persists. Despite the poorness of the techniques used to combine the spatial and non-spatial dimension of the problem, it is paramount to greenspace authorities to have both sources of information coming together in an integrated framework.

Finally, the fourth issue is related to the complexity of the problem and the lack of a systematic (and integrated) process for decision making, where decision makers have to rely on their own methodology and experience. Hence, there is potential for improvement in the methodology used when a framework that integrates and structures models, tools and database needed in every stage of the decision making process is provided. However, such a framework needs also to be flexible and interactive so that decision makers with different cognitive styles can comfortably work under a common framework.

The discussion above suggests that a SDSS could decrease uncertainty in every stage of the decision making process, by:

- Integrating a range of models to address social issues related to greenspace focusing on the causal relationship between the physical and behavioural system;

- Derive a range of performance indicators to assess quantitatively the benefits of greenspace;
- Providing a GIS-based tool for scenario development and spatial analysis, to stimulate the decision makers creativity, strategic thinking and option search, and articulate the information-compilation process needed for the development of potential alternatives;
- Providing a Multicriteria Evaluation tool to assist decision makers during the evaluation of alternatives in light of multiple and possibly conflicting criteria.
- Integrating tools, models and data in a structured, flexible and interactive problem solving environment.

Motivated by the requirements specified above, we propose a SDSS for the planning, design and maintenance of greenspaces, which concept is described in the next section.

## **4.2 Conceptual System**

The objective of this section is to present an overview of how the system works as far as the user is concerned. To this effect, we first briefly present an overview of GRAS and its key concepts. Next, following a process-oriented view of the system conceptualisation, we present the structure given to the decision making process. Besides user guidance to solve complex spatial decision problems, structuring the decision making process is also important to a successful and proper implementation of the system concept. Hence, by breaking down the decision making process into phases we systematically place tools, models and methodologies as strategic requirements for a proper system design and implementation. Finally, in the third subsection, the conceptual framework of the models proposed to evaluate greenspace problems (and derive greenspace performance indicators) is described.

### **4.2.1 Overview of GRAS**

This subsection describes in main lines the key concepts and functional characteristics of GRAS (Greenspace Assessment System), a spatial decision support system for the planning, design and maintenance of greenspaces. The system presented here is a windows application, developed in Borland C++ Builder 5 programming environment in combination with an Active X Control (MapObjects 2.0) to embed GIS capabilities into the system. Potential users are decision makers/planners of the greenspace field.

From the most macro perspective, GRAS can be thought of as a GIS-based system. The GIS-based user interface of GRAS is very important because it provides the system with a visual and interactive map-based user interface, where the user can quickly retrieve information of several elements (or subsystems) of the urban environment, by simply clicking on the target object of a map. Because diagnosis/decisions are mostly based on the judgement of information, this capability is of great importance to the decision maker in every stage of the decision making process. In addition, the GIS-based user interface will allow the user to easily compose greenspace alternative scenarios as a means to predict the impact of future changes in the urban environment on human behaviours by using appropriate models and/or performance indicators. The full integration approach used to embed GIS capabilities into the models integrated in GRAS to calculate greenspace performance indicators, overcomes the historical problem of spatial data manipulation. Spatial data inputted into models no longer requires user intervention for data transformations between different data sources and data formats.

GRAS is also a scenario-based spatial decision support system. Modelling and planning in situations where complex spatial problems are ill- or semi-structured, and decision makers cannot define their problems exactly, for example, because they cannot fully articulate their objectives is a hard task in the urban planning domain. In this capacity, a scenario set (meaning greenspace development scenarios) is an essential instrument of GRAS. In line with Xiang and Clarke (2003), greenspace-development scenarios are the product of an information-compilation process. They are *synthesized* images of what some, but not all, future greenspace patterns will look like. By selectively depicting hypothetical development contingencies associated with particular combinations of goals and their priorities, greenspace-development scenarios provide the basis for explicit considerations of different assumptions concerning greenspace-development futures, and act as a stimulus for critical thinking about greenspace planning, design and maintenance strategies. This qualitative character makes greenspace-development scenarios an attractive rhetorical guide in a planning, design and/or maintenance process, both for organizational learning and in searching for attractive options. Greenspace scenarios are then evaluated and confronted in order to minimise the discrepancy between the present state and a desired state.

On the level of conceptual models for prediction, analysis and evaluation, GRAS can be viewed as a micro-simulation spatial decision support system. The conceptual framework adopted to develop the models and performance indicators for greenspace evaluation, described later in this section, suggests that every individual is simulated within the system and individuals' spatial

and/or spatio-temporal choice behaviour is predicted in order to estimate the impact of different possible plans/actions on people's behaviour. Therefore, the concept proposed requires first that a synthetic population of the study area is created, with demographics closely matching those of the real population. These socio-demographics are then the basis for individual and household green activities (type and location). The concept of a Synthetic Population is discussed later in Chapter 5 (section 5.2).

The move from macro (aggregated group of individuals by neighbourhood, for instance) to micro (individual level) suggests a fundamentally new organization of spatial choice models based on a microscopic view of the built environment. This implies that spatial models need to get their spatial dimension from a much higher spatial resolution. To that effect, urban subsystems such as the road network, land use, greenspace facilities, population, and workplaces are disaggregated and integrated into a fine representation of the urban environment, given by a grid system (1 hectare). Spatial models utilise GIS technology to structure, manipulate, process and store spatial data under a common framework.

Disaggregated spatial choice models integrated with a high spatial resolution of urban representation likely imply a more realistic prediction of how the use of the urban system is likely to change under different planning actions potentially made. In principle, it allows one to identify the right greenspace portfolio that is greenspace location, size, attributes and facilities, and/or relationships between these elements that are evaluated best by the local population (or a subgroup of the population).

Performance indicators, such as accessibility (based on different concepts), awareness, maximum utility, preferences and probabilities of visits, will allow the user to systematically compare alternative plans scenarios. Likewise, multicriteria evaluation techniques will guide users through conflicting decision situations and choose among alternative scenarios. In this sense, GRAS is also a Multicriteria Spatial Decision System.

The system's potential is enhanced by spatial querying capabilities. Problems can be formulated at different levels (from regional to local, district and/or neighbourhood level) by querying spatial data from the region or zone of interest. A thematic mapping tool supports the visualization of the spatial distribution of one or more specific data themes for standard geographic areas. The map may be qualitative in nature (e.g., predominant greenspace types) or quantitative (e.g., output from data models).

The uniqueness of this SDSS lies in combining GIS technology and urban planning models for a specific decision problem, and the multicriteria evaluation technique using disaggregated data from different data sources of relevant urban subsystems. The GIS component allows communication and

intermediate storage between the various sub-models. The models can communicate with the spatial database and thus, modelling routines can automatically extract the relevant spatial/non-spatial data, without user intervention. The user only intervenes in the system to control the decision process and not to conduct the basic operations needed for modelling.

It is important to make clear that the scope of our research project and its contribution to the state-of-art in the greenspace planning and monitoring field is to bring a number of domain models together to provide and facilitate a recursive and interactive decision-making process. Our focus is not, however, on improving technological perspectives in the SDSS field, although we do use state-of-the-art technologies.

#### **4.2.2 Structuring the decision making process**

The objective of this subsection is to derive a conceptual model for structuring the decision making process. A process-oriented view of the conceptual system is very important to successfully implement a system that supports the user during every stage of the decision making process.

There are several models of how decisions are made (e.g., Simon, 1960; Mintzberg *et al.*, 1976), and there is no universally accepted model of the decision making process. The too many variables, too many different types of decisions and too much variety in the characteristics of decision makers requires a DSS that provides the decision maker with a set of capabilities that can be applied in a sequence and a form that fits each individual cognitive style (Sprague, 1980). Common opinion is that DSS must support all phases of the decision making process.

Keeping this in mind, we identify the phases of the greenspace decision problem in line with the ones covered by Mintzberg *et al.* (1976) in their framework proposed to structure the decision making process.

A particularity of Mintzberg's framework that suits well the greenspace decision problem is the breaking down of the phases to smaller routines and sub-routines in order to respond more effectively to the dynamic factors influencing the decision making process. Dynamic factors influence the decision process (especially at the strategic level) in a number of ways. They delay it, they stop it, restart it. They cause it to speed up, to branch to a new phase, to cycle within one or between two phases, and to recycle back to an earlier point in the process. Therefore, more important than structuring a main sequence of actions for the problem solving process, a framework must be flexible enough to support a dynamic course of decision actions, operating in a system where it is subjected to inferences, feedback loops, dead ends, and other factors. Hence, such a framework will have a positive effect on the users' perspective, because it allows users (planner/ decision-

makers) with different (cognitive) styles to comfortably work under a common framework.

Figure 4-1 shows the intrinsic structure given to the problem solving process supported in GRAS. The *identification* phase of the decision making process comprises two routines: decision recognition and diagnosis. The *recognition* of the need for a decision is identified by the difference between some actual situation and some expected standard. The sooner it is recognized that decisions must be made, the *diagnosis* routine may (or may not) be evoked in order to help decision makers to comprehend cause-effect relationships for the decision situation. From the *recognition* routine to the *analysis* routine there is a link (relationship) in order to support the decision maker seeking information to better comprehend the actual scenario and therefore avoid uncertainties.

The heart of the decision making process is the set of actions that leads to the development of one or more alternative solutions, that is, the *development* phase. The development phase may be described in terms of two basic routines: the design routine and the search routine.

The “*design*” routine consists of the development of a custom-made solution, i.e., the user, having identified problems and/or opportunities, modifies the scenario (urban design) in order to achieve the goals/objectives. This is a complex, interactive procedure that may begin with a vague idea of some ideal solution. Hence, the users factor their decision into a sequence of nested design and search cycles, essentially working their way through it. To support the users during this procedure a “Scenario Management Model” is provided.

The *search* routine, on the other hand, consists of the inclusion of an existing alternative choice (alternative scenario) designed before and kept.

The *selection* phase is concerned with choosing the best solution and it is comprised of three routines: *screen*, *analysis* and *choice evaluation*. The *screen* routine is evoked when the search routine brings ready-made alternatives that need improvement. This seems to be an appropriate shortcut in the decision making process for time-constrained decision-makers. The Scenario Management Module thus will support the users to manipulate changes in the scenario as well.

By far, the largest number of models and tools implemented in GRAS is concerned with the *analysis* routine. In this, we follow a more pragmatic point of view of greenspace provision and maintenance, where decisions should be made on the basis of a more objective evaluation.

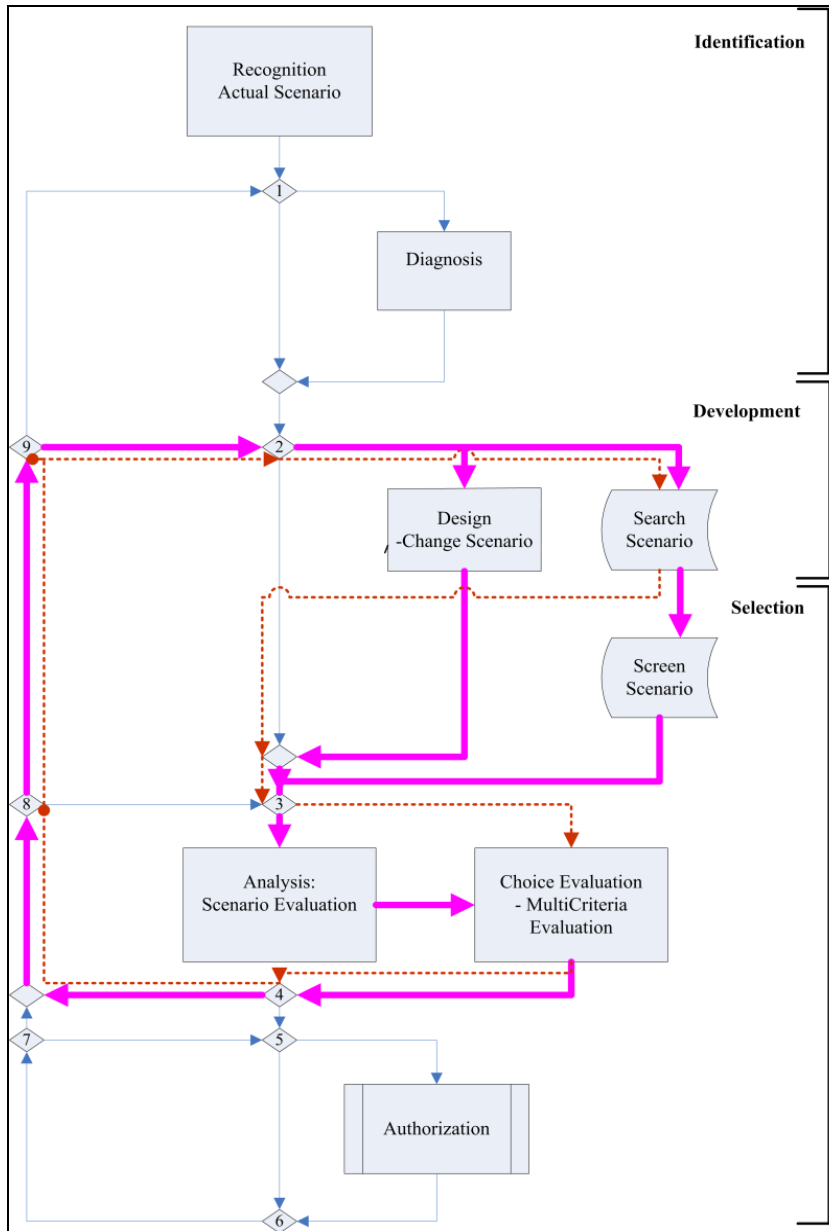


Figure 4-1. Decision making process within GRAS (Adapted from Mintzberg *et al.*, 1976)

The system has a set of models and tools, which use the conceptual framework described in the next section to support scenarios evaluation and assessment.

Finally, the *choice evaluation* routine is supported with the Multicriteria Evaluation Model to investigate a number of alternative scenarios in light of often conflicting, multiple criteria and a set of priorities. A multistage, interactive process, involving progressively investigating alternatives, gathers the *development* and *selection* phases. Although several multistage patterns may appear within this framework as a function of user cognitive style, two typical patterns may occur in the greenspace problem solving process, as illustrated in Figure 4-1 with the dark solid and dark dashed lines, respectively. First, design or search routines are applied to the creation of alternative solutions. Then, the process evolves to the *selection* phase, first evoking the *analysis* routine for the assessment of the alternative scenarios and then evoking the *choice evaluation* to compare the choice alternatives in light of selected weighted criteria. This course of action is a cyclic process that comes to an end when the decision maker is satisfied with a certain solution. Note that custom-made solutions can be kept in the system archive to be used/screened as ready-made solutions on another occasion. A second typical pattern consists of creating a single choice alternative that is engaged in a sequence of nested (cyclic) routines given by: screening-analysis-choice evaluation-screening.

The *authorization* routine appears to be a typically binary process, acceptance or rejection of a solution (or alternative scenario). Acceptance leads to the implementation of the changes in the urban design and rejection leads to its abandonment or redevelopment. If an alternative scenario is accepted, the changes in the urban design must be updated in the GRAS main database. In order to keep the system database up to date, the scenario management module comprises a functionality to automatically update the system database, as soon the user approves a solution.

### **4.2.3 Spatial behaviour: A conceptual framework**

The main goal of the models provided is to support decision makers with a better understanding of the use of urban greenspace. The idea is that by clarifying the relationship between greenspace provision and use, the right portfolio of urban parks can be arranged and monitored, given population needs/preferences. Traditionally, research on spatial behaviour in many different domains of application was related to the intensity of use and the impact of socio-economic and spatial attributes on spatial awareness, preference and choice. While such an approach seems adequate in a variety of application contexts, characteristic of greenspaces is their variety,



implying that the choice of greenspace is likely much more context-dependent and time-sensitive. Hence, as a guiding principle for the empirical analyses, we developed a more elaborated conceptual framework of context-dependent and time-sensitive choice behaviour. The reader will note that certain parts of this framework have been implemented directly, that other models are in line with this framework and that still other components can be further elaborated in future work.

Spatial behaviour in general can be viewed as a choice between various alternatives, such as greenspaces, located at different point in space. Because not all alternatives are located at the same points in space, travel is required. Hence, when choosing between different alternatives, individuals need to trade-off the characteristics of the choice alternatives against the accessibility or distance or travel time to reach these destinations. In reality, the decision-making process is more complicated in the sense that individuals are not necessarily familiar with all destinations, and may also not have perfect information about the characteristics or attributes of the choice alternatives. Hence, decisions are made conditional upon individuals choice sets and awareness space. Thus, we assume that, dependent on the choice problem, individuals perceive their environment in a particular way, resulting in a mental map (awareness) that does not necessarily include all the choice options in their direct environment and that may also include some distortion of the actual attributes of the choice alternatives.

Further, we assume that the decision-making or choice process is based on an individual's explicit or implicit perception as opposed to the actual characteristics of the choice alternatives. Based on their perceptions, individuals are assumed to trade-off the positive and negative attributes of the choice alternatives and distance/travel time and arrive at some ultimate choice by integrating their evaluations of these attributes according to some combination rule. That is, individuals are assumed to derive some utility from their visits to greenspaces by combining according to some function their part-worth utilities of the attributes of the various choice alternatives (greenspaces). Operational decisions and theoretical considerations are required to choose the combination rule that best describes the assumed integration process. In most research, a linear function is assumed. It describes a compensatory decision making process in the sense that a low evaluation of a particular attribute can at least partially be compensated by a higher evaluation of one or more of the remaining attributes. In contrast, a multiplicative function would be indicative of a non-compensatory decision process in the sense that a zero evaluation of some attribute cannot be compensated at all (the corresponding alternative would never be chosen), regardless of the evaluation of all other attributes of that choice alternative. Intermediate processes can be captured by, for example, interaction effects.

Once an individual has build up a utility for a choice alternative, a choice can be made. This involves applying some choice rule to the utility function. The commonly used choice or decision rule states that the alternative with the highest utility in this choice set will be chosen. This rule assumes that choice is deterministic. In reality, however, for various reasons, choice is likely probabilistic, implying that the probability of choice is some function of the utility of the various alternatives included in an individual's choice set. Again, several alternative rules can be formulated, but in research on spatial choice behaviour, the multinomial logit model has received most attention. It assumes that utility consists of a systematic component, which is a function of the attributes of the choice alternatives and an error component. If the error components of the choice alternatives are independently and identically Weibull distributed, the following model can be derived:

$$p_j = \frac{\exp(\sum_k \beta_k X_{jk})}{\sum_{j'} \exp(\sum_k \beta_k X_{j'k})} \quad (4.1)$$

where,

$p_j$  is the probability of choosing alternative  $j$ ;

$\beta_k$  is the part-worth utility of attribute  $k$ ;

$X_{jk}$  denotes whether alternative  $j$  has attribute  $k$ .

The conceptual framework discussed thus far has proven to be useful in many studies of spatial choice behaviour (for an overview see for example Timmermans and Golledge, 1992). Again, the key notion of this conceptual framework is that individuals derive some utility from choice alternatives. In most domains, this utility function is assumed time-invariant. That is, either it is explicitly or implicitly assumed that the utility that individuals derive from a choice alternative is the same, regardless of time. It should be noted that the utility function of course has a random component, but this typically is assumed to depict any inconsistency in behaviour or the effect of any attributes not included in the systematic part of the utility function, or heterogeneity when the model is estimated at an aggregate level.

The assumption of time-invariant utility functions may be reasonable for many types of spatial choice behaviour, but too limited to explain the choice of greenspace. When we consider for example the problem of choice of transport mode for the commute trip, once individuals have established some reliable idea about travel times, we could argue that at least in the short to medium run, utilities for alternatives transport modes do not change that much. A similar plea could be made for grocery shopping. Perhaps, utility

may differ a little, but probably the researcher would not gain that much when formulating more complicated utility functions.

In the choice of greenspace, however, there are various reasons why the typical assumption of time-invariant utility functions is too rigorous. First, the attributes of greenspace differ widely across seasons. Consequently, the utilities that individuals can derive likely vary across seasons. Secondly, one could also argue that individuals choose parks to conduct particular activities. In turn, activity participation may vary by season, implying that the indirect utility that individuals derive from their choice of greenspace necessarily will also vary from season to season. Thirdly, while traditional approaches have mostly assumed that the history of previous visits does not have an effect on utility, one might argue that especially in the context of the use of greenspace, variety or novel seeking behaviour plays a relatively important role. To some extent, this may be because people are involved in different activities in successive visits to greenspaces, but there may also be some inherent drive to variety seeking behaviour. Conceptually, this would mean that the utility that people can derive from successive visits to the same park may reach some point of saturation, after which the gain in marginal utility derived from visiting the same park is decreased. The probability of visiting another park would then increase. Thus, utility would be time-dependent, and the probability of visiting different parks during successive trips would increase. Fourthly, an individual will face certain constraints (time and other) to conduct a particular activity. Perhaps the most important of these are the other (especially mandatory) activities that need to be conducted on a particular day. The flexible time that remains to visit a greenspace may therefore vary from day to day, and therefore the utility that can be gained from a visit will also vary.

#### *An activity-based perspective*

The various considerations discussed in the previous section can be combined into an activity-based perspective. It articulates the notion that spatial choices (the choice problem) can be best understood by realizing that individuals wish to pursue particular activities, and that the set of activities needs to be organized in time and space. The need to conduct activities will vary over time. Some activities are mandatory and need to be conducted frequently and are more constrained in terms of their duration, timing and locations. Other activities are discretionary and less constrained in terms of their duration, timing and location.

Spatial choice can then be viewed as deciding which activities to conduct (activity participation choice), where (activity location or destination choice), when (choice of timing), for how long (duration choice), with whom (choice of travel party), in which order (activity scheduling choice), and the transport mode (mode choice involved). These various choice facets are

heavily mutually dependent. In addition, from a dynamic perspective, there is also the time dimension. Activities need to be scheduled in terms of various time horizons. As indicated, the nature of the activity and its history become important in this respect. Mandatory activities that need to be conducted on say a daily basis likely have a time-invariant utility, except for the non-work days. The utility of activities that involve greenspace may be more influenced by how long ago that activity was conducted, while the utility to conduct that activity at a particular destination may also be influenced by considerations of variety-seeking behaviour.

For the system conceptualisation, we adopt the conceptual framework described here. The methodologies and models developed and implemented within the system have their conceptual foundation in spatial and space-time choice models. In line with the conceptual framework, GRAS includes two kinds of choice behaviour: non-temporal and temporal. On the non-temporal level, greenspaces are conceptualised 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 preference for different greenspace attributes and location, and the effect of these preferences on their use. On the spatio-temporal level (activity-based approach), besides individual's preferences for certain types of greenspace, individuals needs or desires to pursue other activities in space and time are also considered. The results provide additional information about the intensity of greenspaces' use.

In the next section, we describe GRAS's architecture and design that implements the conceptual system presented in this section.

### **4.3 System's Architecture and Design**

The SDSS for the planning, design and maintenance of greenspace is a GIS-based decision support system. The development of this system is presented in the context of the framework proposed by Sprague (1980). As described before (section 2.3.1), this framework recognizes three levels of technology in the development and operation of a DSS: Specific DSS, DSS Generator and DSS Tools.

The traditional approach in developing SDSS or GIS-based DSS for the urban planning domain uses a standard GIS package as a "DSS Generator", meant to quickly and easily build the "Specific DSS". In this research project, however, we decided to start with the most fundamental level of technology to build the "*Specific DSS*". We started from the modelling side and GIS functionalities were added conform the required analysis and subroutines within the system. This approach gets rid of all the overhead and limitations of a particular GIS package. Furthermore, standard GIS packages

have not fully addressed the issue of model communication among different application systems, which is quite problematic when the objective is mainly to bring together and integrate a number of urban planning models under a common interface.

As noticed before (Keenan, 1997), we believe that in DSS applications the focus of the decision maker is the decision being made. The user wants to use the tool to explore aspects of the decision. To do so, it should not be necessary for the user to go through long sequences of commands, to enable data moves between modules of the system. It is essential that modelling routines can automatically extract the relevant data from the database component of the system. The user should only have to intervene in the system to control the decision process and not to conduct the basic operations needed for modelling. The models should be able to make use of the spatial database tools. This requires that the SDSS be built with modelling tools that allow the models to access the database and interface components of the SDSS.

Three major components can be identified: database management system (DBMS), model based management system (MBMS), and the component for managing the interface between the user and the system, which might be called the dialogue generation and management system (DGMS). As suggested in the Figure 4-2(b), the database and the model base have some interrelated components. These three major subsystems are described in detail in the next subsections.

#### **4.3.1 Database management system**

Decision-making is heavily dependent on data emanating from different sources. Data must come from external as well as internal sources, i.e. the typical accounting oriented transaction data must be supplemented with non-transactional, non-accounting data, some of which has not been computerized in the past. Thus, an important characteristic of any DSS is the data capture and extraction process from this wider set of data sources.

Sprague (1980) identified a set of capabilities required in the database management system: (i) the ability to combine a variety of data sources through a data capture and extraction process; (ii) the ability to add and delete data sources quickly and easily; (iii) the ability to portray logical data structures in user terms so that users understand what is available and can specify needed additions and deletions; (iv) the ability to handle personal and unofficial data so the user can experiment with alternatives based on personal judgment; and (v) the ability to manage this wide variety of data with a full range of data management functions.

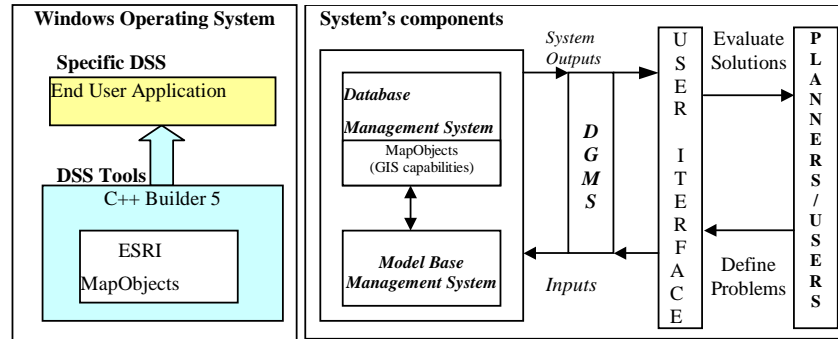


Figure 4-2. (a) Development environment; (b) System's architecture

In addition, the nature of a spatial decision support system requires that the capturing and extraction process, and the DBMS which manages it, be geographically referenced when needed. The data organization of GIS is very similar to those requirements for the Database Management System above. GIS clearly provides possibility to co-process, under one common framework, data stored in different data models, whether spatial or non-spatial referenced.

Therefore, as shown in Figure 4-2(b), we built a Database Management System with GIS capabilities. Technically speaking, the DBMS is a hybrid composition of the Borland Database Engine and the MapObjects development tool from ESRI. Embedding GIS capabilities to the objects and relational tables of Borland, spatial and non-spatial data from different sources can be easily co-processed with appropriate spatial interpolation techniques. The full integration of these two technologies allows the DBMS to be the heart of the spatial and operational information system and allows communication and intermediate storage between the various submodels without user intervention.

The data sources required by the models within the system are:

1. Land Use;
2. Post Code addresses;
3. Road Network;
4. Zone system (census tract);
5. Greenspace amenities;
6. Work facilities.

Until recently, the spatial dimension has seriously restricted urban models capabilities to respond to current planning issues. The spatial dimension of existing aggregate urban models was typically given through a

zone system. Zones provide a stable, consistent spatial representation, and much of the data we use in constructing even disaggregated models inevitably comes in zone-based formats from sources such as the census. Nevertheless, arbitrary spatial aggregations introduce aggregation bias into models, which use them as their unit of analysis. Zone's attributes were assumed to be uniformly distributed throughout the zone and spatial interaction between zones was established via networks linked only to the centroid of the zones.

Spatial modelling in the straitjacket of the zone systems is too aggregate to predict impacts on small-scale planning, for instance neighbourhood-scale planning (Wegener, 2001). At the very least, they lacked a theoretical basis. For instance, surface characteristics such as greenspace built-up area, individual activity patterns and models based on human behaviour require much higher spatial resolution. Thus, not only the attributes and assumptions of the modelled system are of interest but also their micro-location. Moreover, as noticed elsewhere (Wegener, 2001), the limitation of the zone systems have led to serious methodological difficulties such as the modifiable areal unit problem (Openshaw, 1984; Fotheringham and Wong, 1991) and problems of spatial interpolation between incompatible zonal systems (Flowerdew and Openshaw, 1987; Goodchild *et al.*, 1993; Fisher and Langford, 1995).

Following trends in urban planning towards more disaggregated and thus realistic models, the type of models proposed for the problem of greenspace provision and monitoring (described in detail in the next section) suggest a fundamentally new organization of micro-data based on a microscopic view of the urban environment. The move from macro to micro in complex urban systems requires efficient data structures to overcome processing time and/or system's performance, being still an issue even considering the new technological potential.

A solution to deal with such issues came across by means of the so-called *Cell-Based Database Management System*. The Database Management System 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 all data sources required by the system into cells.

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 overlay 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 (100x100 meters) to represent space. That means that spatially aggregate data from land use, greenspace, workplaces, urban zoning system/socio-demographics and postcode addresses must be disaggregated and combined into a singular spatial source defined as cells of 100x100 meters.

It is important to make clear that, although the cell size is an arbitrary value that can be easily changed by the user, we strongly recommend the dimension suggested. The 100x100m 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.

To conclude, the intermediate data organisation, the so-called Database Management System, stores, retrieves, manipulates and pre-processes information needed in the models. In summary, there are many advantages of information storage following the cell structure, such as:

- 1) Much higher spatial resolution: disaggregating the zone system, spatial dimension of most urban models, avoids 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 aerial 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.

#### **4.3.2 Model base management system (MBMS)**

The Model Base Management System (MBMS) is an integrated urban model environment built with a range of models designed and implemented to support the evaluation and assessment of the urban greenspace provision and monitoring. It basically incorporates various procedures that enable the users and planners to easily create alternative development scenarios and decisions based on a number of analytical models for greenspace assessment.



A very important characteristic of the MBMS component is its ability to integrate data access and urban (decision) models. It does so by embedding the urban models in an information system, which uses the database as the integration and communication mechanism between models. This characteristic unifies the strength of data retrieval and reporting from the *Cell-Based Database Management System* and advanced developments in urban science that decision maker can use and trust. Opening the MBMS “box”, the tools and models illustrated in the Figure 4-3 are found. The arrows in the figure represent communication mechanism and data flow between models.

The type of urban (decision) models implemented within the system was developed using the conceptual framework described in the section 4.1.2 to describe individual behaviour patterns within the urban built environment. Such a conceptual framework is a state-of-art modelling approach for urban planning and monitoring processes and implies that planners can predict the impact of their likely future plans and actions by describing/observing and predicting individual behaviour in the urban environment in constant change. The idea is that cities have to resort to less authoritarian ways of influencing urban development rather than by command and control instruments of statutory planning.

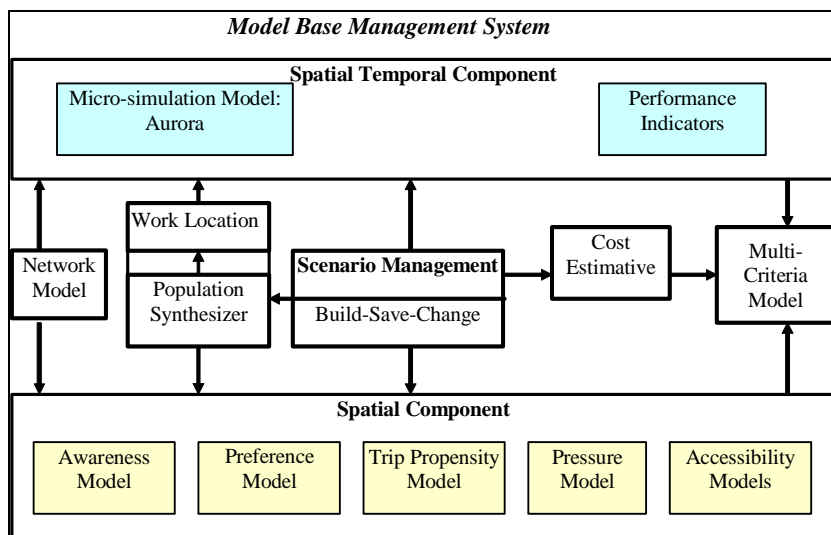


Figure 4-3. Model base management system

The Model Base Management System consists of seven major integrated modules: the Scenario Management, the Population Synthesizer, the Network Model, the Spatial Component, the Spatio-temporal Component, the Cost Estimative Spreadsheet and the Multicriteria Model. The *Spatial Component* contains five models: 1) The Awareness model; 2) The Preference model; 3) The Trip Propensity model; 4) The Pressure model; 5) The Accessibility model. These are static (or spatial, non-temporal) models for the analysis of greenspaces planning, design and maintenance based on a theory of spatial behaviour.

Therefore, temporal constraints are not taken into consideration to estimate green space values. However, the trip propensity and the pressure models do take time into account in the sense that time of the day, day of the week and season of the year are among the situational exploratory variables of the model. However, the needs and/or wishes in conducting other activities are not taken into account to estimate green activities patterns. On the other hand, the *Spatio-temporal Component*, represented by the micro-simulation model named Aurora (Joh *et al.*, 2004) is meant to suppress the static characteristic of the spatial models. A detailed description of models, sub-models and tools within the Model Based Management System will be given in Chapter 5.

### 4.3.3 Dialogue generation and management system (DGMS)

The dialogue generation and management system is the component for managing the interface between the system and the user. Graphical User Interface (GUI) is the system used to make the human-computer interface of GRAS. A major feature of GUI programs is the ability to allow individuals to manipulate the computer easily and intuitively (i.e., with little or no instruction) even by inexperienced users. GUI (and hence GRAS) uses windows, *icons*, pull-down menus and a pointer that all can be manipulated by a mouse (and usually to some extent by a keyboard as well). An icon is a small picture or symbol that represents a program (or command), file, directory (also called a folder) or device (such as a hard disk or floppy disk).

The main interface of GRAS is shown in Figure 4-4. Indeed, the so-called dialogue generation and management system (DGMS) gathers the actions initiated by the user via GUI 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 information).

GRAS main user interface, which is a GIS-Based Map window, provides several functions, hereafter described in some degree of detail.

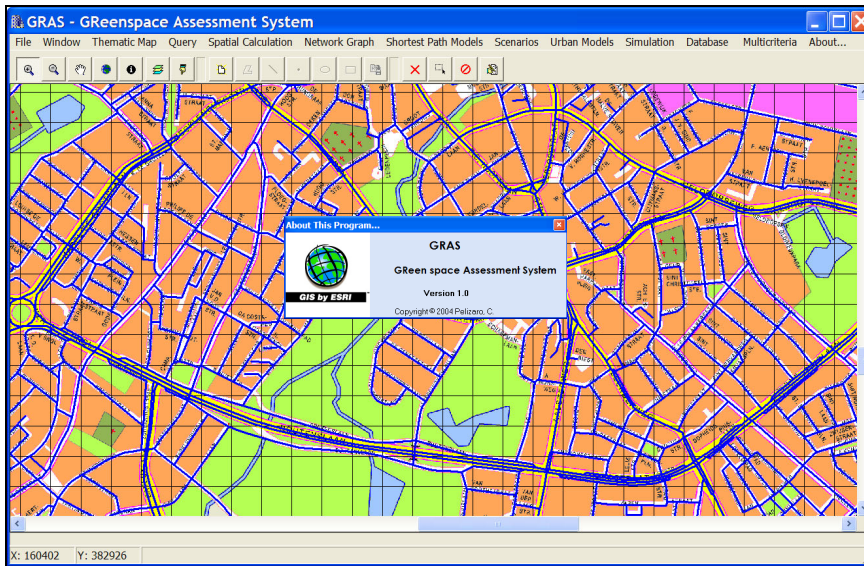


Figure 4-4. GRAS main user interface

#### 4.3.3.1 The Geographic Information System (GIS) Map Window User Interface

The Geographic Information System (GIS) map window user interface allows the user to visualize and interact with raster (images in TIFF and BMP formats) and vector (ESRI shapefiles) maps, by means of *icons* such as: (i) zoom in; (ii) zoom out; (iii) pan; (iv) clear window; and (v) add map layers. Raster maps are simple images for visual orientation. Hence, raster images can be used as a background for visualization purposes only. When geo-referenced in the same scale of a vector map, raster and vector maps can be overlaid and used in combination to increase the power of map visualization, as shown in Figure 4-4. On the other hand, vector map addresses a georeferenced database, allowing storage, manipulation and retrieval of spatial and non-spatial data. Additional functionalities are provided to the user to interact with vector maps (and respective georeferenced databases), by means of *icons* such as: pop-up information; create new vector map layer; draw map objects (rectangle, circle, line and points); clear window; select map objects; clear selection; edit layer/scenario; and, save map.

The “*File*” menu opens a file that can be a vector map (ESRI shape file), a raster map (bitmap or TIFF file) or a combination of both.

Although GRAS can handle raster and vector maps, only vector maps will have a spatial database. Hence, raster (bitmap and/or TIFF file) maps have only imaging functions.

The “*Windows*” menu allows the user direct access to the database of the current map opened.

The “*Thematic Map*” menu opens another map window (Figure 4-5) to allow the user to generate thematic maps. Thematic maps can be used for exploratory spatial data analysis, confirming hypotheses, synthesizing spatial data by revealing patterns and relationships, and data presentation. Because of the value of this tool in a GIS application, the thematic map tool will be described in some detail later in this section.

The “*Query*” menu opens a dialog box (Figure 4-6) to support the use in exporting a selection of spatial data (vector map) and respective database by means of a SQL (Structured Query Language) statement. This query tool increases system’s potential allowing the system to be used in different levels of decision making: from regional planning to local or neighbourhood planning. Drop-down lists will support the user to ease formulate the right query statement to select the study area (region, city or neighbourhood(s)).

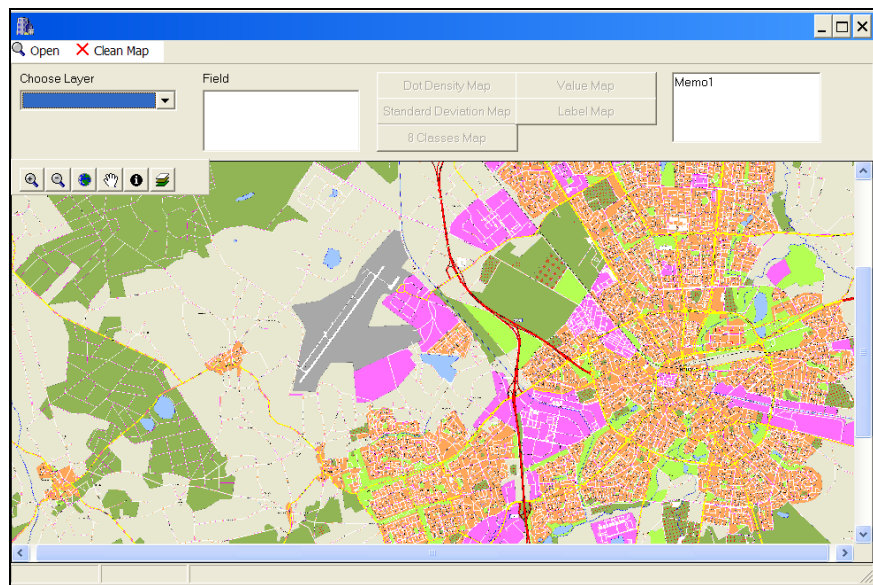
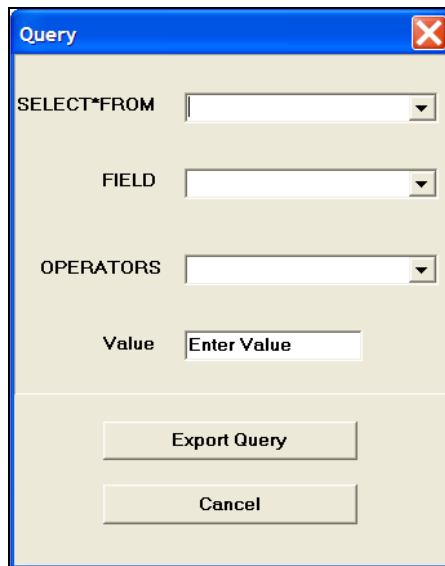


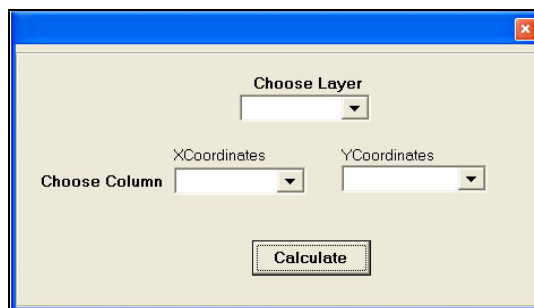
Figure 4-5. Thematic Map user interface



The image shows a 'Query' dialog box with a blue title bar and a close button (X) in the top right corner. The dialog has a light beige background. It contains four dropdown menus: 'SELECT\*FROM', 'FIELD', and 'OPERATORS', and a text input field labeled 'Value' with the placeholder text 'Enter Value'. Below these fields are two buttons: 'Export Query' and 'Cancel'.

Figure 4-6. Query dialog - User interface

The “*Spatial Calculation*” menu contains two submenus with different functionalities to extract spatial information of maps’ objects (or shapes). The first is the “*Centroid (x,y)*” submenu, which pop-up the dialog show in Figure 4-7. As it suggests, it will guide the user to calculate and store in the right database field, the x,y coordinates of the polygons’ centroid (polygon shape map). The second submenu, named “*Area*”, calculates the area of the polygons of a polygon shape vector map.



The image shows a dialog box for the 'Spatial Calculation' menu, specifically for the 'Centroid (x,y)' submenu. It has a blue title bar and a close button (X) in the top right corner. The dialog has a light beige background. It contains three dropdown menus: 'Choose Layer', 'Choose Column', and 'YCoordinates'. The 'Choose Column' dropdown is labeled 'XCoordinates' above it. Below these dropdowns is a 'Calculate' button.

Figure 4-7. Spatial Calculation “Centroid (x,y)”

The “*Network Graph*” menu lets the user build a graph based on a road network map as input to the Shortest Path algorithm. It is a pre-processing step of the shortest path algorithm in order to reduce computation time when the shortest path algorithm is called by other models within GRAS. By clicking on this submenu option (*build graph*, *save graph* and *load graph*), the user will build and save a graph (based on a street map opened) as a binary file, which is automatically accessed by the shortest path algorithm. The graph must only be rebuilt if changes are made in the road network map.

Although the shortest path algorithm is internally accessed by the models without user intervention, a “*Shortest Path Model*” menu is provided to give the user access to this model as an extra tool. There are three submenus under the “*Shortest Path Model*” menu, which are: “*find closest node network*”, “*find closest green facilities*” and “*find path origin→destination*”. Each of these submenus pop-up different dialogs box. For example, the “*find closest green facilities*” user interface (Figure 4-8) finds the closest greenspace facility in a given scenario (using the road network) for every individual located as points on a map or described as x,y coordinates in a tabular database. By means of the interface, the user must address the individuals table and the scenario database/map (directory and file name) and specify required fields in the drop down list box that automatically pushes the existing fields of the databases addressed.

The “*Scenario*” menu assists the user through a process of implementing the changes made in a scenario by simply “click on the buttons” actions, using the mouse device.

Figure 4-8. User interface “*find closest green facilities*”

A description of the scenario management system is given in Chapter 5 (section 5.1), and a systematic demonstration of this tool is described in Chapter 7 through a case study.

The “*Urban Models*” menu holds the set of models included in the “Spatial Models Components” and the cost estimative spreadsheet, described later in Chapter 5. The following submenus are under the umbrella of the “*Urban Models*” menu:

- (i) The “*Awareness*” submenu: opens the Awareness dialog box (see Figure 5-7).
- (ii) The “*Preference Model*” submenu: opens the Preference Model dialog box (see Chapter 5, Figure 5-8).
- (iii) The “*Trip Propensity Model*” submenu: opens the Trip Propensity Model dialog box (see Chapter 5, Figure 5-9).
- (iv) The “*Pressure Model*” submenu: opens the Pressure Model dialog box (see Chapter 5, Figure 5-10).
- (v) The “*Accessibility Measures*” submenu: opens the Accessibility Module dialog box (see Chapter 5, Figures 5-11, 5-12, and 5-13).
- (vi) The “*Cost Estimative Spreadsheet*” submenu: opens the Cost Estimative spreadsheet (see Chapter 5, Figure 5-23).

The interface of these models uses fill-in-the-blank parameters settings, pop-down lists, buttons, error message boxes and Memo to inform the user about the process (processing time mostly) and displays results or information notes.

The “*Simulation*” menu holds three submenus: the “*Synthetic Population*” simulator (see Chapter 5, Figure 5-6), the “*Find Work Location*” simulator and the “*Aurora*” simulation model.

The “*Find Work Location*” submenu opens a dialog box as shown in Figure 4-34. Individuals’ work location is elementary information for the Aurora activity-based model, described in Chapter 5, section 5.5.1. Having the synthetic population already generated for the scenario being evaluated, this tool finds the work location cell to the economically active individual of the synthetic population.

The “*Aurora*” submenu lets the user start up the scenario evaluation using the spatial temporal concept. The Aurora submenu opens another window, as shown in Figure 4-10. In the “Aurora main window” user interface, the “*File*” menu accommodates six submenus: (i) “*create project*”; (ii) “*open project*”; (iii) “*close project*”; (iv) “*save project*”; (v) “*export schedule*”; (vi) “*import schedule*”.

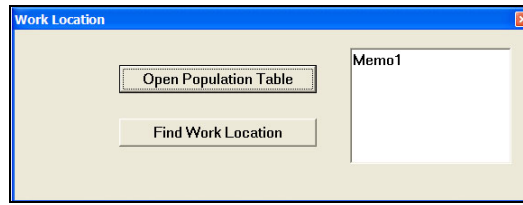


Figure 4-9. User interface "Find Work Location" simulator

It is important to make clear that, a project, which specifies the scenario file, the synthetic population and simulation settings, is the input for simulating individuals' activity schedules. Hence, a project must be created (submenu "*create project*") or an existing project (created earlier) must be opened (submenu "*open project*").

The "*create project*" submenu opens the dialog box shown in Figure 4-11. By clicking the buttons, the user will choose the scenario under evaluation, the population under the scenario, the activity locations and parameters settings. The activity location is a separate routine to assign: (i) work locations to economically active individuals; and, (ii) greenspace locations that particular individuals' are likely to visit. Individuals' work location is simulated outside the Aurora Model, by means of the "*Work Location*" simulation tool as described before in this section.

The "*Choose Activities Locations*" button (Figure 4-11) finds the greenspaces location that individuals are likely to visit, following the procedure described later in Chapter 5 (section 5.5.2).

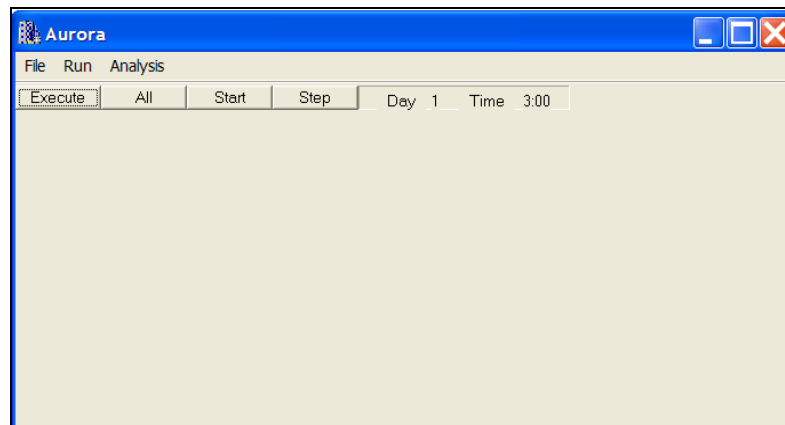


Figure 4-10. Aurora Model – Main Window User Interface



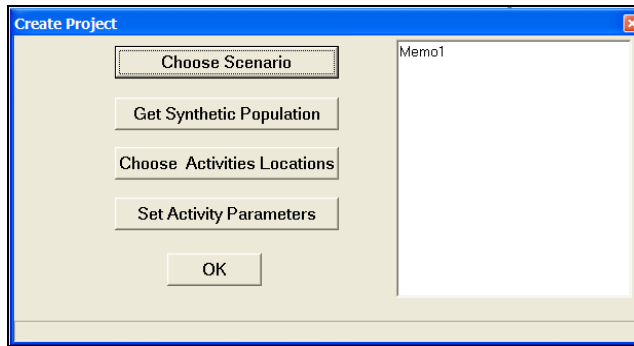


Figure 4-11. Aurora user interface - Create new project

At last, activity parameters must be set before Aurora simulates individuals schedule of activities. The activities' parameter setting user interface is shown in Figure 5-17. Users (planners/decision-makers) have full control and entire responsibilities on the activity parameters settings, which are easily manipulated by fill-in-the-blank, edit boxes. Notice that, once a project is saved (automatically done by pressing the "OK" button of Figure 4-11) it can be re-called and simulated at anytime (or stage of the decision process) the user wishes to do so. To execute the simulation, a project must be opened ("*open project*" submenu of "*File*" menu) and give the command to execute the simulation, by simply pressing the "*Start*" button below the main menu.

If the simulation is ready, the simulation output (i.e., the individuals' schedule) can be analysed ("*Analysis*" menu) using descriptive analysis ("*Descriptive...*" submenu) or frequency tables ("*Frequencies...*" submenu). The "*Frequencies...*" submenu opens the frequency analysis window as shown in Figure 5-19 (see Chapter 5, section 5.5.3), and the "*Descriptive...*" submenu opens the descriptive analysis user interface, as shown in Figure 5-21. By selecting options and pressing buttons within the user interface, the user can perform several frequency tables and descriptive analysis (described later in Chapter 5, section 5.5.3). If the results of the simulation are meant to take part in the "*Multicriteria Evaluation*" tool, the simulation output must be exported by using the "*export schedule*" submenu located under the "*File*" menu.

The "*import schedule*" submenu (in the "*File*" menu) is used when the user wishes to perform descriptive and frequency analyses of a schedule produced before.

The "*Database*" menu gives access to non-spatial tabular data in order to allow users to make changes in the attribute table. It also lets the user create a new table (shown in Figure 4-12), by defining the field name, type

(numeric – integer, float or string) and insert records. This could be useful in case the user wants to reproduce the effect of the scenario on different population parcels (specific gender, age or household composition or a combination of this restrictions), for instance.

Finally, the “*Multicriteria*” menu opens the “Multi-criteria Evaluation” dialog box, as shown in Figure 5-24 (see Chapter 5, section 5.7). By clicking on the “*Include Scenario*” button, the system will assist the user in seeking the scenario file to be included in the evaluation and once included the scenario file name is displayed in the lists file (one as the result of the spatial models and the other containing the schedule resulted from the spatio-temporal model). If any mistake is made during scenario selection, a *remove* button is available to fix the problem.

The criteria must be selected by the user from a drop-down list and weights must be assigned using the fill-in-the-blank box, as described in Chapter 5 and demonstrated through a case study in Chapter 7.

### *Thematic Map*

A thematic map shows the spatial distribution of one or more specific data themes (attributes) for standard geographic areas. The map may be qualitative in nature (e.g., predominant land use types) or quantitative (e.g., accessibility to greenspaces).

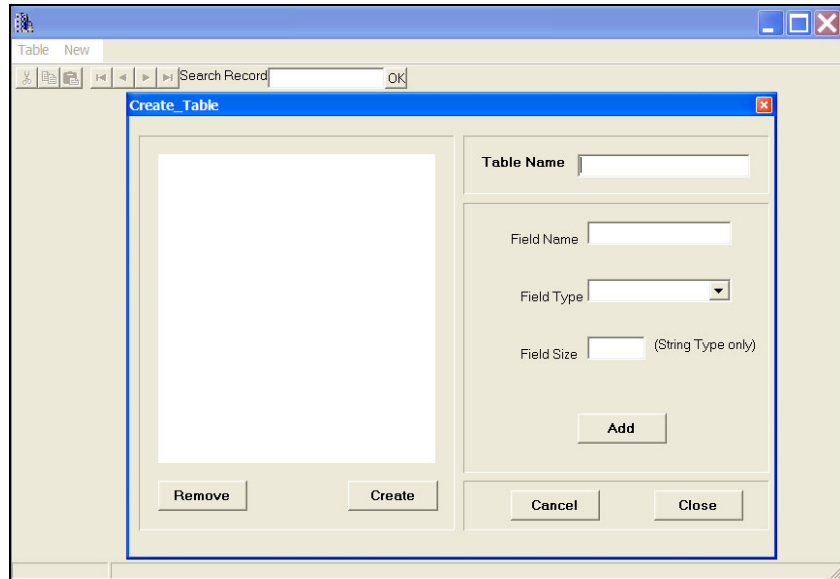


Figure 4-12. Database User Interface - Create New table

All thematic maps are composed of two important elements: a base map and statistical data. Because every object on the map is linked to a database of field information, the thematic map tool can present the database information in different colours, representing the results of some statistical analysis or information pattern.

The Thematic Map tool (Figure 4-5) automatically opens a raster map of the study area as a background image to provide extra spatial reference to the user.

In the Main Menu of the Thematic Map window (Figure 4-5), a vector map layer can be added to the Thematic Map window and the DGMS takes care of populating automatically the pull-down “*Choose Layer*” List with the layers’ name.

The later the map layer added, the highest its name appears in the list. The same happens to the “*Field*” list, i.e. when the user selects the map layer from the “*Choose Layer*” list, the DGMS automatically updates the “*Field*” list with the field’s names of the selected map layer database. Hence, the user must pick the field containing the interested values to create colour patterns in the map and the method to do so.

There are six methods implemented to draw the map colour patterns. These methods will be enabled/disabled by the DGMS depending on the map layer type (line, polygon, point) and the field data type (quantitative or qualitative) chosen.

The “*Dot Density Map*” method applies to the polygon map type for quantitative (numeric) fields. It will draw dots within the map objects (polygons) as a function of the respective numeric data values.

The “*Standard Deviation Map*” and the “*8 Classes Map*” apply to every map type (polygon, line and points) for quantitative (numeric) fields. The *standard deviation map* method draws the map shapes (line, polygon or points) with six ranges of colours, ranging from yellow pale to orange (colour patterns). The standard deviation map creates thematic maps assuming that the data are normally distributed. In order to create an effective colour patterns for visual analysis, the following procedure is used to define categorized data:

$$\begin{aligned} \text{ClassBoundary}_1 &= \text{Mean} - (\text{StandardDeviation} * 3); \\ \text{ClassBoundary}_{n+1} &= \text{ClassBoundary}_n + \text{StandardDeviation}; \text{ for } n=1, \dots, 6. \end{aligned}$$

where,  $n$  is the class number. The smaller the class, the lighter the shape colour pattern.

The “*8 Classes Map*” simply draws the map shapes (line, polygon or points) with one from eight colours ranging from yellow to blue (colour

patterns). Data values (and therefore the respective map object – shape) is categorized into eight classes using the following expressions:

$$\begin{aligned} \text{Range} &= (\text{max}-\text{min})/8; \\ \text{ClassBoundary}_1 &= \text{min} + \text{range}; \\ \text{ClassBoundary}_n &= \text{ClassBoundary}_{n-1} + \text{range}; n = 2, \dots, 8; \end{aligned}$$

where  $n$  is the class number. Thus, this is based on a uniform distribution. The smaller the class, the lighter the colour pattern.

The “*Value Map*” is enabled for every type of data and map shape. It is very useful method to colour maps as a function of binary (or categorical numeric) data or qualitative data, because it paints the shape with different colours given different values.

#### 4.3.3.2 Discussion

Sprague (1980) argues that much of the power, flexibility, and usability characteristics of a DSS are derived from capabilities of the user interface. The richness of GRAS’s user interface described above is indeed the consequence of accommodating these three dimensions when developing the system.

The several domain decision models that were implemented and integrated under a common GIS-based environment, provide a powerful tool to support decision makers in all phases of the decision making process. GRAS is a flexible system in the sense that users can execute models and use tools (for instance thematic maps, query, etc.) at any time of the decision making process they wish. Although the system offers a generic process to guide decision makers, there is no fixed structure enforced by internal dependencies between models and tools during the decision making process. In this sense, the system is flexible enough to support decision makers with different cognitive styles. In addition, GRAS includes a highly interactive and user driven (controlled) user interface, where users are required to add their knowledge and judgment into models to evaluate different decision types (decision levels), increasing system flexibility and usability.

It should be emphasized however that the GRAS user interface was not evaluated by potential users. For the purpose of this project research, we do not address this topic of research, leaving it for the future.

#### **4.4 Conclusion and discussion**

In this chapter, the structure and components of a spatial decision support system for the planning, design and maintenance of greenspace, the so-called GRAS (Greenspace Assessment System), was described in general terms. GRAS is a GIS-scenario-based micro-simulation multicriteria decision support system, with a range of domain-specific models inspired by a commonly accepted conceptual framework of spatial behaviour. Although we use a more elaborated framework of context-dependent and time sensitive choice behaviour, the key notion of these models is that individuals derive some utility from greenspaces, which can be derived from choice behaviour and hence, measured. Decision makers being able to predict individual choice behaviour patterns are able to assess and evaluate the impact of possible changes/actions in the greenspace portfolio. In this sense, the sources of uncertainties can be diminished, and decisions can be made more objectively when the aim is to improve public welfare.

The suggested system is capable to assist 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. In addition, the system identifies interdependencies among planning, design and maintenance elements of the greenspace problem, and integrates these three levels of decision effectively.

Unlike most of the SDSS reported in the literature up-to-date, GRAS was not built by adding models to a standard GIS package. Rather, we started from the modelling side and GIS functionalities were added conform the required analysis and routines within the system. This approach eliminated issues regarding overhead and limitations of standard GIS packages. The advantage is flexibility and full integration of GIS technology, a scenario development tool, domain-specific models, the multicriteria evaluation technique, and disaggregated data from different data sources of relevant urban subsystems. Consequently, the user only intervenes in the system to control the decision process and not to conduct the basic operations needed for modelling.

In the next chapter, a detailed description of models and tools integrated in GRAS to support the decision making process is given.

## CHAPTER 5

### 5. THE MODEL BASE MANAGEMENT SYSTEM

In the previous chapter, we described in general terms the structure and components of GRAS. The three major components of GRAS, i.e. the database management, the model base management and the dialogue generation and management subsystems, were introduced. Having described the database management system and the dialogue generation and management system in the previous chapter, this chapter is dedicated to the description of the models and tools within the Model Base Management System (MBMS). The chapter is organized as follows. Section 5.1 describes the scenario management model as an instrument to represent and predict future greenspace plans and actions. For an effective contribution to the decision making process, the scenario-development tool incorporates some concepts and credentials, which are explained in this section. Section 5.2 describes the population synthesizer, a model to create a population imitation of the study area (or scenarios) with demographics closely matching those of the real population. Together, scenario and synthetic population compromise the built environment, which is the starting point for modelling choice patterns and deriving system performance indicators, topics discussed subsequently. In Section 5.3, we present the *Spatial Models Component* (also called “static component”), which consist of a family of discrete choice models and accessibility performance measures. This component holds models based on a more traditional *statically-oriented* approach to urban processes modelling to calculate performance indicators. Section 5.4 describes a micro-simulation activity-based model implemented in GRAS to examine the participation of individuals in green activities, given spatial-temporal constraints. To that effect, we also derive a set of performance indicators to evaluate the impact of greenspace actions and plans. Section 5.5 describes a tool for estimating greenspace provision and maintenance. Section 5.6 describes the multicriteria evaluation model and a set of criteria or performance indicators derived from the models integrated in GRAS, to support the decision makers in evaluating alternative scenarios. The chapter will end with a conclusions and discussion.

## 5.1 Scenario management module

As an instrument for strategic thinking and option search, scenarios have been an urban planner's toolkit for several decades. As remarked by Xiang and Clarke (2003), it is a successful tool to articulate the information-compilation process that is underlying both the stream modelling and planning, which cognitive psychologists term *chunking*.

Scenarios are the product of one chunking process – modelling – and the raw material of the other – planning. In modelling, scenarists compile small and less-meaningful pieces of information (that is small chunks) with expertise, knowledge, and, arguably, values as well as various external cognition aids, such as models for calculation and computers for memory augmentation and visualization, into large and more meaningful chunks-scenarios. These are then brought into a planning process by the scenario users and combined with other pieces of information to form even larger and more advanced chunks-goals, strategies, plans, and policies (Kaiser *et al.*, 1995). Schwartz (1996) even claims, on the grounds of the latest evidence of neuroscience, that humans are “the scenario-building animals” which have an inbred ability to build scenarios and foresee the future for decision-making (Xiang and Clarke 2003).

Examples of DSS using this approach include, among many others, the Metropolitan Landscape Planning Model – METLAND - (Fabos *et al.*, 1978); the Environmental Prediction and Decision Support System for the Seymour Watershed, B.C., Canada (Lam *et al.*, 1994, 2002); the Xplorah System<sup>1</sup>, an analytical instrument supporting integrated spatial planning under conditions of a changing climate in Puerto Rico; an environmental management model using ecological engineering approach used to conduct scenarios analysis of the metropolitan region of Taipei (Huang *et al.*, 1995); a scenario-based micro-simulation model used for assessment and prediction of urban wind flow in the city of Sacramento, CA (Cionco and Ellefsen, 1995); a sustainable water management scenario-based study for the Netherlands (van de Graaf *et al.*, 1997); and scenarios-based control measures of the M8 Eastbound Corridor in Glasgow using the macroscopic modelling tool METACOR - Modèle d'Écoulement du Trafic sur Corridor (Diakaki *et al.*, 1997). Schäfer (1998) also used scenarios to project global long-term trends in motorized traffic volume and discussed implications of rising travel demand on world passenger transport energy use, on global automobile motorization rate, and dealt with the long-term implications of unlimited mobility growth. Another example is an integrated simulation system for traffic induced air pollution performs emission and air pollution (Schmidt and Schäfer, 1998). Sadownik and Jaccard (2001) used two

<sup>1</sup> <http://www.riks.nl/projects/Xplorah>

alternative scenarios of urban growth throughout China in an integrated model to evaluate aggregate energy-related emissions in the year 2015. Kousa *et al.* (2002) proposed a scenario-based approach to evaluate the impacts of traffic planning and land use developments on the population exposure to ambient air pollution in an urban area.

Following the growing popularity and interest among planners and academics, as shown by the above examples, scenarios are means to represent and/or predict the future. Xiang and Clarke (2003) describe scenario-development tools as good and likely to contribute to an effective decision-making process, only if they perform well the two functions of bridging and stretching. A scenario is both a bridge, in the sense that it connects the process of modelling with that of planning, and a cognitive apparatus that stretches people's thinking and broadens their views in planning. These authors also claim that a scenario-development tool may best perform the bridging and stretching functions if the scenario-development futures it presents are *surprising* and *plausible*; when the information it uses and the way it presents the information are *vivid*; and when its design is *cognitively ergonomic*, that is, *effective* and *safe*. Having that in mind, these credentials were incorporated into GRAS to support a good scenario development process. In the remaining of this section, each of these credentials (and its ingredients) is described in the context of GRAS, resembling Xiang and Clarke's (2003) work.

#### *Plausible unexpectedness credential*

A plausible and surprising scenario set articulates the notion that scenarios must be plausible, that is, worthy of belief to win people's acceptance, and at the same time strike people with a thought-provoking and unexpected future. A fundamental requirement for plausibility is coherence. Coherence guarantees that the casual relationship between an alternative and its consequences are properly maintained, and does not violate the logic of the modelling approach used. *Plausible unexpectedness* is encouraged in the greenspace-scenarios-development by means of two ingredients: diversity in perspective and comprehensiveness.

The greenspace decision-making process is characterized by multiplicities in levels (plan, design, and maintenance), goals, and objectives. A variety of discrete scenario themes (shown in Figure 5-1) allow users to implement a diverse set of scenarios. Greenspace authorities with different expertise and experience may portray and elaborate the image of the future greenspace-developments under substantially different assumptions. Such a diverse set of scenarios is likely to present a diversity of beliefs, competing perspectives, disagreements, and various analytical results that might bring unexpected surprises to the users and/or trigger creative strategies/plans. In



addition, it will promote decision makers to take others' perspectives when looking into the future. In this capacity, a scenario set becomes a vehicle for consensus building, collaborative planning and problem solving.

Scenario's *comprehensiveness* is promoted by allowing the users to apply a range of models integrated in GRAS for an understanding of the interactions among all the agents that shape the future greenspace-developments, such as greenspace portfolio (spatial distribution, size, and attributes and relationship among them), population socio-demographics and urban design.

#### *Informational vividness*

As remarked by Xiang and Clark (2003), a good scenario set should use only vivid information in its composition and should present that information in a vivid way. Vivid information is more likely to attract and hold people's attention, excite their imagination, and become readily available to them. Information may be regarded vivid when it is: *emotionally interesting*, *imagery provoking*, and *proximate* in a sensory, spatial, and temporal way (Nisbett and Ross, 1980; Xiang and Clark, 2003).

The screenshot shows a software dialog box titled "EditBox". At the top, there is a "Scenario Theme" dropdown menu. A context menu is open over it, listing five options: "Change facilities existent Park", "Green Cell-New Park", "Non Green Cell", "Delete Complete Park", and "Add Cell to a Park". Below the dropdown, there are several input fields: "Green Cell" (empty), "Park\_ID" (containing "1065"), and a numeric field (containing "12"). The main area of the dialog is a grid of 20 dropdown menus, each with a label and a value. The labels and values are: GreenType (Grass/), PublicTransport (No), WaterLake (No), SportFacility (Yes), Allow Dogs (Yes), WalkSite (Yes), Quiet (No), NiceView (No), Organized (Yes), Busy (Yes), Safe (Yes), Maintain (Yes), Clean (Yes), Ecologica (Yes), Benches/Tables (Yes), Cafe (Yes), Playground (Yes), Toilet (Yes), Lighting (Yes), and TrashBins (Yes). At the bottom of the dialog, there are two buttons: "Save Scenario" and "Cancel".

Figure 5-1. Scenario themes

There are few aspects of GRAS, which promote proximity and directness, imagery provoking, and emotionally interest to the scenario set. Proximity and directness is promoted by the system's geo component. Concomitant with the nature of the geo-computational technology, the information available in GRAS is presented in a sensory direct way, i.e. maps and georeferenced database. The geographic scope of the study area automatically sets the level of spatial proximity – the larger the study area, the lower the level of spatial proximity in the scenario set, and the smaller the study area, the higher the level of the spatial proximity in the scenario set (Xiang and Clark, 2003). By means of a querying tool (spatial selection or SQL statement) available in GRAS main user interface, users are able to specify the study area and consequently, the spatial proximity desired.

A leading factor that contributes to the informational *imaginability* is “concreteness”, i.e. the degree of detail and specificity in the composition and presentation of a scenario set (Nisbett and Ross, 1980; Xiang and Clarke, 2003). To make a scenario set concrete and therefore imaginary provoking a number of visualization tools are provided within the system environment. A raster picture (TIF or bitmap) of the study area can be used as a background picture to provide extra visual information on the land use and spatial location to the scenarios layer. An information prompt button will bring to the user information regarding a particular geo-object of interest in the scenario map. The Thematic Map tool can be used to colour the scenarios (vector) maps against quantitative and qualitative information derived from the scenarios composition process. Figure 5-2 shows an example of how the thematic map tool can be imagery provoking when used to visualize greenspace accessibility issues in a scenario. In that particular case, the accessibility increases with the effect of the colour ramping from lighter to darker.

Finally, providing such a georeferenced and vivid informational environment (GIS-based) to users will also promote *emotional interest*, in the sense that scenario users are able to visualize and recognise when alternatives “would affect, and/or consequences happen to, people that the scenario users know or have strong feeling about than when they would affect people about whom scenario users do not know or about whom they have only neutral feelings” (Xiang and Clarke, 2003).

#### *Ergonomic Design*

As an apparatus for the mental exercise of stretching, a scenario set should be designed ergonomically so that it interacts with the users both effectively and safely (Xiang and Clarke, 2003).

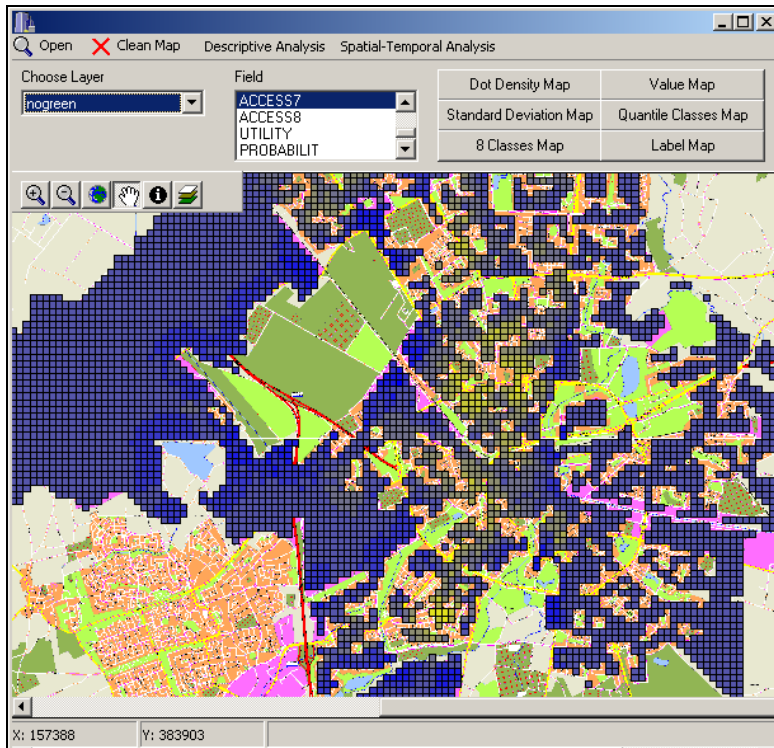


Figure 5-2. Thematic map representing accessibility to greenspace based on the gravity consumer surplus measure (Coelho and Wilson, 1976; Miller, 1999)

In order for the scenario users to receive the maximum amount of benefit from this mental workout, the scenario development process is strategically designed within the system using the concept of “scenario themes”.

Scenario themes are topics around which scenarios are composed. They are five:

- 1) Build a new greenspace (Figure 5-3a);
- 2) Change the design of a greenspace (Figure 5-3b);
- 3) Redefine the land use of an area – impact on the socio-demographics characteristics (Figure 5-4a);
- 4) Destroy a complete greenspace (Figure 5-4b);
- 5) Extend the area of a greenspace (Figure 5-5);

A scenario set can be built around one or several different themes and therefore falls into one of the two categories: single-themed or multiple-themed.

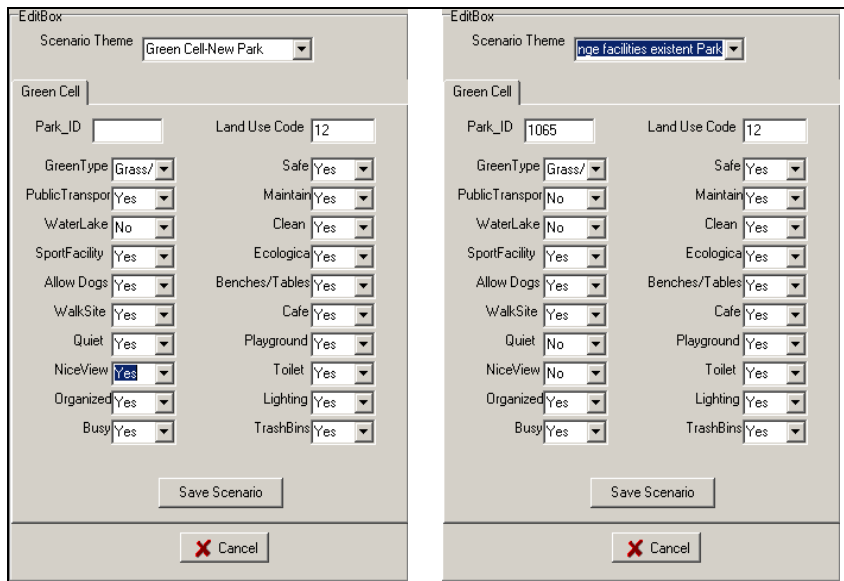


Figure 5-3. Scenarios themes: a) Build new greenspace; b) Change design of a greenspace

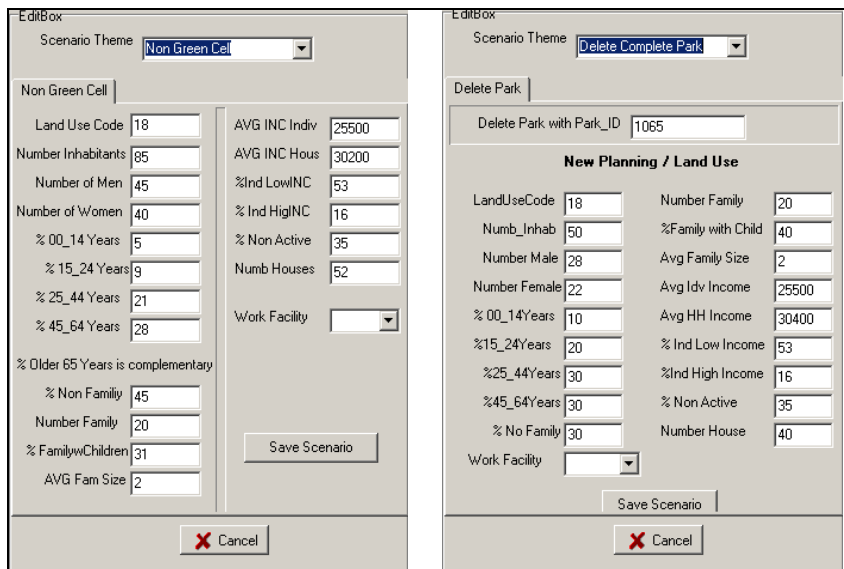


Figure 5-4. a) Redefine the space by land use; b) Destroy a complete greenspace

Figure 5-5. Increase the area of a greenspace

A single-themed scenario set is typically arranged sequentially using a single thematic dimension. For example, a set of greenspace development scenarios can be formed under a common theme of “Change the design of a greenspace” (Figure 5-3b) in order to decide what is the combination of facilities and/or attributes (vegetation, playground, sport facilities, toilet, lighting, etc.) of a specific greenspace, that will bring the highest benefit to the population. Hence, each scenario will progressively include (or exclude) a particular attribute/facility of that specific greenspace. In the end, decision makers will be able to identify what is the greenspace design that will bring the highest benefit to the population.

On the other hand, in a multiple-themed scenario set, each scenario is composed along a thematic dimension that emphasizes a specific pathway into the future, and each of these scenarios in the set is radically different from another dimension. For instance, the decision-maker wishes to improve accessibility to urban greenspace. A set of greenspace development scenarios can be formed by a combination of scenarios formed under different dimensions. Increasing the area and changing the attributes of an existing greenspace can form one scenario. Building another greenspace in the study area can compose another scenario, and so on.

In practice, the modelling process, that is, the chunking process through which scenarios are composed, involves a simple operation of changing cell

attributes (data and/or information) using the “scenario themes” strategy (Figures 5-3, 5-4 and 5-5) on the cell-base map. The number of discrete scenarios that can be possible generated is myriad.

As noted by Xiang and Clarke (2003), despite the immense universe of a scenario set composition, no individual or organization does or can plan for so many possible scenarios. There is evidence that there comes a point beyond which the quality of the decision starts to decline yet the confidence in the decision still increases with the amount of information gathered. Although there is no golden rule on the number of scenarios in a scenario set, a range of two to seven scenarios is considered generally acceptable. This range is definitively within the cognitive limit of human comprehension and is also consistent with the well-established size standards in the multiattribute assessment and evaluation literature both for objective-attribute hierarchies and for preferences sets.

Nevertheless, the strategy used to create or compose scenarios within the system does not enforce limits on the scenario set size. Indeed, GRAS automatically makes a copy of the cell-based layer under analysis as a new scenario of the scenario set and therefore, the user composes a new alternative scenario starting from an initial scenario that is, the cell-based layer under analysis, in another file basis. It is important to notice that the cell-based layer could be the main “cell based database management system” or a spatial selection of it representing a small study area or even a scenario that was composed before. This procedure will avoid or minimize potential data errors in the system’s database and scenario set without limiting the user’s flexibility. Consequently, the number of scenarios in the scenario set is left to the scenario users/scenarists preferences. Regarding aspects of timeframe or stretch into the future, it is important to make clear that we do not attach any timeline to the scenarios.

Other remarkable aspects of the scenario development process are issues related to data safety and consistency. To avoid errors in the database the following issues were considered:

- 1) Data accessibility and consistency during a new scenario composition process; and
- 2) Database update: acceptance and implementation of scenarios.

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 accessible for user manipulation. For instance, when the user wishes to destroy (delete) a greenspace, a new land use must be specified for the new development in the area. Therefore, the system will automatically delete the data describing

this greenspace, and impose consistency constraints on data manipulation of the user in order to describe a new land use development. Possible new developments are industrial/commercial or residential area. In this sense, land use and socio-demographic data are required to be given by the user in order to describe new land development. Another example, when the user wishes to redesign an existing greenspace, only data regarding attributes and facilities are necessary to be manipulated.

Finally, when a scenario is accepted and implemented, the “Implement Scenario” routine updates, automatically and safely, the Cell-Based Management System.

The scenario population is defined by means of the *Population Synthesizer*, a model within GRAS that creates a synthetic population, which is an imitation of the real population living in the urban environment being studied. GRAS allows the creation of scenarios to represent the urban design and the reproduction of the population with demographics closely matching those of the real population. Together, the scenario composition tool and the synthetic population model represent the built environment. In the next section, the population synthesizer model is described in more detail.

## 5.2 Population synthesizer

In GRAS, significant efforts were made in the direction of adopting a disaggregated approach to system modelling, in which behaviour is the sum of the behaviour of the individual actors comprising the urban system.

Population socio-demographics are crucial to spatial models because such demographics influence the behavioural pattern of each individual. The Aurora micro-simulation model is based on the movement of individual travellers between different locations to conduct activities and individual’s socio-demographics influence how individuals travel across the network to pursue activities in space and time. The same applies to the more static models. Although the static models do not consider the actual movements of individuals in space and time, they do take into consideration the socio-economic characteristics of individuals to express differences in individuals’ preferences and/or behaviour.

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:

- 1) Age;
- 2) Gender;

- 3) Employment status in working hours;
- 4) Household composition: whether or not he/she belongs to a household with child(ren).

Obviously, this information has to be attached to a spatial location. For example, individuals live and work in certain physical locations.

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. Extending a population is required when the aggregate marginal distributions of the relevant variables are known, but the individual profiles that are used in the simulation and that jointly produce the known marginal distributions are not known. Therefore, to create a synthetic population, the Population Synthesizer requires the following type of data source:

- 1) Census tract data of the study area (scenario) on the cell level;
- 2) Demographic data of a representative sample of the real population on the individual level;

As will be explained in Chapter 6 (section 6.1), demographic data available at the level of neighbourhoods was spatially disaggregated to cells (100 x 100 meters), the spatial dimension adopted in GRAS (Chapter 4, section 4.3.1). The scenarios, spatially represented as a cell-based map, contain demographic data on the cell level used by the population synthesizer. The socio-demographics data on the cell level needed by the population synthesizer are:

- 1) Number of inhabitants per cell;
- 2) Percentage of males/females;
- 3) Age groups, defined in terms of 5 subcategories:
  - Age group1: from 0 to 14 years old;
  - Age group2: from 15 to 24 years old;
  - Age group3: from 25 to 44 years old;
  - Age group4: from 45 to 64 years old;
  - Age group5: 65 years or older
- 4) Percentage of the population that is economically active (employment status);
- 5) Percentage of the population that is part of a family based household; and
- 6) Percentage of families with one or more children.

To create a population for small geographic areas (the cell level) of



census groups that maintain the statistical characteristics of the census, a crosstable of the type of Table 5-1, is created. In this sense, the marginal values  $c_{age}$ ,  $c_{children}$ ,  $c_{job}$  and  $c_{gen}$  of Table 5-1 are filled with values from the statistics of the census available in the cell-based file that represents the scenario. However, the cell proportions (filled with exclamation marks – “?” – in Table 5-1) are not available in the tract census, reason why sample data is required. Note that age ( $c_{age}$ ) has five levels, while family composition ( $c_{children}$ ), employment status ( $c_{job}$ ), and gender ( $c_{gen}$ ) have two levels.

Once sample data are available, initial cell counts (cell proportions) for the Table 5-1 are derived from the sample data. The IPF technique is then applied to adjust cell count  $m_{i_1, \dots, i_m}$  given marginal count  $c_{j(i_j)}$ , done by (Beckman *et al.*, 1996):

$$m'_{i_1, \dots, i_m} = m_{i_1, \dots, i_m} \frac{c_{j(i_j)}}{\sum_{i_1 \dots i_{j-1}, i_{j+1} \dots i_m} m_{i_1, \dots, i_m}} \tag{5.1}$$

where,  $j$  is an index of attribute and  $i$  is an index of level.

Adjustment of cell count (or proportion) in a given cell is the basic operation of IPF. This operation is repeated for every margin and every cell until convergence is reached.

As argued by Arentze and Timmermans (2000), IPF is a suitable technique for solving the missing information problem, because of its known property to converge, on the one hand, and to preserve correlation structures between attributes represented in the initial cell proportions, on the other. In other words, IPF keeps odd ratios given by the initial table constant. In case of a 2 x 2 table, this ratio is defined as:

$$\phi = \frac{p_{11}p_{22}}{p_{12}p_{21}} \tag{5.2}$$

Table 5-1. Cross tables for iterative proportional fitting (IPF)

	Job										No-Job										
	Kids					No-Kids					Kids					No-Kids					
Age Groups	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	$c_{gen}$
Female	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	$c_{fe}$
Male	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	$c_{ma}$
$c_{age}$	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
$c_{children}$	$c_{children(ves)}$					$c_{children(no)}$					$c_{children(ves)}$					$c_{children(no)}$					
$c_{job}$	$c_{job(ves)}$										$c_{job(no)}$										

where,  $p_{ij}$ ,  $i = 1, 2$  and  $j = 1, 2$  is the cell proportion of cell  $ij$ .

For a multiway table, odd ratios are defined as a simple extension of the above equation for the  $2 \times 2$  table. Beckman *et al.*, (1996) describe the general form for a  $I_1 \times I_2 \times \dots \times I_m$  table as:

$$\phi = \frac{(P_{i_1 i_2 \dots i_m})(P_{i_1 \dots i_j + c_1 \dots i_k + c_2 \dots i_m})}{(P_{i_1 \dots i_j + c_1 \dots i_k \dots i_m})(P_{i_1 \dots i_j \dots i_k + c_2 \dots i_m})} \quad (5.3)$$

where,  $c_1$  and  $c_2$  are positive integers such that  $i_j + c_1 \leq I_j$  and  $i_k + c_2 \leq I_k$ .

It can be shown that, at every iteration,  $\phi$  is invariant under row and column multiplications implying that the ratios remain unchanged under IPF.

This procedure can of course only be employed if the underlying information is available. If not, complementary steps are required. For instance, when the system was applied to the Eindhoven case study (to be described in Chapter 7), information about the percentage of the population that is economically active was available, but data about the number of working hours was absent. Therefore, the IPF technique will generate individuals with or without jobs only. However, to the greenspace problems, it is important not only to know whether people work or not, but also how many hours per week they work. Full time working individuals are likely to develop different greenspace activity patterns than part-time individuals working.

To generate working hours data, a stepwise regression model (results showed in Appendix A) was applied to the sample data to estimate the number of working hours of each individual of the synthetic population. In particular, the number of working hours of an individual with a job generated by the population synthesizer is a function of his/her age, gender and household composition (child /no child).

Figure 5-6 shows the Population Synthesizer window. As shown in this figure, the user must choose a scenario to create the synthetic population. The interface allows one to create a table with a percentage or even subgroups of the entire population, using age, gender, household composition, and work status constraints or a combination of all these possibilities. Note that the user interface only filters the entire population created by the synthetic population model.

The possibility of reproducing only segments of the population provides extra support to the user to analyse greenspace actions with a particular focus on certain groups of the target population.

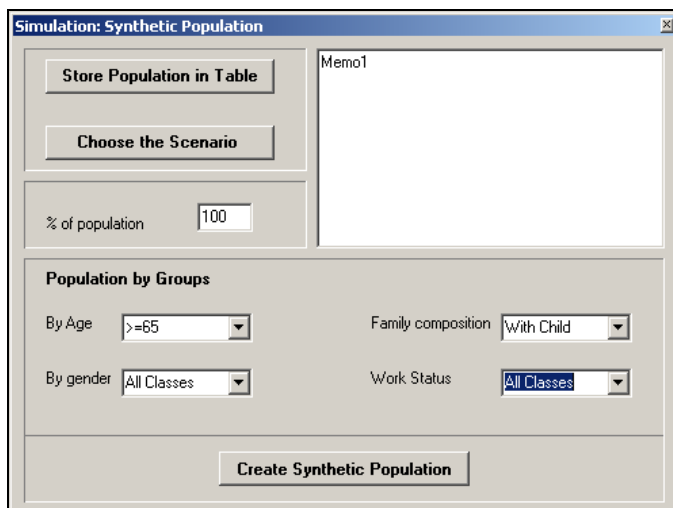


Figure 5-6. Population synthesizer window

### 5.3 The network model

The network model plays an important role in the system. It estimates distances using information of 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.

The shortest path algorithm implemented within this model is based on Dijkstra's algorithm<sup>2</sup>. Dijkstra's algorithm (named after its discoverer, E.W. Dijkstra<sup>3</sup>) solves the problem of finding the shortest path from a point in a graph (the *source*) to each destination. It turns out that one can find the shortest path from a given source to *all* points in a graph at the same time, hence this problem is sometimes called the *single-source shortest path problem*.

The *single-source shortest path problem* is the problem of finding a series of edges connecting two vertices such that the sum of the weights on those edges is as small as possible. More formally, given a weighted graph, (that is a set  $N$  of nodes, a set  $E$  of edges and a  $\mathbb{R}$  real-valued weight function  $f: E \rightarrow \mathbb{R}$ ), and given further two elements  $n, n'$  of  $N$ , the problem is to find a path  $P$  from  $n$  to  $n'$ , so that:

<sup>2</sup> <http://ciips.ee.uwa.edu.au/~morris/Year2/PLDS210/dijkstra.html>

<sup>3</sup> <http://www.cs.utexas.edu/users/EWD/>

$$\sum_{p \in P} f(\hat{p}) \quad (5.4)$$

is minimal among all paths connecting  $n$  to  $n'$ .

Because the transport mode (or travel speed) is not taken into consideration to describe individuals' spatial behaviour on the static level (*Spatial Models Component* describe later in this section), we assume that individuals move in space looking for the shortest distance to generate data for the static models. In these cases, the *Network Model* uses the distance between two vertices to weigh the graph and the shortest path is given by the shortest distance.

On the dynamic level where the simulation of individual behaviour patterns is based on an activity-based perspective (*Spatio-temporal Models*) it is assumed that people seek to minimise travel times in choosing a route to a given destination. The time pressure of everyday life will lead individuals to seek smaller travel times in order to gain time and consequently extra activities can be included in the daily schedule and/or greater time spent on the activities already scheduled. Hence, in this case, the *Network Model* minimises travel time and consequently the graph is weighted using travel times between the connected vertices.

## 5.4 Spatial Models Component

The *Spatial Models Component* consists of a family of discrete-choice models to describe individual's greenspace choice behaviour and a model to calculate spatial accessibility measures to urban greenspaces. This component can be also called a "*Static Component*" in the sense that the models within this component do not consider the movements of the individuals in space and time. Therefore, these models assume that the doorstep is the individual's reference point and the choice set of greenspace alternatives is restricted by some accessibility measure from the individual's doorstep.

This section is organized as follows. In line with the conceptual framework presented in Chapter 4, Subsection 5.4.1 introduces the theoretical underpinnings of discrete choice models and develops a general model of individual choice behaviour. Using this paradigm, four models with different degrees of complexity are implemented in GRAS. They are the awareness model, the preference model, the trip propensity model, and the pressure model. These models are described next. Subsection 5.4.2 then describes a range of accessibility measures implemented under the umbrella of the "*Static Component*" of GRAS.

### 5.4.1 Spatial choice behaviour models

The theoretical underpinnings of the choice models implemented within this component contain elements of traditional microeconomic theories of consumer behaviour, such as random utility theory (RUT) and other assumptions of traditional preference theory, which assume the existence of a single objective function called utility.

Ben-Akiva and Lerman (1985) consider, in more general terms, a universal set of choice alternatives, denoted  $\{J\}$ . The constraints faced by an individual  $i$  determine his or her choice set  $J_i \subseteq \{J\}$ . As in consumer theory, the individual is assumed to have consistent and transitive preferences over the alternatives that determine a unique preference ranking. Thus, a real-valued utility index associated with every alternative can be defined:

$$U_{ij}, j \in J_i \quad (5.5)$$

such that alternative  $j \in J_i$  is chosen if and only if:

$$U_{ij} > U_{ij'}, \forall j \neq j', j' \in J_i \quad (5.6)$$

The essential point of departure is the postulate that utility is derived from the “properties” of things (Louviere *et al.*, 2000). Lancaster (1966) defined utility in terms of the attributes of “commodities”. Using his approach, or the concept of indirect utility, the utility function is defined in terms of attributes:

$$U_{ij} = U(\mathbf{x}_{ij}) \quad (5.7)$$

where,  $\mathbf{x}_{ij}$  is a vector of the attributes values for alternative  $j$  as viewed by individual  $i$ . Income and time budgets and other external restrictions (spatial and/or temporal) determine choice set  $J_i$ . The indirect utility interpretation means that these budgets can also be included in the utility function. Generally, in empirical applications, a vector of socio-economic characteristics that explains part of the variability of tastes across the individuals of the population to which the model of choice behaviour applies is introduced into the utilities. Thus, we write:

$$U_{ij} = U(\mathbf{x}_{ij}, \mathbf{S}_i) \quad (5.8)$$

where,  $\mathbf{S}_i$  is a vector of socio-economic characteristics of individual  $i$  such as income, age, education, household composition, etc.

The notion of rationality is a concept used to describe the individual decision process. In rational choice theories, individuals are seen as motivated by the wants or goals that express their “preferences”. They act within specific, given constraints and on the basis of the information that they have about the conditions under which they are acting. It means a consistent and calculated decision process in which the individual follow his or her own objectives, whatever they may be.

Perfect rationality assumes that individuals (decision makers) can gather and store large quantities of information, perform very complex computations, and make consistent decisions based on those computations. Bounded rationality recognizes the constraints in the decision process that arise from limitations of human beings as problem solvers with limited information-processing capabilities. Thus, it is clear that even in its scientific use, the concept of rationality can be ambiguous unless defined by a specific set of rules.

In this research project, the concept of rationality is used to describe a decision maker with consistent and transitive preferences (if  $U_1 > U_2$  and  $U_2 > U_3$ , then  $U_1 > U_3$ ). It implies that individuals (as decision makers), under identical circumstances, will repeatedly make the same choice, and if choice one is preferred to choice two and choice two is preferred to choice three, then choice one is also preferred to choice three. In choice experiments, however, individuals have been observed not to select the same alternative in repetitions of the same choice situations. Moreover, by changing choice sets, violations of the transitive preferences assumption are also observed. Therefore and for other reasons, a probabilistic choice mechanism was introduced to explain these behavioural inconsistencies.

One can argue that human behaviour is inherently probabilistic. Yet, it can be also argued that the statement behaviour is probabilistic amounts to an analyst’s admission of a lack of more precise knowledge about individual’s decision process. If it were possible to specify the causes of these inconsistencies, deterministic choice theory could be used. The causes, however, are usually unknown, or known but not measurable.

Another type of inconsistency arises in empirical applications when we observe the choices made by a sample of individuals. In this case, we may observe two or more individuals with identical choice sets, attributes, and socio-economic characteristics, selecting different alternatives. The probabilistic mechanism can be used to capture the effects of unobserved variations among individuals and unobserved attributes of the alternatives. It can also take into account pure random behaviour as well as error due to incorrect perceptions of attributes and choices of sub-optimal alternatives. Thus, probabilistic choice theories can be used to overcome one of the weaknesses of traditional consumer theory.

In short, “there is clearly and irresolvable dichotomy between the assertion of fundamentally probabilistic behaviour and what may only appear to us to be probabilistic because of our inability to understand fully and measure all the relevant factors that affect human behaviour” (Louviere *et al.*, 2000).

Referring to this dichotomy, Luce and Suppes (1965) distinguish between two approaches to the introduction of a probabilistic choice mechanism: constant utility and random utility. In the *constant utility* approach, the utilities of the alternatives are fixed. Instead of selecting the alternative with the highest utility, the individual decision maker is assumed to behave with choice probabilities defined by a probability distribution function over the alternatives that include the utilities as parameters. The selection of a probability distribution function in the constant utility approach can only be based on specific assumptions with respect to properties of choice probabilities.

In the *random utility* approach, however, the observed inconsistencies in choice behaviour are taken as a result of observational deficiencies on the part of the analyst. The individual is always assumed to select the alternative with the highest utility. However, the utilities are not known to the analyst with certainty and therefore treated by the analyst as random variables. From this perspective, the choice probability of alternative  $j$  is equal to the probability that the utility of alternative  $j$ ,  $U_{ij}$ , is greater than or equal to the utilities of all other alternatives in the choice set. Manski (1973) identified four distinct sources of randomness:

- 1) Unobserved attributes: the vector of attributes affecting the decision is incomplete;
- 2) Unobserved taste variations: may have an unobserved argument, which varies among individuals;
- 3) Measurement errors and imperfect information: some attributes in the real utility function are not observed.
- 4) Instrumental (or proxy) variables: some of the socio-economic characteristics (instruments) are not captured because they are related to some elements (or attributes) not observed (imperfect relationship between instruments and attributes).

In general, we can express the random utility of an alternative as a sum of observable (or systematic) and unobservable components of the total utilities as:

$$U_{ij} = V(\mathbf{x}_{ij}, \mathbf{S}_i) + \varepsilon(\mathbf{x}_{ij}, \mathbf{S}_i) \quad (5.9)$$

Because the distribution of the residual  $\varepsilon$  is not known, it is not possible at this stage to derive an analytical expression for the model. What is known is that the residuals are random variables with a certain distribution which we can denote  $f(\varepsilon)=f(\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n)$ .

This research project adopts *Random Utility Theory* as the theoretical framework for studying human behaviour and explaining choice behaviour. Let  $\{J\}$  represent the global choice set of greenspace alternatives. Then, a randomly drawn individual  $i$  from the population (i.e. in a simple random sample), will have some attribute vector  $\mathbf{S}_i$ , and face some set of available alternatives  $J_i \subseteq J$ . Hence, the actual choice for an individual, described by particular levels of a common set of attributes  $\mathbf{S}_i$  and alternatives  $J_i$  across the sampled population, can be defined as a draw from a discrete probability distribution (multinomial) with selection probabilities:

$$p(j | \mathbf{S}_i, J_i) \quad \forall j \in J_i \quad (5.10)$$

Two elements of this paradigm of choice behaviour are central to the development of each one of the choice models implemented within the system. These elements are the function that relates the utility of each greenspace alternative  $j$  to the set of attributes  $\mathbf{x}_{ij}$  that, together with utility parameters, determine the level of utility of each alternative, and the function that relates the probability of an outcome to the utility associated with each alternative.

Using this paradigm, we estimated three discrete choice models with different degrees of complexity (and behavioural realism) capturing different aspects of the theoretical framework discussed in Chapter 4, section 4.2.3. From these three discrete choice models, we derived four models to assess/evaluate greenspaces. They are: 1) an *Awareness* model; 2) a *Preference* model; 3) a *Trip Propensity* model; and, 4) a *Pressure* model.

#### *Awareness model*

According to the conceptual framework discussed in Chapter 4 (section 4.2.3), people's awareness of their environment, influences their preference and utility. The concept awareness level is defined here as the probability that individuals know a certain spatial choice alternative. A model developed by Ponjé *et al.* (2005) is embedded in GRAS. This model assumes that the awareness level of an urban greenspace is a function of (a) a set of relevant attributes of the greenspace, (b) a set of relevant characteristics of individuals, and (c) some measure of accessibility. Unfortunately, the data on awareness used to estimate the model only included a list of the 5 best-known greenspaces for each individual. Therefore, they followed the



following procedure. In analogy to random utility theory, they assumed that the awareness level is a latent variable. The awareness level  $A_{ij}$  measures the unobserved awareness of greenspace  $j$  to individual  $i$  as a function of the attributes of the greenspace, the set of socio-economic variables and accessibility ( $a_{ij}$ ). Thus,

$$A_{ij} = F(\mathbf{x}_j, \mathbf{S}_i, a_{ij}) \quad (5.11)$$

In addition, they assumed that the awareness level is a stochastic variable because one generally cannot capture all factors influencing awareness, the functional form may not be specified correctly and individuals may exhibit idiosyncrasies. Thus,

$$A_{ij} = \tilde{A}_{ij} + \varepsilon_{ij} \quad (5.12)$$

Now let there be given a set  $\{J\}$  of greenspaces. Individuals were asked to select a subset  $J_i$  and rank these greenspaces in terms of awareness. In analogue to Luce and Suppes Ranking Choice Theorem (Luce and Suppes, 1965, see also Chapman and Staelin, 1982) it can be stated that:

$$p(j', j'', j''', \dots) = p(j' | J) \cdot p(j'' | j', J) \cdot p(j''' | j', j'', J) \dots \quad (5.13)$$

where,

$p(j', j'', j''', \dots)$  is the probability of observing rank order  $(j', j'', j''', \dots)$ ;  
 $p(j' | J) \cdot p(j'', j''', \dots)$  is the probability that  $j'$  has the highest awareness.

By successfully applying this theorem to the subranking events, it follows that:

$$p(j', j'', j''', \dots) = p(j' | J) \cdot p(j'' | J - \{j'\}) \cdot p(j''' | J - \{j', j''\}) \dots \quad (5.14)$$

Thus, assuming that  $j$  is now the index for the rank order of awareness,

$$p(A_{i1} \geq A_{i2} \geq \dots \geq A_{iJ'}) = \prod_{j^*=1}^{J_i} p(A_{ij^*} \geq A_{ij}) \quad j = j^*, \dots, J_i \quad (5.15)$$

This independence leads to the notion of exploding the rank order. The observation that individual  $i$  ranks the greenspaces in order of awareness, that is  $A_{i1} \geq A_{i2} \geq \dots \geq A_{iJ'}$ , can be decomposed into  $J_i - 1$  statistically

independent choice observations of the form  $(A_{i1} \geq A_{ij}, j = 1, 2, \dots, J_i)$ ,  $(A_{i2} \geq A_{ij}, j = 2, 3, \dots, J_i)$ , ...,  $(A_{iJ_i} \geq A_{ij})$ .

Assuming that the error terms are identically and independently doubly exponential distributed, the multinomial logit model can be estimated from these exploded observations. Thus,

$$p_{ij} = \frac{\exp(\tilde{A}_{ij})}{\sum_{j^*} \exp(\tilde{A}_{ij^*})} = \frac{\exp(\sum_k \alpha_k x_{jk} + \sum_{k'} \beta_{k'} S_i + \gamma_{ij})}{\sum_{j^*} \exp(\sum_k \alpha_k x_{j^*k} + \sum_{k'} \beta_{k'} S_i + \gamma_{ij^*})} \quad (5.16^4)$$

The model was implemented within the system in the following way. First, greenspace awareness is calculated on the individual level. Hence, for every individual we calculated the awareness of each greenspace within its choice set, using equation (5.16). After going through each (and every) individual, a greenspace within the study areas will have an average awareness value that is given by the sum of the individuals' awareness of this particular greenspace.

Individuals' choice sets are given by the subset of greenspaces within the spatial constraint specified by the decision maker/planner through the user interface, shown in Figure 5-7. Hence, an individual's choice set is composed of the greenspaces within a maximum (road network) distance from the individual's doorstep, as specified by the user. Such maximum distance can differ according to greenspace type, assuming that individuals are willing to travel further for larger/better greenspace facilities. The greenspace awareness level will therefore inform the decision-maker/planners about the best known greenspaces in the study area. This type of information is very useful, because it could be used, for instance, as an indicator of maintenance budget management.

Figure 5-7 shows the user interface of the awareness model within GRAS. The estimated parameters of the awareness model (described later in Chapter 6) are inputted in the "Parameters" field of this user interface (Figure 5-7). Due to the small sample size, age, gender, and household specific parameters could not be estimated simultaneously in a reliable way. The parameters listed in Figure 5-7 are based on the full sample for the general attributes and separate sample splits for each of the socio-demographics variables. This assumes that the socio-demographics are mutually independent and not correlated with the general attribute-effects.

<sup>4</sup> Because vector  $\mathbf{x}$  and  $\mathbf{S}$  will consist of categorical variables, a set of indicator variables is typically constructed. This is not explicitly represented in Equation (5.16).

Parameters				
	General	Age Specific	Gender Specific	HHSpecific
LocalParks	-1.2079	0.0132	0.0180	-0.0079
NeighborParks	-0.5632	0.0384	-0.0207	0.0116
DistrictParks	0.51767	-0.0242	0.0044	0.0348
Sport Facilities	-0.0404	0.0609	-0.1031	-0.0427
Walk Path	0.7079	-0.0353	0.0185	-0.1523
Picnic Facilities	0.5330	0.0850	-0.0150	-0.0263
Cafe/Terrace	0.3623	0.0202	0.01786	-0.0661
Toilet	-0.1398	-0.0251	-0.0221	0.0071
Lighting	-0.1489	-0.0030	-0.0373	0.0051
TrashBins	-0.0001	0.0446	0.1100	-0.0700
Playground	0.0713	-0.0799	0.1197	0.1013
Door Step Dist	-0.0003	0	0.00001	0

Figure 5-7. Awareness model user interface

Because this is not true, some (small) bias is introduced. Ideally, the model should be estimated simultaneously on a larger sample. However, the estimated parameters can be used perfectly to illustrate the potential of the system.

### *The preference model*

As indicated in the conceptual framework (Chapter 4, section 4.2.3), we assume that choices are based on the utility individuals derive from the alternatives, which allows them to rank the alternatives in terms of preference. A preference scale can be observed from actual individual behaviour in real markets (revealed preference). Alternatively, it can also be based on individuals stated choices or preferences under experimental conditions. The preference model as estimated by Ponjé and Timmermans (2003), which is embedded in GRAS, is based on the latter approach.

The *preference model* assumes that the preference/utility function has a linear form. In other words, the utility that an individual  $i$  derives from greenspace  $j$  is given by:

$$U_j = \sum_k \beta_k x_{jk} \quad (5.17)$$

where,

$\beta_k$  is a parameter representing the contribution of attribute  $k$  to the utility of park  $j$ ;

$x_{jk}$  is the  $k^{\text{th}}$  attribute of the park  $j$ .

Notice that, because individuals' characteristics are not taken into account the model can be and is in fact applied to the cell unit (100x100m), and we dropped the subscript for the individuals in equation (5.17).

A conjoint choice experiment was conducted to collect data needed to estimate the preference/utility function. A total of 22 attributes was selected and assumed to influence park preferences. Table 1, Appendix B, lists the chosen attributes. First, the distance between the place of residence and the urban park was varied in the experiment. It is believed that distance to the park will influence the probability that a park will be chosen to conduct a particular activity. Secondly, the type/size of park was selected as an influential attribute. The third attribute selected was the type of green. In addition, a set of attributes was chosen to represent the kind of activities that can be conducted in the park and the presence or absence of particular facilities. Finally, accessibility, safety, maintenance and the presence of other people were varied in the experiment. Further details about the estimation results will be discussed in Chapter 6.

Figure 5-8 illustrates the user interface of this model within GRAS. Notice that there are three different rules to define the set of alternatives (choice set) across individuals. Rule 1 defines the choice set for individual  $i$  located in cell  $z$ , as those greenspaces  $j \in J_i$ , 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 as rule1, but allows the user to define different distance criteria for different types of greenspace, suggesting that individuals are willing to travel further to reach bigger/better greenspaces. Rule 3, on the other hand, uses integer  $r$  defined by the user to delineate the choice set, where  $r$  is a constant that counts the number of alternatives. In this rule, the closest  $r$  greenspaces to the individuals doorstep are assumed to make up an individual's choice set.

#### *The trip making propensity model*

A third model (Kemperman *et al.*, 2005), predicts the trip making propensity of individuals to particular greenspaces.

The screenshot shows the 'Preference Model' user interface. It is divided into several sections:

- Choose Scenario:** A button labeled 'Choose Scenario'.
- Results:** A section with two dropdown menus: 'Utility' (set to 'Utility') and 'Probability of use' (set to 'Probability').
- Choice Model Settings:** A section containing three rules:
  - Rule 1:** 'Maximum Distance' set to 400. A 'Calculate1' button is below it.
  - Rule 2:** 'Maximum Distance for different Types of Parks'. It includes input fields for 'Local Parks' (400), 'Neighborhood Parks' (800), 'District Parks' (1600), and 'City Parks' (3200). A 'Calculate2' button is below it.
  - Rule 3:** 'Get a number of Closest Parks' set to 2. A 'Calculate 3' button is below it.
- Parameters - Utility Function:** A list of parameters and their values:
 

Base Value	-0.1798868
Type	-0.0855543
Public Transport	-0.0615927
Lake	0.0252512
Sport Facilities	0.036301
Dogs Allowed	0.0782534
Path	0.1427452
Relaxation	-0.0052548
Nice View	0.0704856
Organized	0.0562399
Crowded	-0.0074667
Safe	0.0277016
Maintained	-0.0238824
Clean	0.0179699
Ecological	-0.0086232
Benches	-0.0002808
Cafe	0.0898522
Playground	0.0097614
Toilets	0.0200434
Lights	0.0148342
Dustbins	0.0025557

Figure 5-8. Preference model user interface

This model characterises urban greenspace based on the trip making propensity of individuals to these urban greenspace. It is important to make clear that, while the preference model calculates the utility of (and preference order for) greenspaces based on spatial and non-spatial attributes using stated preference data, the trip making propensity is intended to simulate individual choice behaviour based on revealed preference data.

To predict the allocation of trip frequencies across different types of urban greenspace, the model assumes that the choice of greenspaces for recreational and leisure trips involves substitution. Therefore, besides individual socio-demographics and greenspace's specific attributes, the model tries to capture the effect of temporal variation (time of the day, day of the week and season of the year) on the individual's choice.

A mixed logit model (Revelt and Train, 1998; Train, 1998; Bhat, 2000) is used to estimate individuals' trip making propensity for urban greenspaces. The mixed logit model obviates three limitations of the standard multinomial logit model. First, it allows the parameters associated with each variable to vary randomly across individuals, often referred to as unobserved heterogeneity. In the current study, this implies that different individuals can

have different preferences for urban greenspaces. Second, the variance in the unobserved individual specific parameters induces correlations across the alternatives in the stochastic portion of the utility. Hence, the mixed logit model does not exhibit the so-called Independence from Irrelevant Alternatives (IIA) property that is implied by the assumption of independently and identically distributed error terms causing independency of the choice probabilities from the characteristics of any other alternative in the choice set. A pattern of correlations in unobserved factors influencing trip making propensity for urban park types and hence substitution patterns between these parks can be obtained. Third, correlation in unobserved factors over time can be examined. Thus, the mixed logit model allows the efficient estimation when there are repeated choices by the same individuals.

This model can be described as follows. An individual  $i$  chooses among  $J_i$  possible alternatives (greenspaces). The utility that individual  $i$  derives from greenspace  $j$  at observation  $t$  is:

$$U_{ijt} = \alpha_{ij} + \beta \mathbf{x}_{ij} + \varepsilon_{ijt} \quad (5.18)$$

where,

$\alpha_{ij}$  is a random alternative-specific constant associated with  $i = 1, \dots, I$  individuals and  $j = 1, \dots, J_i$  alternatives;

$\beta$  is a non-random parameter representing the contribution of individual-specific and alternative-specific attributes to the utility function;

$\mathbf{x}_{ij}$  is a vector representing the contribution of individual-specific and alternative specific attributes to the utility function;

$\varepsilon_{ijt}$  is an unobserved random term for the utility of visiting greenspace  $i$  to individual  $i$  for observation  $t$ , that is independently and identically distributed (IID) according to a Gumbel distribution.

The alternative specific constant is a random parameter and allowed to vary across individuals. For each random parameter  $\alpha_{ij}$ , a new parameter can be defined. Let the distribution of the variation of the individual-specific parameter be normally distributed (lognormal is often used if the response parameter needs to be of a specific sign):

$$\alpha_{ij} = \gamma_j + \mu_{ij} \quad (5.19)$$

where,

$\gamma_j$  is a vector of parameters that identify the average preference for alternatives  $j$  in the population;

$\mu_{ij}$  is a random term assumed to be normally distributed with mean zero

The  $\mu_{ij}$ 's are individual and alternative-specific, unobserved random disturbances and are the source of unobserved heterogeneity across individuals in the preference for alternative  $j$ . The probability that individual  $i$  will choose alternative  $j$ , conditional on  $\mu_{ij}$  can be described in terms of the multinomial logit form:

$$p(j|\mu_{ij}) = \frac{\exp(\alpha_{ij} + \beta \mathbf{x}_{ij})}{\sum_{j=1}^{J_i} \exp(\alpha_{ij} + \beta \mathbf{x}_{ij})} \quad (5.20)$$

Figure 5-9 illustrates the user interface of this model within the system. In short, given a scenario and its synthetic population, this model predicts the probability of greenspace usage, given the season of the year, the day of the week and the time of the day. Notice in Figure 5-9 that users can control the way the system outlines the individual's choice set, by means of the "*Spatial Constraints*" field in the user interface. In this field, there are four "fill-in-the-blank" edit boxes where the user may define distance thresholds that will be used as a rule to compose the greenspace choice set. Hence, an individual's choice will be defined as the set of greenspaces that are located within the distance threshold inputted in the user interface, given greenspace type, from the individual doorstep. In the "*Temporal Aspects*" field of the user interface, the user may specify the season of the year, the day of the week (weekdays or weekends) and the time of the day (morning, afternoon or evening) to choose the level for which trip making propensity to greenspaces will be calculated.

The estimated parameters of the trip making propensity model (described later in Chapter 6) are inputted in the "*Parameters*" field of the user interface (Figure 5-9). Observe that the type of greenspace is the only greenspace-specific variable that will influence an individual's trip making propensity to greenspaces. Others exploratory variables are the temporal elements and individual socio-demographics.

In short, the following procedure is implemented. First, the system calculates the accumulated trip propensities (probabilities) to which an individual make to the greenspaces of the choice set, using equation (5.20) and the variables and parameters shown in the user interface (Figure 5-9). Next, the system generates consistent uniform random variables and uses them to simulate the individual choice of a particular greenspace in the choice set to make a trip, given the season of the year, the day of the week and the time of the day. In this sense, the higher the trip making propensity, higher is the probability of a particular greenspace be chosen.

**Choose Scenario**  
**Synthetic Population**

**Spatial Constraints**  
 Local Parks: 400  
 Neighborhood Parks: 800  
 District Parks: 1600  
 City Parks: 3200

**Temporal Aspects**  
 Day of the week: [dropdown]  
 Time of the day: [dropdown]  
 Season: [dropdown]

Save Results in: Results [dropdown] **Calculate**

Parameters		Interactions		LocalP	NeighbP	DistrictP	
Constan	-2.451			Spring	0.074	0.09	0.034
LocalP	0.323			Summer	-0.038	-0.032	0.01
NeighbP	0.104			Autum	-0.0422	-0.0357	-0.0639
DistrictP	-0.451			Weekday-Morning	-0.043	-0.103	0.175
Distance	-0.0001			Weekday-Afternoon	-0.117	-0.0455	-0.014
Spring	-0.08			Weekday-Evening	-0.198	-0.219	-0.211
Summer	0.096			Weekend-Morning	0.004	-0.126	0.028
Autum	0.042			Weekend-Afternoon	-0.002	-0.031	-0.085
Winter	-0.058			Weekend-Evening	0.071	0.198	0.122
Gender	0.066			Gender	0.006	-0.05	-0.015
WorkHours	-0.001			WorkHours	-0.0005	0.005	-0.003
HHWithKids	0.039			HHWithKids	-0.078	-0.112	-0.07

Figure 5-9. Trip making propensity model user interface

This procedure is repeated to every individual of the scenario population. Every time an individual visit a specific park, the park is scored with a visit. As output, greenspaces are scored with the number of visits of individuals, given the season of the year, the day of the week and the time of the day.

*Greenspace Pressure Model*

The trip propensity model ultimately results in a prediction of the number of individuals within some time horizon (day, time of the day, and season) that visit a particular greenspace. To allow planners/decision makers to identify the greenspaces that are highly visited during a particular season, in the sense that the number of visitors may cause some environmental concerns (number of visits exceed norm), a greenspace pressure model was added.

The *pressure* of greenspace usage is defined here as the number of individuals visiting a given greenspace per hectare of greenspace, per day, per season. To calculate this performance indicator the following procedure was implemented.

First, based on the greenspace main survey questionnaire described in Chapter 6, frequency distributions of individuals’ visits across greenspaces were estimated for the different seasons of the year. The CHAID (Chi-



square-Automatic-Interaction-Detection) technique was used to detect interactions between a dependent variable (in this case the total number of visits to greenspaces per season – continuous variable) and a series of predictive variables (in this case, individuals’ socio-demographics characteristics, such as age, gender, employment status and household characteristic - with or without children). CHAID selects a set of predictors and their interactions that optimally predict the dependent variable. In other words, CHAID identifies discrete groups of respondents (segmentation of individuals with similar and relevant socio-demographics characteristics) and predicts the number of visits to greenspaces across the seasons (see results in Appendix C).

Having found the frequencies with which individuals visit greenspaces across seasons, we may now apply a model to predict to which particular greenspaces individuals actually go. To this end, we use the parameters and equations of the “trip making propensity to urban parks” model described above (Kemperman *et al.*, 2005) to calculate the probabilities of greenspace visits in the choice set.

The screenshot shows the 'Pressure' model interface with the following data:

Spatial Constraints		Temporal Constraints	
Local Parks	400	Season	[Dropdown]
Neighborhood Parks	800	Memo1	[Text Area]
District Parks	1600		
City Parks	3200		

Variables		Interactions			
Constant	-2.451	[Results Dropdown] [CalculatePressure Button]			
LocalP	0.323				
NeighbP	0.104				
DistrictP	-0.451				
Spring	-0.80	LocalP	NeighborhoodP	DistrictP	
Summer	0.096	Spring	0.074	0.090	0.034
Autumn	0.042	Summer	-0.038	-0.032	0.010
Gender	0.066	Autumn	-0.044	-0.031	-0.043
WorkH	-0.001	Gender	0.006	-0.050	-0.015
HHType	0.39	WorkH	-0.0005	0.005	-0.003
Distance	-0.0001	HHType	-0.078	-0.112	-0.070

Figure 5-10. Pressure Model user interface in GRAS

Finally, the number of visits that an individual pays to each greenspace from its choice set is given by the number of visits that this individual makes to greenspaces in a given season (result of the CHAID analysis), multiplied by the probability of visiting such a greenspace found by the trip propensity model.

Repeating this procedure for each individual of the population scenario returns an aggregate number of visits across the greenspaces in the study area. The aggregate number of visits of each greenspace is then divided by the number of days in the season and by the size of the greenspace (in hectare) resulting in a measure of greenspace pressure.

Figure 5-10 shows the user interface of the pressure model. Notice that the effect of the day of the week and time of the day is not taken (as it is in the “*trip making propensity*” model) into account. Rather, this model is focused on informing administrators about the intensity of use of greenspaces by season as an indicator of pressure.

#### **5.4.2 Accessibility performance measures**

Many different measures of accessibility have been proposed in the literature. Sometimes accessibility measures focus on individual accessibility (Pirie, 1979; Talen and Anselin, 1998; Kwan, 1998), while others more or less focus on place accessibility (for example, Geertman and Ritsema van Eck, 1995; Song, 1996; Handy and Niemeier, 1997).

In this project, the concept of accessibility refers to the level of access for green activity from any home within cell  $z$  to each of greenspace locations  $j$ , given the distance  $d_{zj}$ . Handy and Niemeier (1997) argued that, a best approach to measuring accessibility does not exist. Different situations and purposes may demand different approaches.

GRAS includes nine accessibility measures. Six of the ten accessibility measures implemented within GRAS 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). One of them, known as 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). Another measure, also known as container measure, counts the number of opportunities (Wachs and Kumagai 1973) i.e. the number of greenspaces within a certain distance threshold defined by the decision maker. The minimum distance simply measures the distance from a home location to the closest greenspace facility.

In the remainder of this section, each accessibility measure implemented in GRAS is described in more detail.

*Container Measure*

This measure, also called isochronic index, counts the number of opportunities within some maximum travel distance (threshold) from the home location. For example, Wachs and Kumagai (1973; see also Talen and Anselin, 1998; Breheny, 1978) suggested the following measure:

$$a_z = \sum_{j=1}^{J_z} y_j \quad (5.21)$$

where,

$a_z$  is the accessibility of individuals in zone  $z$  to greenspaces;

$J_z$  is the set of locations included in the calculation of accessibility for zone  $z$ .

$$y_j = \begin{cases} 1, & \text{if } j \in J_z \\ 0, & \text{otherwise} \end{cases} \quad (5.22)$$

and,

$$J_z = \{j \mid d_{zj} < D_z\} \quad (5.23)$$

Equation (5.23) indicates that a greenspace  $j$  is counted in the calculation of the accessibility container measure if the distance from the individual home  $z$  to such a greenspace is smaller than some threshold  $D_z$  defined by the decision maker. By setting  $D_z$  at infinity, all locations in the study area will be included in the calculations. Church and Marston (2003) suggested to limit the set to some fixed number, which are at the closest distance to home. A disadvantage of this measure is that all locations within the distance band contribute equally to accessibility; there is no spatial discounting. A higher value implies better accessibility.

The user interface for this accessibility measure is shown in Figure 5-11. Notice that the *minimum distance* accessibility measure can also be calculated by the algorithm for the container measure. In that case, if the user chooses the option “*Find Closest Facility Distance*” from the “Save Results” drop down box of the user interface (Figure 5-11), the system finds for every cell of the study area, the distance to the closest greenspace facility. In this case, a higher value implies worse accessibility.

The screenshot shows the 'Accessibility' software window with the 'Container Measure' tab selected. The interface is organized into several sections:

- Choose Scenario:** A button to select a scenario.
- Within Distance (meters):** A text input field containing the value '400'.
- Save Results:** A dropdown menu currently showing 'First Closest Facility Distance'.
- In Field:** A dropdown menu currently showing 'CLOSESTPAR'.
- Add:** A button to add a new entry to the table.
- Table:** A table with two columns: 'Number of Opportunities' and 'ACCNUMOPPO'. The first row contains 'First Closest Facility Distance' and 'CLOSESTPAR'.
- Remove:** A button to remove an entry from the table.
- Calculate:** A button to perform the accessibility calculation.

Figure 5-11. Accessibility: container measure

### *Cumulative Opportunity Measure*

As said, a disadvantage of the container measure is that the influence of distance is the same within the selected threshold, which is an unrealistic assumption. Black and Conroy (1977) and Kwan (1998) therefore suggested an accessibility measure, called *cumulative opportunity measure*, where accessibility is the weighted sum of distances to opportunities, and the weights are defined as the size (space floor) of opportunities at the activity locations. Thus,

$$a_z = \sum_{j=1}^{J_z} O_j f(d_{zj}) \quad (5.24)$$

where,

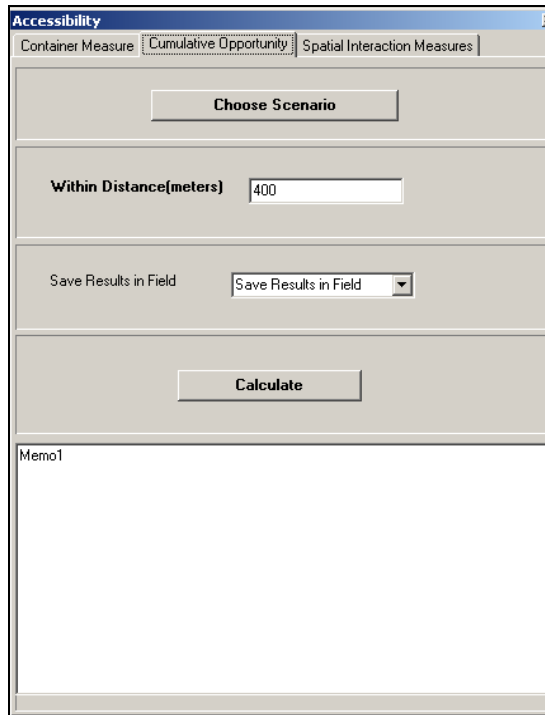


Figure 5-12. Accessibility: cumulative opportunity measure

$$f(d_{zj}) = \begin{cases} (D_z - d_{zj}) / D_z & \text{if } d_{zj} \leq D_z \\ 0 & \text{otherwise} \end{cases} \quad (5.25)$$

A smaller value of the cumulative negative linear function implies a better accessibility.

Figure 5-12 illustrates the user interface window for the cumulative opportunity measures. As before, the user (decision maker/planner) takes the responsibility of setting a proper distance threshold, i.e. the  $D_z$  value, using the user interface.

#### *Spatial Interaction Measures*

Other accessibility measures implemented within GRAS are based on models of spatial interaction. For example, Hansen (1959) proposed a gravity-based measure, here called *gravity potential* (Talen and Anselin,

1998), leading to a power function of the following form (implemented in GRAS as *Gravity Potential* measure):

$$a_z = \sum_{j=1}^{J_z} O_j d_{zj}^{-\beta} \quad (5.26)$$

where,

$\beta$  is the friction parameter or the distance decay factor.

An alternative formulation is the following exponential function, which is derived from Wilson's entropy-maximisation model (see e.g. Dalvi, 1978).

$$a_z = \sum_{j=1}^{J_z} O_j \exp(-\beta d_{zj}) \quad (5.27)$$

This measure places more emphasis on accessibility over short distances and is implemented in GRAS as *Entropy Maximising Model* measure.

The magnitude of the friction parameter  $\beta$  can be arbitrary set by the user via user interface (see Figure 5-13). For the current application of GRAS, the parameter value derived from the trip propensity model ( $\beta = -0.0001$ ) was assumed. Arguably, this model differs from the gravity and/or entropy maximising models, and the user could estimate the  $\beta$ -parameter using these models instead.

The equations above do not take into consideration the probability that a location will be visited. To incorporate this notion into the calculation of accessibility, probabilistic measures have been suggested (Zakaria, 1974; Geertman and Eck, 1995):

$$a_z = \sum_{j=1}^{J_z} p_{zj} d_{zj} \quad (5.28)$$

In case of a gravity-based measure, these probabilities are calculated within GRAS (measure named *Probability Gravity-Based*), using the following equation:

$$p_{zj} = \frac{O_j d_{zj}^{-\beta}}{\sum_{j=1}^{J_z} O_j d_{zj}^{-\beta}} \quad (5.29)$$

and in case of a entropy maximisation based measure (named in GRAS as *Probability Entropy-Based*), as follows:

$$p_{zj} = \frac{O_j \exp(-\beta d_{zj})}{\sum_{j=1}^{J_z} O_j \exp(-\beta d_{zj})} \quad (5.30)$$

In general, a lower score on these accessibility measures means a better accessibility.

The *Consumer surplus* approach (Niemeier, 1997), also known as accessibility measures based on random utility theory (see also Ben-Akiva and Lerman, 1985; MacFadden, 1981), is based on the notion that individuals derive some utility from each destination and select the destination that maximizes their total utility. The expected value (mean) of this quantity is then a measure of accessibility. The exact definition depends on the specification of the choice model. In case of the gravity model, accessibility is equal to:

$$\frac{\alpha}{\beta} \ln O_j - d_{zj} \quad (5.31)$$

Wilson (1976; see also Coelho and Wilson, 1976; Miller, 1999) showed for the *gravity model* (named in GRAS as *gravity consumer surplus measure*) that the net interaction benefits for an individual living in cell  $z$  who chooses location  $j$  is equal to where  $\alpha$  is equal to the exponent of the attractiveness variable, implying that a locational benefits based accessibility measure incorporating  $j$  location can be expressed as:

$$a_z = \frac{1}{\beta} \sum_{j=1}^{J_z} \ln(O_j - d_{zj}) \quad (5.32)$$

Martin and Williams (1992), and Love and Lindquist (1995) formulated an alternative log sum measure (named in GRAS as *log sum consumer surplus measure*):

$$a_z = \frac{1}{\beta} \ln\left(\sum_{j=1}^{J_z} O_j \exp[-\beta d_{zj}]\right) \quad (5.33)$$

The screenshot shows a software window titled "Accessibility" with three tabs: "Container Measure", "Cumulative Opportunity", and "Spatial Interaction Measures". The "Spatial Interaction Measures" tab is active. The interface includes a "Choose Scenario" button, a "Within Distance (meters)" input field set to 400, a "Beta Value" input field set to -0.0001, and a "Save Results in Field" dropdown menu set to "Result Field". Below these are two columns of model selection buttons: "Accumulative Distance Models" (Gravity Potential, Entropy Maximising Model) and "Probability Models" (Probability Gravity-Based, Probability Entropy-Based). At the bottom left are "Consumer Surplus Models" (GravityConsumerSurplus, Log Sum Consumer Surplus), and at the bottom right is a "Memo2" text area.

Figure 5-13. Accessibility: spatial interaction methods

Figure 5-13 shows the user interface to calculate accessibility using the spatial interaction methods. As before, the user (decision maker/planner) must choose a scenario to analyse accessibility issues, the distance threshold to outline the cell based greenspace choice set  $J_z$  and the value of the distance friction parameter  $\beta$ .

As noted by Arentze (1999), it seems that most of the accessibility measures proposed in the literature can be derived from a limited set of generating principles or rules. First, some *inclusion rule* determines which locations are incorporated in the calculations of accessibility. The most common inclusion rule is that all locations in the study are incorporated in the measurement of accessibility. It can also be assumed that only those locations within some action space from home are included. Secondly, an *attractiveness rule* determines the contribution of the non-locational attributes of the location to the accessibility measure. Thirdly, an *allocation rule* represents how users are allocated to optional destinations. Fourthly, a *evaluation rule* determines the relative importance of travel distances and attributes of the locations in the calculation of accessibility. Finally, a



*normalization rule* dictates whether or not the measure of accessibility is standardized.

## 5.5 Spatial Temporal Component

Micro-simulation, which simulates the dynamic behaviour of an individual explicitly over both time and space to generate aggregate system behaviour, has been applied with increasing frequency over the past decade or more in the field of transportation system analysis (Arentze *et al.*, 2005).

The need for more realistic representations of behaviour in urban modelling is well acknowledged in the literature (e.g., Pas, 1985; Kitamura, 1988; Ettema *et al.*, 1993; Bhat and Koppelman, 2000; Timmermans *et al.*, 2000; Wegener, 2001; Joh, 2004; Miller *et al.*, 2004) as the result of an increasing realization that the traditional *statically-oriented* approach to urban processes modelling needs to be replaced by a more *behaviourally-oriented* modelling approach. A more disaggregate approach to modelling socio-demographic processes such as public facilities location, travel behaviour, etc. is generally desirable in order to reduce model aggregation bias, enhance its behaviour fidelity, etc. (Goulias and Kitamura, 1992). Furthermore, the dynamic evolution of urban systems must be explicitly captured if future system states are to be properly estimates. That is, it can be strongly argued that the urban systems evolve in a path-dependent fashion (especially in the presence of significant policy interventions into the system) that may not be well captured by conventional static equilibrium models. Putting these two observations together leads inevitably to the adoption of the micro-simulation approach to modelling such systems (Miller *et al.*, 2004).

Today there are several micro-simulation models of urban land use and transport. Examples of such models include TRANSIMS (Barrett *et al.*, 1995), DYNASMART<sup>5</sup> (Hu and Mahmassani, 1995), PARAMICS (Quadstone, 1999), INTEGRATION (Van Aerde and Yager, 1988), DynaMIT<sup>6</sup> (Ben-Akiva *et al.*, 1999), *Albatross* (Arentze and Timmermans, 2000) and ILUTE (Miller *et al.*, 2004). They differ in terms of their goals and objectives, but a detailed discussion goes beyond the topic of this chapter. Suffice it to say that none of these models address (re)scheduling behaviour of individuals in a space-time prism. In GRAS, we implement a simplified version of a model of activity (Re)scheduling, named Aurora (Joh *et al.*, 2001; Joh, 2004), which is based on the activity-based approach.

<sup>5</sup> <http://www.ce.utexas.edu/prof/mahmassani/DYNASMART-X/>

<sup>6</sup> <http://mit.edu/its/dynamit.html>

The activity-based approach to the study of urban travel behaviour is founded on the principle that the demand for travel is based upon the need to participate in activities outside of the home (Jones *et al.*, 1990; Ettema *et al.*, 1993; Bhat and Koppelman, 2000).

Our interest in applying the activity-based approach to this research project is to examine the participation of individuals in green activities. The ultimate goal of our effort is concerned with the need to understand and therefore predict activity *choice dynamics*. Such a need is particularly acute as it shifts the unit of analysis from greenspace facilities to individual greenspace activities participation. In this sense, 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 how individuals schedule their planned activities as a function of available time, transport mode, etc., is more relevant, especially when the focus is on examination of non-mandatory activities such as greenspace. Spatio-temporal constraints are critical in the sense that the temporal considerations on individual activity participation decisions (with more temporal 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. Thus, the restrictions imposed by mandatory activities and external (spatio-temporal) constraints reflect the individuals' available activities and locations choice set.

This section is organized in three subsections. In the first subsection, the conceptual framework and formalization of the Aurora model is described. The conceptual framework involves the development of two complementary components of the model: an activity utility function and a heuristic search method for decision-making related to schedule adjustment. In the second subsection, we introduce some operational procedures/solutions that were treated differently in GRAS in order to have the Aurora model operational and appropriate to cope with some specific issues in the greenspace context given the available data. In the third subsection, we develop greenspace-specific performance measures based on the Aurora model outputs.

### **5.5.1 A Model of Activity (Re)scheduling**

This section describes the conceptual framework and the formalization of the Aurora model implemented within GRAS. The Aurora's implementation

within GRAS is an adaptation of the original model (Joh, 2004; Joh *et al.*, 2001) that came about because of a further elaboration of the model and limitation of data availability.

It should be emphasized from the very beginning, however, that this section is not meant to be a comprehensive, in-detail review of the original work (Joh, 2004; Joh *et al.*, 2001). Rather, this section will present in some detail the parts of their work that have direct relevance to the implementation of Aurora within GRAS.

Individuals' scheduling and rescheduling behaviour involves the following conceptual considerations. First, individuals execute activities to meet a variety of needs. Fulfilling activities returns satisfaction or utility as a reward for meeting the needs.

Secondly, a set of circumstantial conditions limits the extent to which individuals can increase utility. These conditions include individuals' spatio-temporal constraints and the physical environment surrounding them. Activities are then organized in space and time (Pred, 1981; Thrift, 1983).

Thirdly, individuals are assumed to use heuristics in looking for alternatives instead of becoming involved in an exhaustive search, because their rationality is bounded. Individuals usually have numerous alternative ways of specifying a schedule given a time horizon, each of which may result in a different level of utility. Cognitive constraints however prevent individuals from identifying and evaluating every single alternative in the universe of alternatives. Individuals therefore use heuristics to reduce the burden of search and to pursue cost effectiveness.

Finally, an activity schedule is tentative and may be changed at any time. Every moment in time, there may be the need for changing the schedule of remaining not-yet-completed activities. An individual may be forced to change the schedule due to time pressure or may actively decide to change and improve the existing schedule. Any (sub-optimal) decision is enforced until a further need to reschedule the activities arises.

Based on the above discussion, a conceptual framework of individuals' scheduling and rescheduling behaviour is formulated. Initially, mandatory (or fixed) activities, such as work or school, are typically fixed in a short time horizon of a day. As the model focuses on daily scheduling, the selection, location, duration and start-time of such fixed activities are considered given. Following previous work (Kitamura and Fujii, 1998; Arentze and Timmermans, 2004), the term schedule *skeleton* is used to refer to the fixed and given part of the schedule. Given the activity skeleton, scheduling involves decisions to add optional activities, hereafter referred to as *flexible* activities. The set of activities included in the current schedule is a subset of a larger activity program. The individual evaluates the utility of activities for possible implementation. When an individual evaluates the

utility of alternative activities under a set of constraints, he/she examines whether some change of the schedule can improve the total utility. When no more improvements are possible, the adjusted activity schedule is implemented. During execution of the schedule unexpected events may occur, such as traffic congestion, cancellation of a business meeting, etc., causing increased or reduced time pressure. Therefore, the schedule will often be only partially implemented, and the adjusted schedule remains tentative.

This scheduling theory uses the following notation.  $AP = \{1, \dots, a, \dots, A\}$  represents an activity program, where  $a$  is an index for activities. Furthermore, let  $S$  represents a set of scheduled activities.  $R$  represents the complementary set of activities that are not scheduled at the current stage of scheduling.  $U$  represents the *total utility* of the schedule that consists of the utility  $U(S)$ . An activity schedule is a sequence of activities  $[a_1, \dots, a_k, \dots, a_K]$ , where  $a_k \in S$ , and  $k$  is an index for positions in the current schedule.

Each activity includes a variety of schedule resources such as duration  $v$  ( $v > 0$ ), start time  $t$  ( $t \in \{0, 1, \dots, T\}$ ), location  $l$  ( $l \in \{1, \dots, L\}$ ), and travel time  $\Lambda$  ( $\Lambda \geq 0$ ).

The nature of each activity and, institutional and situational constraints limit these schedule resources. Activities can be conducted only at a particular location  $l$ . Institutional constraints sometimes confine the start and end times of an activity. The start time  $t_a^s$  should be in-between the earliest and latest possible start times  $t^{s-}$  and  $t^{s+}$ . Likewise, the end time  $t_a^f$  should be in-between the earliest and latest possible end times  $t^{f-}$  and  $t^{f+}$  (e.g., opening hours or work contract). Travel is treated as an independent activity. Thus, a travel episode takes place when the next activity is conducted at a different location than the current activity location. Let  $j$  ( $j \in \{1, \dots, J\}$ ) denote the travel episode index and  $v_j^t$  is the duration of the travel episode  $j$ . For all episodes (activity or travel), start time equals end time previous episode and end time equals start time next episode.

The scheduling problem is to find the activity schedule at a particular point in time on a particular day by which an individual achieves the following objective.

$$\max_{\{S\}} U \quad (5.34)$$

The total function for an entire schedule should aggregate the utilities across activities and travels episodes of  $S$ . In the current implementation, we assume a simple additive aggregate utility function as:

$$U = \sum_{a=1}^A U_a + \sum_{j=1}^J U_j \quad (5.35)$$

Given the utility function for individual activities,

$$U_a = U_a^{\min} + \frac{U_a^{\max} - U_a^{\min}}{(1 + \gamma_a \exp[\beta_a(\alpha_a - v_a)])^{1/\gamma_a}} \quad (5.36)$$

and travel episodes,

$$U_j = v_j^t \omega \quad (5.37)$$

subject to:

$$S \cup R = AP \quad (5.38)$$

$$S \cap R = \emptyset \quad (5.39)$$

$$t_e^s + v_e = t_e^f, \forall e \quad (5.40)$$

$$t_e^s + v_e = t_{e+1}^s, \forall e \quad (5.41)$$

$$\sum_{e=1}^E v_e = B \quad (5.42)$$

$$l_a \in \{l\}_a, \forall a \quad (5.43)$$

$$t_e^{s-} \leq t_e^s \leq t_e^{s+}, \forall e \quad (5.44)$$

$$t_e^{f-} \leq t_e^f \leq t_e^{f+}, \forall e \quad (5.45)$$

where,  $a$  is an index of activities;  $v$  is the duration of the episode;  $U^{\min}$  and  $U^{\max}$  are constants that asymptotically determine the minimum and maximum utility of the activity, respectively;  $\alpha$ ,  $\beta$  and  $\gamma$  are additional coefficients of the activity utility;  $\omega$  is a transport-mode specific marginal utility of a minute travel;  $e$  ( $e \in \{1, \dots, E\}$ ) is the index for an episode in general (activity or travel);  $e+1$  is the episode scheduled next to  $e$ ;  $B$  is the time budget of the day, which normally stands for 24 hours, as we consider the case of daily scheduling.

The additive form of the utility function (Equation 5.35) with the time budget constraint (5.42) implies that activities and travel episodes have a general relationship with all others regarding their duration in the schedule. Increasing the duration of an activity means without exception that the duration of other activities is decreased, depending on their utility function. To increase total utility, therefore, utility increase of the increased activities must exceed utility decrease of the decreased activities, and no change is induced otherwise. Thus, in equilibrium the marginal utilities of the activities in the schedule are equal.

Equations (5.38) and (5.39) state that the list of activities to be scheduled should be a subset of a given activity program. Equations (5.40) to (5.42) show that the sum of durations across activities and travels episodes equals the total duration of the schedule, and hence, satisfies the time budget constraints in all situations. Equation (5.43) determines the location of a scheduled activity  $a$ . Equation (5.44) and (5.45) dictates that the start and end time of an episode  $e$  should meet the time constraints set by the institutional context and episodes duration.

Equation (5.36) is used to define the general form of the relationship between utility and duration of an activity and Equation (5.37) is used to calculate the (dis-)utilities of travel episodes. In the following, we provide a detailed description of these utility functions.

### *Utility functions*

The general form of the activity utility function of equation (5.36) is an asymmetric S-shaped curve with an inflection point. This functional form was originally developed in biological science, and is called a generalized logistic curve or growth curve (Richards, 1959). Although the original application of the function far differs from the present topic of research, this functional form is employed because it suits the description of the activity utility theory of the Aurora model (Joh, 2004; Joh *et al.*, 2001). The elements have the following interpretation.

The maximum utility ( $U^{\max}$ ) represents the (anticipated) utility derived from the activity if the time available is unlimited. Second, the minimum

utility ( $U^{\min}$ ) represents an individual's evaluation of the situation if activity duration is zero. The minimum utility is zero because not conducting the activity merely means the absence of benefits.

The  $\alpha$  parameter determines the duration at which the marginal utility reaches its maximum value (inflection point). The  $\beta$  coefficient determines the slope of the curve, a larger  $\beta$ -value meaning that the activity utility is more sensitive to duration and hence less flexible in terms of adaptation. The  $\gamma$  coefficient determines the relative position of the inflection point. If the value is close to 1, the curve approximates a symmetric curve, and the inflection point is in the middle between the maximum utility and zero. When the value approximates 0, the utility at the inflection level is also close to zero, implying that marginal utility is diminishing at virtually all levels of duration.

Figure 5-14 shows various specifications of the activity utility function that illustrate the impacts of parameters determining the level of utility over duration. In this figure, the X-axis represents activity duration  $v$ , while the Y-axis represents utility of activity. Thus, each point in the curve describes an individual's utility of the anticipated value of the activity under that duration choice.

The upper left figure of Figure 5-14 illustrates two activities having the same utility parameter values, except for the  $\alpha$  values, which are 100 and 150 for utility curves of activities A and B, respectively. As a result, activity B requires much more duration to reach the same level of utility than activity A.

The upper right graph of Figure 5-14 illustrates two activities with different  $\beta$  values of 0.5 and 1.0, respectively. The utility curve of activity B is steeper and shows more rapid changes of utility levels around the inflection point. The implication of the bigger size of  $\beta$  is that the activity has smaller interval of durations between very low (near zero) and very high (near maximum) utilities and therefore is less flexible in duration adjustment.

The bottom left figure of Figure 5-14 illustrates two activities of different  $\gamma$  values of 1 and 0.1 for utility curves of activities A and B, respectively. The curve of activity A shows a symmetric S shape, while the curve of activity B is asymmetric. Activity B has a bigger proportion of the diminishing marginal utility, and the level of utilities before inflection point is quite small compared with activity A. The implication of the bigger size of  $\gamma$  is that the activity would more likely have the duration of either bigger than inflection point or rather zero.

The bottom right figure of Figure 5-14 shows two activities of different  $U^{\max}$  values of 1000 and 800 and  $U^{\min}$  values of 0 and -100 for their utility curves, respectively.

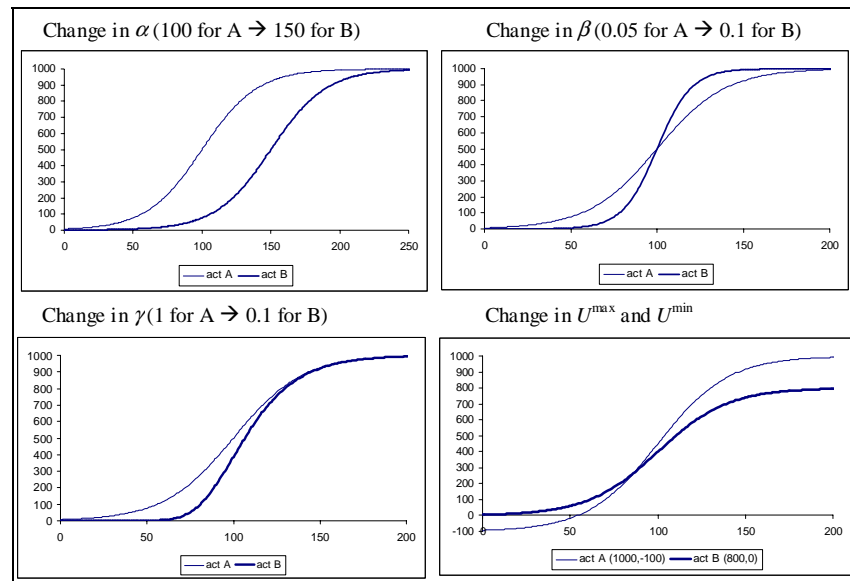


Figure 5-14. Impacts of Utility parameters (Source: Joh, 2004)

The impacts of different levels of the maximum utility are obvious from the figure. The higher level of  $U^{\max}$  offers higher level of utility for the same amount of activity duration. The minimum utility level is also associated with the minimum duration of the activity. The minimum duration represents the duration in which the activity starts producing positive outcomes when time is added. In the range of duration with positive utility, the individual would choose to conduct that activity unless a competing activity would have higher returns.

Schedule context may be a moderator in the sense that the maximum utility of a utility may depend on the time of day and interactions with other activities (preferred combinations of activities). Moreover, history may be a moderator in the sense that the time passed since performing the activity last time may influence utility. It is assumed that parameters  $\alpha$ ,  $\beta$  and  $\gamma$  are not context-dependent, i.e. exclusively depend on the nature of the activity. The underlying notion is that these parameters relate to technical aspects of the activity related to the productivity of time units (indirect utility) or strength of the saturation effect (direct utility). In contrast, the maximum utility,  $U^{\max}$ , is moderated by context and history factors. The activity's nature determines a base line, which is moderated in upward or downward direction by context and history effects. The more urgent the activity (given its history) the bigger  $U^{\max}$  will be. In addition,  $U^{\max}$  will increase when the activity can be



conducted at the preferred time of day while negative carrying-over effects from previous activities are absent.

Formally, the following general form of the  $U_a^{\max}$  function is assumed:

$$U_a^{\max} = f(t) * \left[ \frac{U_{x_a} + f(l_a, \Psi_a)}{1 + \exp[\beta_{x_a} (\alpha_{x_a} - T_a)]} \right], 0 \leq f(t) \leq 1 \quad (5.46)$$

where,

$f(t)$  is a factor that reflects changes in the maximum utility value along the time of the day.

$U_{x_a}$  is the intrinsic level of maximum utility of activity  $a$ ;

$l_a$  is the activity location

$T_a$  is the time elapsed since the last implementation of activity  $a$ ;

$\Psi_a$  represents the level of preference for the chain relationship between previous, current and next activities;

Equation (5.46) implies that a same asymmetric S-shaped curve used to determine the activity utility, is assumed to determine the maximum activity utility ( $U_a^{\max}$ ).

The time of the day that an activity is conducted, affects the level of  $U_a^{\max}$ , which is controlled by an adjustment factor  $f(t)$ , as shown in Figure 5-15. The  $BT\_Min$  is the earliest scheduling position that the marginal utility of the activity returns a positive value, which means that (re)scheduling the activity before  $BT\_Min$  would decrease the total schedule utility.

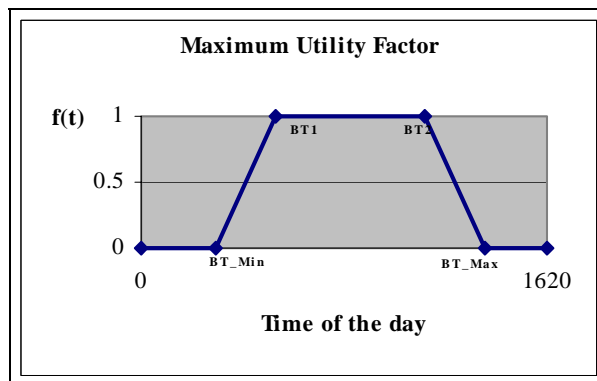


Figure 5-15. The effect of time of the day in the level of  $U^{\max}$

The adjustment factor increases linearly (and so the  $U_a^{\max}$ ) by shifting the activity's start time (BT) from  $BT_{Min}$  to  $BT1$ , when it reaches the maximum value. Between  $BT1$  and  $BT2$ , the factor has a constant and maximum value, which means that, if the activity is scheduled with start time (BT) positioned in the schedule between  $BT1$  and  $BT2$  will return the maximum utility  $U_a^{\max}$ . Between  $BT2$  and  $BT_{Max}$ , the factor decreases linearly from its maximum value to zero. Notice that the time is represented in minutes and the following convention was adopted: schedule starts at 0 (zero) minutes (3:00a.m. clock time) and ends 1440 minutes (27:00 p.m.).

$U_{x_a}$  implies that the  $U_a^{\max}$  level is primarily determined by a certain level of intrinsic maximum utility of activity  $a$ .  $U_a^{\max}$  level is also dependent on many other choice facets and aspects of the schedule context.  $T_a$ , the history of the implementation of activity  $a$ , will also greatly affect the level of  $U_a^{\max}$ . As the history becomes longer, the urgency for conducting the activity grows, and the  $U_a^{\max}$  will increase. This is important in the sense that if the functional relationship of history with the maximum utility is known, a schedule model could also predict the frequency of the activity.

Finally, notice that a linear (negative) utility function (Equation 5.37) is used to calculate the (dis-)utility of travel episodes (see Figure 5-16). A constant decrease in the travel time utility function is assumed, for additional units of time spent with travelling. Thus, travel time has a negative effect in the overall utility function, as shown in Figure 5-16.

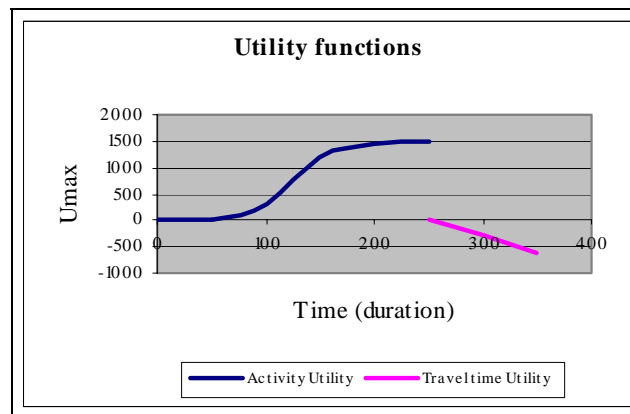


Figure 5-16. Activity and Travel time Utility Functions

Unlike the existing utility maximization models, and in line with the original proposal of Aurora, we assume bounded rationality as a result of incomplete information and imperfect choice behaviour. An individual is limited in his/her cognitive capacity to identify and optimise a complex decision problem. In particular, we assume that the cognitive constraints induce the following heuristic search strategy for schedule adaptation.

- 1) Identify the problem
- 2) Identify alternative courses of actions to change the schedule
- 3) Evaluate these actions in terms of the total utility of the schedule
- 4) Implement the action maximizing the total utility of the schedule
- 5) Repeat

Identifying alternative courses of action implies possible changes in the choice facets to solve the emergent problem of time lack, time surplus, etc. These actions include the application of a variety of rescheduling operators such as changes in the duration of particular activities, the list of activities, the sequence of activities, and the location, and travel mode of activities. Clearly, the assumption of bounded rationality implies that the model does not consider such changes simultaneously. Rather, an iterative procedure in which one operation at a time is evaluated and implemented is adopted. In the following, we provide a description of the heuristic solution method, to operate the conceptualisation.

#### *The heuristic search method*

This fundamental heuristic embeds bounded rationality into the operational model of schedule adaptation, given a utility function for each activity in  $S$ , and relevant institutional, space-time, and situational constraints. Assume an individual who has formulated an initial schedule of activities and related travel for a given day. The initial schedule describes which activities are to be conducted and for each activity, how it is to be implemented in terms of a start time, duration, and location and, if travel is involved, transport mode. During the execution of the schedule, the individual may consider to, for example, add one or more activities if time becomes available, due to shorter travel or activity duration than was anticipated in the planned schedule.

The heuristic search method is a complementary component to the model of activity utility. This component provides heuristics for schedule adjustment decisions by means of a partial search that is a reduction of the entire search space of utility defined by all feasible rescheduling operations. The heuristics of the search-space reduction mimic (human) search

behaviour under bounded rationality. The proposed heuristic search method is based on the following assumptions:

- 1) Individuals evaluate elementary operations on an initial schedule one at a time and implement the operation that maximizes the increase in perceived utility.
- 2) Consequently, the overall heuristic describes an iterative process that stops when the best possible operation does not increase utility.

Based on the conceptual considerations above, this subsection describes the model of rescheduling behaviour, that is the heuristic search component of Aurora. The model outlined here assumes functions for evaluating the feasibility and utility of a schedule as given. Notice that, the model proposed here does not depend on a specific implementation of the utility model. The remainder of this section first outlines the structure of the model and then, focus on each of the operators.

#### *Overall structure*

It is assumed a set of operators that individuals may consider to adjust schedules. The operators refer to a variety of choice facets including *insertion, substitution, deletion, (re)sequencing, trip chaining* and *transport-mode* operators. The proposed model uses a sequential procedure to arrange options for rescheduling and control the search process.

The suggested search structure has several notable characteristics. First, the search is conducted *choice facet by choice facet*. This is opposed to a structure that searches an exhaustive set of combinations of alternative adjustments across choice facets. Instead, the best adjustment alternative is determined for each choice facet evaluated in a pre-defined order. This process is repeated until no further improvement is possible. The model therefore considers an adjustment of a single choice facet at a time. As such, the number of computations required for a solution is additive, instead of multiplicative.

Secondly, the search is repetitive and *recursive*. Obviously, a single adjustment improves only a single choice. The suggested search structure allows the mental process to go back again to the very first step that checks if there is any further adjustment to be made again on the schedule.

The model therefore is expected to successfully advance at each rescheduling step to the better parts of the solution space by this choice facet-by-choice facet, recursive search process, based on the expected utility of rescheduling. The overall scheme of the proposed search method depicts in detail the following control mechanism.

- 1) START with a schedule given as the current schedule. The current schedule can be either an empty schedule at the beginning of the day and scheduling from scratch is performed, or not.
- 2) Try to improve the schedule in the following sequence:
  - a) Try to implement *insertion* operations until no further improvement is possible.
  - b) Try to implement *substitution* operations until no further improvement is possible.
  - c) Try to implement *deletion* operations until no further improvement is possible.
  - d) Try to implement *re-sequencing* operations until no further improvement is possible.
  - e) Try to implement *trip chaining* operations until no further improvement is possible.
  - f) Try to implement *transport-mode* operations until no further improvement is possible.
  - g) If a change then repeat from a).

The *duration* and *start time* operators are repeated within each evaluation and after each adjustment (procedure included in steps “a” to “f”) because a change through all other operators still requires a set of incremental fine-tunings of the activity duration and start time such that the schedule comes to an equilibrium state.

In the current implementation of Aurora, location is not included as a rescheduling operator. A detailed description of decision making related to the location of activities is given later in this subsection.

### *Operators*

This topic provides a detailed description of the operators employed in the search model.

*Duration adjustments.* The purpose of the *duration operator* is to find activities duration such that: (i) the sum of durations is equal to the total time  $B$ ; and, (ii) the array of duration is in equilibrium in the sense that the marginal utility of activities in the schedule is the same. Hence, this procedure starts by assigning very low levels of marginal utilities to the activities in  $S$  (which means long durations and therefore won't fit in the total time of the schedule). Then, the levels of these marginal utilities are gradually increased until activities' duration fit within the total time  $B$ . When the duration of an activity is reduced to zero as a result of the duration adjustments, the activity moves from  $S$  to  $R$ . Duration adjustments goes on

until every activity within the schedule have equal marginal utility, that is the equilibrium state.

*Start-time adjustments.* The *start-time operator* shifts activities start times in order to increase the total schedule utility. Fixed activities, constituting the skeleton (e.g., work activity) have a fixed start-time and duration in the schedule position. Flexible activities (e.g. green activity) however, will be shifted in the schedule position considering the  $U^{max}$  adjustment factor across time of the day, as explained before (see Figure 5-15).

*Composition adjustments.* Composition adjustment may include *substitution*, *insertion* and *deletion* of activities. These operators change the compositions of sets  $S$  and  $R$ . The *deletion* operator simply removes an activity from the schedule if that will increase the total utility maximally.

The *insertion* operator adds a new activity by transferring an activity from  $R$  to  $S$ , whose schedule position and duration are yet to be defined. To determine the schedule position, the operator tries all the positions one at a time for each new activity. Default settings for travel times, trip chaining, etc. are used for the activity and, when needed, default settings are changed to make them consistent with the schedule position considered. For instance, the transport mode used to make the trip to the activity just inserted is assumed to be the same as the one used to reach the antecedent activity of the schedule, even if the default mode is different.

*Re-sequencing and trip-chaining adjustments.* Individuals may also change the sequence of activities. The suggested *re-sequencing* operator tries different positions for the activities in the schedule and implements one if the change increases the overall schedule utility. The *trip-chaining* operator tries the insertion of a return home trip between two activities, if non existing, and deletes one, otherwise.

*Transport-mode adjustments.* The *transport-mode* operator is applied to optimize a mode pattern at the tour level. (A tour is a series of trips included in a home-to-home journey.) The choice on the transport mode is function of the travel duration (modal speed) and travelling parameters, as stated in Equation (5.37). Hence, the decision on the transport mode is done based on the speed and marginal utility of a minute travelling with the mode.

To summarize, given the objective of maximizing the utility of scheduling decisions, subject to constraints, an individual is assumed to try and optimise his/her scheduling and rescheduling in a situation of time lack, time surplus or any other event.

### 5.5.2 Implementation in GRAS

To have the Aurora model operational in GRAS and appropriate to cope with some specific issues in the greenspace context given the data available, some operational procedures/solutions related to activity categorization and activities (possible) locations were treated differently within GRAS, as explained in this section.

#### *Activities categorization*

Given the purpose here, the current implementation of Aurora aggregates activities within 3 major categories:

- (i) greenspace activities;
- (ii) work activities; and,
- (iii) all other activities.

Although most of the activity-based models implemented to date involve a more refined categorization of activities, the amount of effort to collect activities data seems to be yet unrealistic for the application and deployment of the system for the greenspace problem focused on this research project. Considerable effort is required to collect data regarding the several activities data in a common database, such as shopping activities (clothing, groceries, supermarket), recreational activities (museum, cinemas, cafes/bars, restaurant, greenspace, etc), services (hospital, clinics), schools, etc. Therefore, in the current implementation activities that are not work or greenspace related are included in the “all other activities” category and treated as an activity. Nevertheless, this category has a special status in the model: it is not treated as an episode, but rather as a sum of all unused time in the schedule. Still its utility is described by a S-shaped curve like episode-based activities. It is important to make clear however that such categorization is consequence of data availability, rather than model limitations.

Greenspace activities combine visits to greenspaces in general, independent of the type of activity (passive / active) conducted. Although the system has a GIS interface with all possible greenspaces and respective attractiveness information, to distinguish between active and passive green activity patterns, a much more circumstantial and elaborate survey design and data collection is required, once green activities are supposed to involve substitutions in space and time. Therefore, green activities include any kind of activity (passive or active) persuaded within a greenspace. Work activity

aggregates out-of-home work and school related activities (paid / not paid; part-time/full-time).

Furthermore, activities have a second category attribute, which are fix or flexible. As explained before, fix activities, i.e. mandatory activities compose the skeleton of the schedule, i.e. are the part of the schedule that is given and kept fixed. On the other hand, flexible activities (discretionary) are part of the scheduling and moderated by context and history factors.

The user can specify the parameters of all functions involved in the model, via the user interface, as shown in Figure 5-17.

The history factor is handled as a set of parameters given by the user throughout the parameters setting user interface, shown in Figure 5-17. Thus, the mean values of the  $\alpha_x$  and  $\beta_x$  parameters in the user interface (Figure 5-17) moderates the decision on scheduling green activity in the individual's schedule as function of the time passed since green activity was last performed. The  $\alpha_x$  mean can be interpreted roughly as the normal amount of days that passes without including the activity in the individuals' schedule. At the starting of the simulation, the state of individuals must be set, namely the day that individuals last performed a green activity. To this end, the day that an individual last performed a green activity is arbitrary set by a random number generated between  $[0, \alpha_x]$ . The average history thus equals approximately half of the normal interval time between green activities, which is appropriate. Notice that the everyday "other activities" do not have history information, by definition. The parameters  $\alpha$ ,  $\beta$ , and  $\gamma$  (as explained before - see Figure 5-14) exclusively depend on the nature of the activities.

A method to estimate the parameters  $\alpha_x$ ,  $\beta_x$ ,  $U_x$ ,  $\alpha$ ,  $\beta$ , and  $\gamma$  is described in Joh *et al.* (2004). To estimate activity-based models, diary data is deemed necessary. Because diary data are very demanding and, added to the complexity of the estimation method, the parameters of the Aurora model is left for a future work. Nevertheless, the values suggested in the database are manually calibrated using expert knowledge and questionnaire data comes closer. The users, knowing the meaning/effect of such parameters, can arbitrarily set them up via user's interface, as shown in Figure 5-17.

The  $U^{max}$  of green activity (as a discretionary activity) is also controlled by the  $U^{max}$  adjustment factor ( $f(t)$  - see Figure 5-15), to make sure that the green activity is scheduled at an acceptable time of day, as indicated in the "Green Activity Settings" field of the user interface shown in Figure 5-17. The *Minimum Start Time*, *Start Time1*, *Start Time2*, and *Maximum Start Time* edit fields of the user's interface (showed in Figure 5-17) correspond to the inflection points  $BT\_Min$ ,  $BT1$ ,  $BT2$ , and  $BT\_Max$  of the factor  $f(t)$  curve showed in Figure 5-15, respectively. It is the responsibility of the users (decision-makers/planners) to properly set these parameters.



Set Parameters of Activities									
Activity Type	U <sub>x</sub>		U			Work Activity			
	$\alpha_x$	$\beta_x$	U <sub>x</sub>	$\alpha$	$\beta$	$\gamma$	Full Time		
Green recreation	1	1	20	10	0.07	1.5	%	Start Time	
Other activities			60	600	0.0065	1	40	540	
							35	510	
							15	480	
							10	450	
Green Activity Settings		Transport-mode Parameters			Part Time				
Minimum Starting Time	540	hrs	Marginal Utility of a minute travel time by car		-0.2	Freq	%	Start Time	
Starting Time1	620	hrs	Marginal Utility of a minute travel time by bike		-0.1	1	30	540	
Starting Time2	1440	hrs				2	20	720	
Maximum Starting Time	1440	hrs				3	20	300	
			Set Values			4	30	540	
Memo1									

Figure 5-17. Aurora Model within GRAS (Setting parameters)

Users also manipulate transport-mode parameters. In addition to the distance, the transport-mode parameters settings will influence the choice on the transport mode assigned to travel between 2 activities.

The work activity parameters will determine the schedule *skeleton* and therefore influence the scheduling of other, optional activities. Notice that, by changing the parameters settings many scenarios can be evaluated. For instance, the user can put more or less pressure on individuals (by switching start-time of work activities, or by changing the frequency of the part-time jobs) to predict the impact on green activities. Travelling parameters can also play a major role in scenario analysis. Decision makers could be interested for instance, in what would be the impact of enforcing the bike mode to individuals and derive changes in their leisure behaviour, given that less time will be available in their schedule given higher travelling time. Other possible scenario simulation consist of varying the “time-window” of green activities, using the *Green Activity Settings* of the user interface (Figure 5-17). By increasing and decreasing the time window of greenspace activities’ maximum utility, the user can predict differences in green activity patterns across seasons (simulating the impact of the sun set/rise times across the seasons).

#### Location routines

Having defined the activity types/categories, the next question is how to set the location of activities. In this section, we describe the procedures to find individuals home location, work location and greenspace location.

The synthetic population model as described before naturally creates individuals with bases on their home location. Another output of this model is the individuals' employment status that is the number of working hours per week. However, the synthetic population does not give further information on work location.

Individuals work location is predicted by a complementary routine, the so-called "*Work Location*" tool that uses the synthetic population table as input in addition to information from the traveller survey. From the traveller survey we derive the distribution of individuals economically active conducting work related trips across the spatial unities (or zones). Indeed, the following approach is used to solve the work location problem. First, the study area was spatially divided into 5 strategic spatial regions. The strategy to aggregate the cells into regions used the concept of radial spatial aggregation. Hence, an imaginary circle is drawn around the entire study area. Then, the radius length of such an imaginary circle is divided into 5 segments of about the same size in radius. Each radial segment defines then the 5 regions, such that no region overlap is allowed (see illustration in Figure 5-18). At the end, each and every cell compulsory belongs to one only spatial region. Based on the information of the traveller survey, distributions of work related trips can be derived as individuals living in regions  $\{1, \dots, 5\}$  and working in regions  $\{1, \dots, 5, \text{outside the study area}\}$ , respectively and combinatorial.

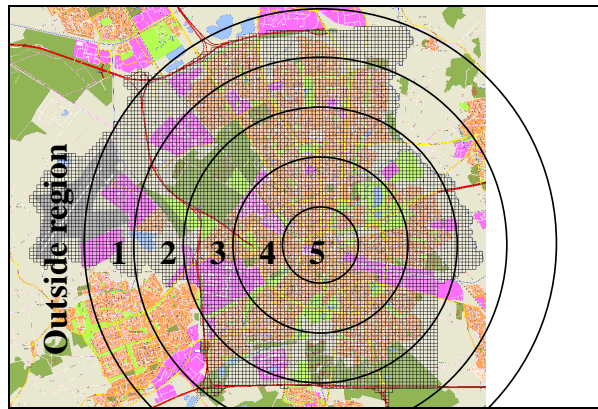


Figure 5-18. Radial spatial aggregation of cells

Finally, the “*Work Location*” tool simulates the individual work location by drawing proportionally from the set of possible work cell locations (given land use information), using the spatial distributions described above.

Notice however, that in our database the work infrastructure does not contain work facilities attributes information, such as number of employees, type of work, etc. Therefore, if an individual is found to work in region 2 for instance, a working facility cell within region 2 is randomly selected.

Finally, the following procedure is used to address the *greenspace location* that an individual is likely to visit. For each individual, the greenspace choice set is defined according to the following spatial rule. Based on rules of the local government for recreational greenspace provision – see Chapter 3 - if there are local, neighbourhood, district and/or city parks within 400m, 800m, 1600m, and 3200m, respectively, from individuals home location, then such greenspace(s) is(are) included in the individual greenspace choice set. Secondly, greenspace’s attributes parameters estimated in Ponjé and Timmermans (2003) were used to calculate the individual’s utility of each park in the choice set derived as explained above. Next, the choice probability of each park in the choice set is estimated according to the multinomial logit model (MNL). Finally, individual greenspace to be visited is randomly selected by drawing proportionally from the respective set of choice probabilities (*Monte Carlo* simulation<sup>7</sup>). Additional simulation settings are: simulation start date (day-month-year); the current day after start simulation (e.g., Current date equal to 100 means that 100 days are passed since the start simulation data); and the number of days to be simulated. This information is necessary to initialise the individuals’ activities history.

In the following subsection, we present the performance indicators developed and implemented to evaluate the scenarios based on the outputs of the Aurora model.

### 5.5.3 Aurora: Performance Indicators

The output generated by the Aurora model is the schedule of activities for every individual in the population. Table 5-3 gives an example of the results generated by the Aurora model, for one day.

Given individuals schedule of activities, there are many urban design performance indicators that can be derived, based on the individuals’ behavioural patterns. Before we present the performance indicators developed to assess greenspaces, we shortly illustrate the tools implemented

<sup>7</sup> Any method that solves a problem by generating suitable random numbers and observing that fraction of the numbers obeying some property or properties.

within the Aurora model to generate descriptive analysis of individuals' behaviour patterns.

Figure 5-19 shows how the user can generate frequency tables. This interface allows a high degree of flexibility for the user to analyse the scenarios under many perspectives. This component is similar to the one developed for the *Albatross* system (Arentze and Timmermans, 2000).

Figure 5-20 shows an example of a frequency table created using the requirements displayed in Figure 5-19. Figure 5-20 illustrates the frequency table as a function of the percentage of individuals who have a green activity scheduled (row) versus activity duration (column) in minutes, and taking between 21 and 30 minutes of travel time to reach the green location. Notice that the "tab control" shown in the bottom of the table in Figure 5-20 displays the frequency table for different travel time intervals.

Another common data analysis is to summarize information about variables of the dataset, such as the averages of variables and standard deviation.

Table 5-2. An example of the Aurora's output

NewPe	Iday	HhId	PeId	Nsq	U	Ty	Ttrv1	Ttrv2	Dur	Mod	BT	FrmH	RetH	Fix	Dlast
1	100	1	1	1	58	0									
0	100	1	1	1	58	3	10	10	480	1	540	1	1	1	99
1	100	2	1	2	66	0									
0	100	2	1	2	66	3	18	0	20	1	540	1	0	1	97
0	100	2	1	2	66	2	7	12	211	1	567	0	1	3	93
1	100	3	1	2	68	0									
0	100	3	1	2	68	3	11	0	420	1	540	1	0	1	97
0	100	3	1	2	68	2	12	2	145	1	972	0	1	3	93
1	100	4	1	1	58	0									
0	100	4	1	1	58	3	9	9	700	1	540	1	1	1	97
1	100	5	1	1	58	0									
0	100	5	1	1	58	3	9	9	504	1	540	1	1	1	99

Note: **NewPe** = start new person's activity schedule (1=yes; 0=not yet); **Iday** = number of days passed since the simulation start date (program settings); **HhId** = household ID; **PeId** = person ID (in our case, person ID is always 1, given lack of information in the household level); **Nsq** = number of out-of-home activities in the schedule; **U** = utility value of the activity; **Ty** = activity type (0=home; 2=greenspace; 3=work); **Ttrv1** = cell row location; **Ttrv2** = cell column location (the study area can be viewed as a grid of 100x100m cells); **Mod** = transport mode (1 = car; 0 = slow mode); **Dur** = duration of the activity (in minutes); **BT** = start time to conduct the activity (in minutes); **FrmH** = individual travels from home to the activity location (1=yes; 0=no); **RetH** = Individual returns home right after conducting the activity (1=yes; 0=no); **Fix** = mandatory activity (1=yes; 3=no); **Dlast** = the day since the activity was last performed.

Figure 5-21 shows another user interface window, where the user can generate such summary or descriptive statistics of a set of variables of the output data. Figure 5-22 shows an example of the descriptive analysis table created using the requirements displayed in the Figure 5-21. The descriptive table shown in Figure 5-22 cross references the number of individuals conducting a green activity and the amount of hours spent on the work activity. Notice that the “tab control” shown in the bottom of the table illustrated in Figure 5-21, displays the different facets of the results of the descriptive analysis, that is the counting of variables per category, mean and standard deviations.

Although frequency tables and descriptive analysis are of great value to inform decision makers and planners on the relationship between urban design and individuals’ behaviour, i.e. identify elements (or a combination of elements) of the urban design that may have a strong impact on individuals’ behaviour, they are not appropriate for a quantitative scenario evaluation, the main purpose of developing a decision support system. Therefore, we developed three performance indicators that are quantitative measures to evaluate scenarios, given individuals’ behaviour. These performance indicators serve as input to the multi-criteria evaluation module.

The first performance indicator, the so-called “*quality of life*” criterion, measures an individual’s utility derived from the activity-travel schedule. For instance, if facilities (whether working facilities, greenspaces, public services, shopping, etc.) are not well distributed in space, individuals must travel further and consequently the utility of conducting a particular activity-travel pattern will be relatively low, because travel has a negative impact on the utility. Moreover, there will be less time left for individuals to conduct activities, compromising once again the total schedule utility. Similarly, if facilities are not very attractive, making individuals to travel further or simply not conducting the activity at all, the quality of life will be less. In the end, because the total schedule utility is equal to the sum of the utilities of the schedule’s activities, the utility of the schedule will be low.

On the other hand, if facilities are well distributed in space and attractive, a higher activity utility will be derived. Based on these considerations, the concept of quality of life articulated here can be quantitatively measured by the utility schedule, as follows:

$$QL = \frac{\sum_i \sum_{e=1}^{S_i} U_{ietm}}{I} \quad (5.47)$$

where,

$U_{iatm}$  is the utility that individual  $i$  derives from conducting episode  $e$ , at time  $t$  using the transport mode  $m$ , such as  $e$  are the episodes (travel or activity) within the schedule  $S_i$  of individual  $i$

$I$  is the number of individuals in the study area.

The second performance indicator is the “Average travel time to greenspaces”. It calculates the average travel time to greenspaces of individual schedules with green activities, as follows:

$$\bar{T} = \frac{\sum_{i=1}^{I'} T_{ijm}}{I'} \quad (5.48)$$

where,

$T_{ijm}$  is the travel time to individual  $i$  reach the greenspace facility visited  $j$  from the location where the activity before was conducted, at time  $t$  using transport mode  $m$ ;

$I'$  is the number of individuals with scheduled green activity.

Finally, the third performance indicator consists of the “Average duration of green activities”. Time duration patterns spent in greenspace facilities can be quite informative to authorities, regarding issues of greenspace attractiveness (design aspects), spatial location effect or a combination of these. Little amount of time spent in certain greenspace can be an indicator of poor attractiveness. On the other hand, long duration of green activities can be interpreted in different ways. It could be an indicator that individuals are coming from far distances and therefore the impacts should be analysed within the urban context.

$$\bar{V} = \sum_i^{S_i} V_{ie'} \quad (5.49)$$

where,

$V_{ie'}$  is the duration of episode  $e'$  as scheduled in the individual schedule,  $S_i$ .

$I'$  is the number of individuals in the study area with greenspace visits scheduled for the time period simulated.

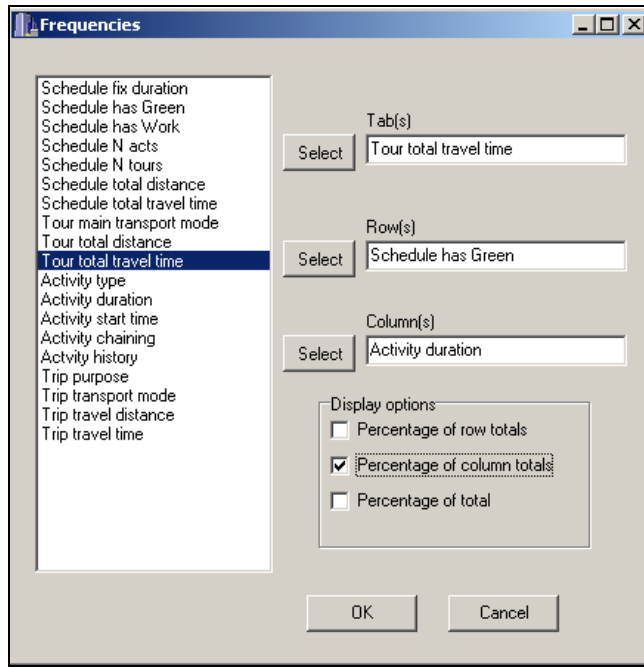


Figure 5-19. Frequency analysis in the Aurora model implementation

Save ...

Tour total trav time: 21-30

		Act duration								
		0-10	11-20	21-40	41-80	81-160	161-320	321-640	641+	Total
Sched	No			0.333	0	0.045	0.158	0.663	0.5	0.41
has green	Yes			0.667	1	0.955	0.842	0.337	0.5	0.59
Total		0	0	6	2	44	38	104	6	200

Navigation: < | 0 min ^ 1-10 ^ 11-20 ^ > 40 ^ 21-30 ^ 31-40 ^ Statistics /

Figure 5-20. A frequency table example

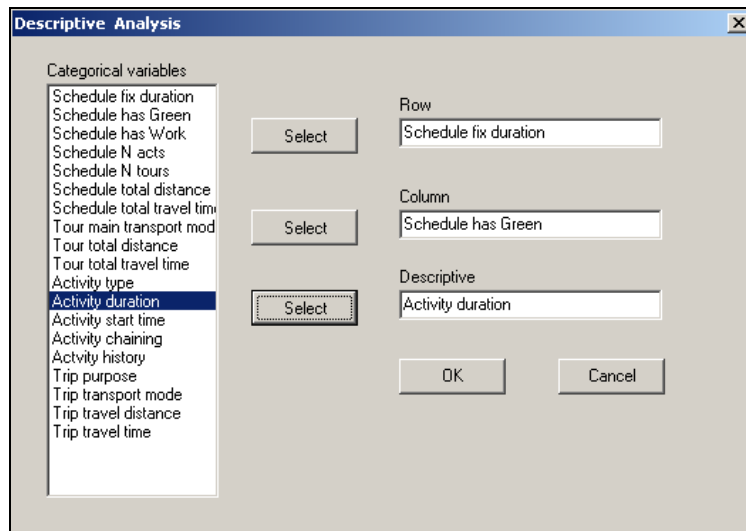


Figure 5-21. Descriptive analysis in the Aurora model implementation

		Sched has green		
		No	Yes	Total
Sched	0-<1.5	10	92	
fix dur	1.5-<2.5	9	20	
	2.5-<3.5	12	24	
	3.5-<4.5	11	42	
	4.5-<5.5	10	14	
	5.5-<6.5	19	20	
	6.5-<7.5	53	64	
	7.5-<8.5	397	166	
	8.5-<9.5	183	44	
	9.5+	194	30	
	Miss	0	0	
	Total			

Figure 5-22. An example of a descriptive analysis table



## 5.6 Cost Estimation Spreadsheet

The cost estimative spreadsheet is a tool to assist decision makers and planners to estimate costs related to the provision and maintenance of greenspace. As shown in Figure 5-23, maintenance and provision are estimated using values given by the decision maker/planner of several cost aggregated elements. Greenspaces provision costs are estimated using the following equation:

$$pCost = \frac{s * (lp + veg + ppath + plight + ptb + ptrash) + plake + psport + ptoilet + pplyg}{s} \quad (5.50)$$

where,

- pCost* is the provision cost per hectare of a certain greenspace;
- s* is the greenspace size (hectare);
- lp* is the price of the land per hectare. The user can define 4 different land prices depending on the spatial location (neighborhood/area);
- ppath* is an average cost per hectare to build walking path in the greenspace;
- plight* is an average cost per hectare to place lights in the greenspace;
- ptrash* is an average cost per hectare to place trash bins in the greenspace;
- plake* is a fixed (average) price to build a lake in the greenspace;
- psport* is a fixed (average) price to build sport facilities in the greenspace;
- ptoilet* is a fixed (average) price to build a toilet in the greenspace;
- pplyg* is a fixed (average) cost to build playgrounds in the greenspace
- veg* is the vegetation cultivation price. If the vegetation is dominantly trees and shrubs, *veg* is simply taken as an average cost per hectare to cultivate trees and shrubs. However, given high costs involved in flower cultivate, when greenspaces have dominantly grass and flowers vegetation type, *veg* is given by:

$$veg = \% f * cf + \% g * cg \quad (5.51)$$

where,

- %f* is the percentage of floor space with flowers;
- cf* is the flower cultivation cost;
- %g* is the percentage of floor space with grass;
- cg* is the grass cultivation costs.

On the other hand, maintenance costs are related to repairing and cleaning services to maintain the greenspace facilities. It is estimated for each greenspace facility using the following equation:

Figure 5-23. Cost estimative spreadsheet: user interface.

$$mCost = \frac{n(s(clean + mv + ppath + plight + ptrash) + mlake + msport + mtoilet + mplyg)}{s} \tag{5.52}$$

where,

- $mCost$  is the maintenance cost of a certain greenspace, per year;
- $n$  is the number of times per year that maintenance services are performed (for instance monthly, seasonally or yearly);
- $s$  is the greenspace size;
- $clean$  is expenses regarding cleaning activities per hectare of greenspaces.
- $mv$ : is the expenses per hectare related to vegetation cares. Trees and shrubs maintenance cares include weeding out, pruning/trimming, herbicides application and refill the field. Grass and flowers requires extra gardening maintenance cares as shown in Figure 5-23.
- $ppath$  is an average cost per hectare to maintain a walking path;
- $plight$  is an average cost per hectare to maintain lights;
- $ptrash$  is an average cost per hectare to repair trash bins;
- $plake$  is a fixed (average) cost to maintain/repair lakes in greenspaces;
- $psport$  is a fixed (average) cost to repair/maintain sport facility in greenspaces;
- $ptoilet$  is a fixed (average) cost to repair toilets in greenspaces;
- $pplyg$  is a fixed (average) cost to repair playground in greenspaces;

Maintenance costs are estimated on an annual basis, while provision costs are estimated as a fix amount lifetime investment. Notice that, costs are estimated per hectare of greenspace, rather than per location unit of greenspace. This procedure allows greenspace administrators to fairly compare expenses among greenspaces of different dimensions (size).

Together with the set of spatial (-temporal) behaviour models implemented in GRAS, the assessment of greenspace costs will allow decision makers and planners to trade off greenspace costs and benefits on a more quantitative basis. Hence, decision-makers can derive quantitative information of specific greenspaces usage and the costs associated with it. Moreover, decisions on the planning and design of greenspaces will affect costs of provision and maintenance. In this sense, scenarios can be compared not only in terms of the greenspace benefits to the community, but also in terms of the costs associated to the implementation of actions.

## 5.7 Multi-criteria Model

Interest is being focused in the literature on integrating multicriteria evaluation (MCE), GIS and domain specific models for solving spatial decision problems (Feick and Hall, 1999; Mendes and Motizuki, 2001; AscoughII *et al.*, 2002<sup>8</sup>; Liu and Stewart, 2004; Hill *et al.*, 2004). MCE techniques are well suited to interactive decision-making as they are flexible, interactive, and transparent – thereby contributing to problem clarification and accountability (Carver, 1991).

The limitations of the spatial (temporal) models within GRAS for providing the “answer” to the complex problems of greenspace provision and maintenance led to the conclusion that the role of such models is to provide “intuition, insight, and understanding that supplements that of the decision-makers” (Brill, 1979). Central to these models is the premise that larger volumes of accurate information will lead to better decision results (Campbell, 1991).

MCE methods complement the other two components in a number of ways, the most significant being a structured environment for exploring the intensity and sources of conflict, generating compromise alternatives and ranking alternatives according to their attractiveness (Janssen and Rietvelt, 1990). Moreover, indicators derived from different domain models are often measured in different scales and dimensions. In this sense, MCE techniques are needed to rescales these indicators into a common measurement unit, allowing comparison among the various performance indicators.

<sup>8</sup> [http://www.iemss.org/iemss2002/proceedings/pdf/volume%20tre/290\\_ascough%202.pdf](http://www.iemss.org/iemss2002/proceedings/pdf/volume%20tre/290_ascough%202.pdf)

Although a comprehensive MCE literature can be found in Voogd (1983), Vincke (1992) and Olson (1996), among others, the discussion in this thesis is restricted to discrete compensatory methods. This class of MCE techniques seems to be appropriate to the type of problem addressed here as it focuses on problems with a finite number of choice alternatives and also permits inter-criteria trade-offs to be made. Hence, high scores that an alternative has on some criteria can compensate for low scores on other criteria, subject to the priorities, or weights, that a decision maker assigns to each criterion (Jankowski, 1995).

As Voogd (1983) argued, the multicriteria evaluation approach serves to investigate a number of choice possibilities (scenarios) in light of multiple criteria and conflicting priorities. The choice possibilities can be alternative greenspace plans or strategies. The core of this evaluation approach consist of a two dimensional matrix, where one dimension expresses the various alternatives and the other dimension the criteria by which the alternative must be evaluated.

The so-called evaluation matrix,  $E$ , contains the set of scenario alternatives  $\{N\}$  that the decision makers developed to choose from and the set of criteria  $\{C\}$ , that describe the relevant characteristics of each alternative.

$$E = \begin{bmatrix} e_{11} & \cdots & e_{1C} \\ \vdots & & \vdots \\ e_{N1} & \cdots & e_{NC} \end{bmatrix} \qquad W = \begin{bmatrix} w_{11} & \cdots & w_{1C} \\ \vdots & & \vdots \\ w_{H1} & \cdots & w_{HC} \end{bmatrix}$$

where,

$e_{nc}$  is the score of alternative  $n$  on criterion  $c$ ;

$w_{ch}$  is the weight of criterion  $c$  for decision-maker  $h$

and,

$$\sum_c w_{ch} = 1 \qquad (5.53)$$

The priorities attached to the various criteria, which can be represented by quantitative numbers usually denoted as weights (Voogd, 1983, Mendes and Motizuki, 2001) quantify the relative importance of these criteria in terms of their contribution to the overall evaluation score.

Although several methods have been proposed and used in the literature for measuring criteria weights (Saaty, 1977; Voogd, 1983; Mendes and

Motizuki, 2001; Lin *et al.*, 2004), the Analytical Hierarchy Process perhaps being mostly used (AHP – Saaty, 1977), there seems to be no generally accepted method for measuring criterion weights. Controversies and argumentations apart, users are free (and responsible) to specify the criteria weights for the scenario evaluation in the multicriteria model implemented in GRAS, as shown in Figure 5-24.

In GRAS, the Weighted Linear Combination (WLC - Voogd, 1983) method is used to combine the evaluation scores and weights to arrive at an overall score:

$$E'_{nh} = \sum_c w_{ch} e_{nc}^* \quad (5.54)$$

where,

$E'_{nh}$  is the final score of scenario  $n$  for the decision maker  $h$ ;

$w_{ch}$  is the weight of criterion  $c$  for decision-maker  $h$  ;

$e_{nc}^*$  is the standardized score of scenario  $n$  on criterion  $c$ .

#### *Standardization of Criteria*

Since the performance indicators involve different scales and dimensions, standardization is necessary. To make the various criteria scores compatible, they are transformed into a common measurement unit, i.e. for each criterion the scores will have a range from 0 to 1. There are various kinds of standardization proposed in the literature (Voogd, 1980; Rietveld, 1980) but here we are especially interested in the interval method defined as:

$$e_{nc}^* = \frac{e_{nc} - e_c^{\min}}{e_c^{\max} - e_c^{\min}} \quad (5.55)$$

where,

$e_{nc}^*$  is the standardized score of scenario  $n$  on criterion  $c$ ;

$e_{nc}$  is the raw score of scenario  $n$  on criterion  $c$  ;

$e_c^{\min}$  is the minimum value of criterion  $c$  score among every scenario of the scenario set.

$e_c^{\max}$  is the maximum value of criterion  $c$  score among every scenario of the scenario set.

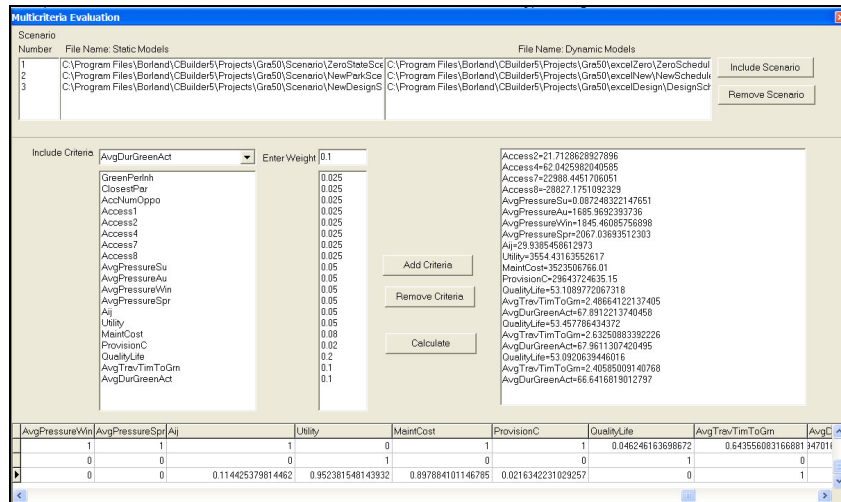


Figure 5-24. Multicriteria Evaluation Model Interface

Notice however that some performance indicators' scales are negative, meaning that the higher values the worse the scenario performance, which is the case of some accessibility measures and cost estimate. In those cases, the system rescales the score, as following:

$$e^{*'} = 1 - e^* \tag{5.56}$$

Those kind of transformations means that after standardization the worst criterion score (among scenarios) will be given always standardized value of 0, whereas the best criterion score will always have a standardized value of 1.

### Performance Indicators

A standard set of criteria {C} has been developed to support decision-makers/users to evaluate the alternative scenarios. In short, these criteria are performance indicators derived from the application of the models available in GRAS. When a scenario is *inserted* (Figure 5-24) in the multicriteria evaluation, the system automatically asks the user to point out the scenarios related files (at least one): (i) the scenarios spatial file (containing the spatial data and the information derived from the application of the spatial models); and (ii) the scenario's schedule file as the result of the spatio-temporal model application (Aurora model).

There are 21 criteria available to evaluate the scenarios. Three criteria are more general spatial assessment measures, fifteen criteria are based on the outputs of different spatial models and three criteria use the performance indicators developed from the spatio-temporal component (Aurora model).

The most general criteria are:

1) *Green/Inh*: the average greenspace (m<sup>2</sup>) per inhabitant. Thus:

$$Green/Inh = \frac{\sum_j s_j}{I} \quad (5.57)$$

where,

$s_j$  is the size (hectare) of the greenspace;

$I$  is the number of individuals in the population of the study area.

2) *MaintCost*: this criterion evaluates the alternative scenarios based on the average greenspace maintenance costs, which is estimated by means of the “Cost Estimation Spreadsheet” (section 5.6). Thus:

$$Cost = \sum_j \$_j s_j \quad (5.58)$$

where,

$\$_j$  is the estimated maintained cost per hectare of greenspace  $j$ ;

3) *Provision Cost (ProvisionC)*: similar to the above, however uses the greenspace provision cost.

The criteria based on the outputs of the spatial models are:

1) *Access<sub>i</sub>*: This criterion evaluates the alternative scenarios using the average distance from individuals’ doorstep to their closest greenspace. Indeed, it uses the output of the “*minimum distance*” accessibility measure in the Accessibility Module to calculate the average minimum distance value. Thus:

$$Access_1 = \frac{\sum_{z=1}^Z i_z d_{ij'}}{I} \quad (5.59)$$

where,

$d_{ij'}$  is the distance between individual  $i$  and its closest greenspace  $j'$ ;

$i_z$  is the number of individuals in cell  $z \in \{Z\}$ ;

2) *AccNumOppor*: is a criterion to evaluate the alternative scenarios on the basis of the average accessibility of greenspaces. The accessibility is measured with the “number of opportunity” measure (see section 5.4.2, Figure 5-11). Thus:

$$Acc = \frac{\sum_{z=1}^Z a_z i_z}{I} \quad (5.60)$$

where,

$a_z$  is the accessibility measure of cell  $a \in \{Z\}$  to greenspaces.

3) *Access*<sub>2</sub>, *Access*<sub>3</sub>, *Access*<sub>4</sub>, *Access*<sub>5</sub>, *Access*<sub>6</sub>, *Access*<sub>7</sub>, and *Access*<sub>8</sub> are similar to above, however the accessibility score of cells  $z$  are measured using different equations, as described in section 5.4.2. Thus, these criteria apply Equation 5.60, however the accessibility score  $a_z$  differ as shown in Table 5-4.

4) *Pressure*: This criterion finds an average pressure of greenspace use, that is, the average number of visits per hectare of greenspace, for a particular season. Indeed, it uses the output of “*Greenspace Pressure Model*” to calculate such average pressure. Thus,

Table 5-3. Accessibility criteria

Criterion	Accessibility measure	$a_z$
<i>Access</i> <sub>2</sub>	Cumulative linear negative	Equation 5.24 and 5.25
<i>Access</i> <sub>3</sub>	Gravity Potential	Equation 5.26
<i>Access</i> <sub>4</sub>	Entropy-maximizing	Equation 5.27
<i>Access</i> <sub>5</sub>	Probability Gravity-based	Equation 5.29
<i>Access</i> <sub>6</sub>	Probability Entropy-Based	Equation 5.30
<i>Access</i> <sub>7</sub>	Gravity Consumer Surplus	Equation 5.32
<i>Access</i> <sub>8</sub>	Log Sum Consumer Surplus	Equation 5.33



$$\bar{P}_{(season)} = \frac{\sum_j P_{j(season)}}{J} \quad (5.61)$$

where, *season* is summer, autumn, winter or spring. The lower the greenspaces' pressure, the better for the built environment and citizen's quality of life.

5) *A*: This criterion evaluates alternative scenarios based on the level of greenspace awareness expressed by the individuals in the population. The more individuals know greenspaces (greater awareness score), the better the scenario will be. The concept of awareness is described in section 5.4.1 (Ponjé *et al.*, 2003).

$$A = \sum_j A_j \quad (5.62)$$

where,  
 $A_j$  is the awareness level of greenspace  $j$ ;

6) *Utility*: This criterion evaluates alternative scenarios based on an aggregate utility measure that the population derives from the greenspaces provided in the scenario, as following.

$$\bar{U} = \sum_j U_j \quad (5.63)$$

where,  
 $U_j$  is the averaged utility value of greenspace  $j$ .

The criteria to evaluate the scenarios given the outputs of the spatio-temporal model (Aurora) were already discussed and presented in detail in the section 5.5.3. In short:

1) *QL*: the so-called “*quality of life*” criterion is meant to assess the urban design as a whole, based on the individual's perception of the urban environment expressed by their activity patterns and overall schedule utility, calculated with Equation (5.47).

2) *AvgTravTimToGrn*: the “*Average travel time to greenspaces*” performance indicator is measured using Equation (5.48).

3) *AvgDurGreenAct*: The “Average duration of green activities” performance indicator is measured using Equation (5.49).

## 5.8 Conclusion and Discussion

According to Geoffrion (1987), there are four factors contributing to low productivity in decision analysis and DSS developments. The first is that different problem representations are typically used in different situations. The second is that the laborious task for the user to model the problem at hand in a format acceptable to the chosen solver requires specialized skills. The third factor is that most of the existing software only addresses one among the many models needed to solve a wide range of problems. The fourth factor is that most methods and software only cater to one or two steps of the problem solution.

We believe that the system described in this chapter potentially overcomes these problems of (S)DSS development. In this chapter we showed that, although the framework provided here is flexible enough to accommodate a range of different decision makers’ cognitive styles, the system attaches a common philosophical approach onto the decision making process, using theories of human behaviour, avoiding multiple problem representations. Secondly, a fully integrated GIS-based system environment, containing tools and domain-models, is structured to provide methodological and technical support to decision-makers and planners, without requiring users’ specialized skill. Thirdly, a complete range of state-of-art analytical domain models (from static to dynamically-oriented) is embedded into this framework to support decision makers in exploring and analyzing the problem under different perspectives. Fourthly, GRAS is designed to support the user during all phases of the decision making process, i.e., from the identification of the problem through the development of alternative solutions to the selection of a solution.

Yet, until recently, most decision analytical research has ignored the initial step of problem identification, concentrating instead on questions of evaluation and choice. As a result, to some extent, problem analysis and structuring are still considered the “art” part of decision analysis (Liu and Stewart, 2004). We argue that, a successful fully-integration approach to combine GIS technology, scenario methodology, domain models (spatial and spatio-temporal) and multicriteria evaluation approach provides a proper environment needed to turn the “art” into science. As described in the beginning of this chapter, the structure of the decision problem is almost a natural consequence of the use of the system to explore the actual situation,

i.e., the use of a model or tool will automatically evoke other models/tools as the result of an interactive and recursive process designed to the system.

In closing Part I of this research project, it should now be clear that although most of the components within GRAS are relatively new to the greenspace field, each individual component embedded in GRAS is well known / established in the literature (at least the underlying ideas as all models are based on the most recent specifications, and often are among the first reported in the field of leisure/recreation), except the model based on space-time behaviour which is quite innovative in its own right.

The uniqueness of GRAS however is the combination of GIS technology, state-of-art disaggregate domain models (including micro-simulation) and multicriteria evaluation techniques under a common and full-integrated GIS-based framework. Therefore, the user only intervenes in the system to control the decision process and not to conduct the basic operations of data transformation and communication.

## **PARTII: SYSTEM APPLICATION**



## CHAPTER 6

### 6. DATA COLLECTION AND MODEL ESTIMATION

Whereas Part I was concerned with the theoretical, methodological and underpinning of the GRAS system, Part II focuses on the application of GRAS in a real case study. This application is supposed to illustrate the possible application of the system to typical classes of greenspace planning, design and maintenance problems.

GRAS is applied to a greenspace provision and maintenance problem within the city/region of Eindhoven, a medium-size city in the Southeast of The Netherlands. This application will be described in the next chapter. In this chapter, we will however first describe the data collection and the database preparation that are needed before the system can be applied to any specific region.

As the reader might have already noticed, as any decision support system, GRAS strongly depends on data. Consequently, spatial and non-spatial data coming from internal and/or external sources are required to provide the data required for model estimation and the description of the study area. In case such data is not available from existing sources, additional fieldwork and surveying will be required in order to properly customize the system.

Ideally, a proper operational setting of the system requires two sets of parameters to be estimated from empirical data. A first set of parameters is required for the static models estimation, and a second, for the spatio-temporal model estimation. However, this chapter covers the parameter estimation of the static models only. The estimation of the spatio-temporal model, i.e. the Aurora model, is left to future research.

This chapter is organized as followed. First, we describe spatial and non-spatial data requirements and their availability as input to the system's database. A procedure to combine all these data from different data sources under a common spatial unit (the cell) is described in detail. Secondly, based on the conceptual framework discussed in the previous chapters, a multitude of data was collected to estimate the models. We will discuss the design and administration of the questionnaires, as well, the statistic procedure used to estimate the models.

Response rates and sample characteristics will be reported as well. This chapter ends with some conclusions and discussion.

## 6.1 Feeding the DBMS: spatial and non spatial data

As mentioned in section 4.3.1, the data sets required within the system are:

- 1) Land use data;
- 2) Post code addresses;
- 3) Road network;
- 4) Zonal system;
- 5) Greenspace amenities;
- 6) Work facilities.

The first three items are geo-referenced files obtained from the Dutch Ministry of Transportation containing information at the national level. The land use file is vector layer (ESRI polygon shape type) that has been developed and updated since 1986. It combines the national land cover/use database of The Netherlands ('LGN data base') using satellite images (Landsat TM and SPOT) and ancillary data. Today, five versions of this database are available (LGN1, 2, 3, 4 and 5), based on satellite images from respectively 1986, 1992-1994, 1995-1997, 1995-2000 and 1999 - 2004. During the up-dating of the LGN database the classification method improved considerably, resulting in a sharp increase of classification accuracy and number of land cover/use classes. At this time, we use the LGN4<sup>1</sup> database, which consist of 46 classes of land use as specified in Appendix D.

The road network file, the so-called Nationaal Wegenbestand (NWB), is a digital format of the national road network (ESRI line shape file), built and maintained as an initiative of the Department of Traffic and Transportation (Adviesdienst Verkeer en Vervoer) together with the Netherlands Topographic Office (Topografische Dienst Nederland - TDN). It describes in detail the road network in the Netherlands, i.e. from intra-cities (highways) to the cities/neighbourhood level, with specifications of road type (national, province, and municipal).

The post code addresses is a vector file (ESRI point shape file) of the x,y coordinates of existing postcode addresses of the entire Netherlands.

The zonal system is also available on the national level. It corresponds to the "Kerncijfers Wijken en Buurten 1999" (KWB99) meaning "Districts and Neighbourhoods Code base", obtained from Statistics Netherlands (CBS –

<sup>1</sup> <http://www.alterra.wur.nl/NL/cgi/LGN/LGN4/>.

Centraal Bureau voor de Statistiek). It describes the Dutch population and household statistics compiled by Statistics Netherlands using a formal subdivision of the Netherlands into zones. This file uses the GBA system, which stands for ‘*Gemeentelijke Basis Administratie Persoonsgegevens*’, the municipal basic registration of population data. ‘Basic’ refers to the fact that the GBA serves as the basic register of population data within a system of local registers. These registers include the local register on social security, the local registers of water and electricity supply, the local register of the police departments dealing with the foreign population in the Netherlands, and the (national) register of the old age pension fund system. For the remaining part of the Census data that cannot be found in these registers, such as education, occupation and unemployment, and some details about the current activity of the economic inactive population, the *Labour Force Survey* (LFS) is the main supplier of data.

The green space amenities and work facilities data were not available, in any ready form, and thus had to be compiled from existing sources. To that effect, a map image of the study area (raster image) was used as a background in a GIS system (MapInfo<sup>2</sup>) to digitalize green spaces within the study area. Information regarding greenspace attributes and characteristics, relevant to this study, were collected partially through the “Park Inventory” (described later in this chapter) and partially through fieldwork. These attributes were inputted into the digitalized green space vector map layer database. The same procedure was used to digitalize the work facilities vector map layer, however, no attribute information (number of employers, type of organization, etc.) was collected.

The data coming from the different datasets were then combined into a unique, cell-based (vector, polygons) layer database, using appropriate spatial interpolation techniques. In other words, spatially aggregate data from land use, greenspace facilities, zonal system (socio-demographics), work amenities and postcode addresses were projected into a singular spatial unit defined as cells of 1 hectare (100x100m). Hence, such a cell layer, named *Cell-Based Database Management System* (DBMS, section 4.3.1), holds all kinds of information related to census, land use, postcode address, and work and greenspace amenities into geo-referenced cells of 100x100m.

As discussed before, the cell size is an arbitrary decision, which means the smaller the cell size, the higher the accuracy but slower the system. In the current implementation, experimental analyses show that 100x100m cells result in optimal system performance, i.e. accuracy versus computation time.

To project the data into cells, a number of steps were performed. First, a vector map layer consisting of 100x100m cells covering the study area was created, as shown in Figure 6-1 and Figure 6-2(a). The user can carry out

<sup>2</sup> MapInfo is a trademark product of MapInfo Corporation



this step by either using a raster image of the study area or the zone layer as a reference to create a grid of 100x100m cells spatially overlaying one (or both) of these reference layers. The result will be a geo-referenced vector *cell* layer with no further information in the database.

Next, to input data to the cells consistent with the aggregate distributions, the following steps were taken. First, the cell layer and the land use layer (Figure 6-2.(b)) were overlaid to assign information of land use to the cells. Information regarding land use is coded in the database using the codes described in Appendix D. The land use code of each cell was defined by the land use code of the area (from the land use layer) that contains the centroid of the cell when these layers are spatially interpolated. Subsequently, the zonal system layer, greenspace amenities layer and cell layer are overlaid (Figure 6-3). By using appropriate spatial interpolation, cells that spatially match greenspace areas are fed with information of the greenspace in the database.

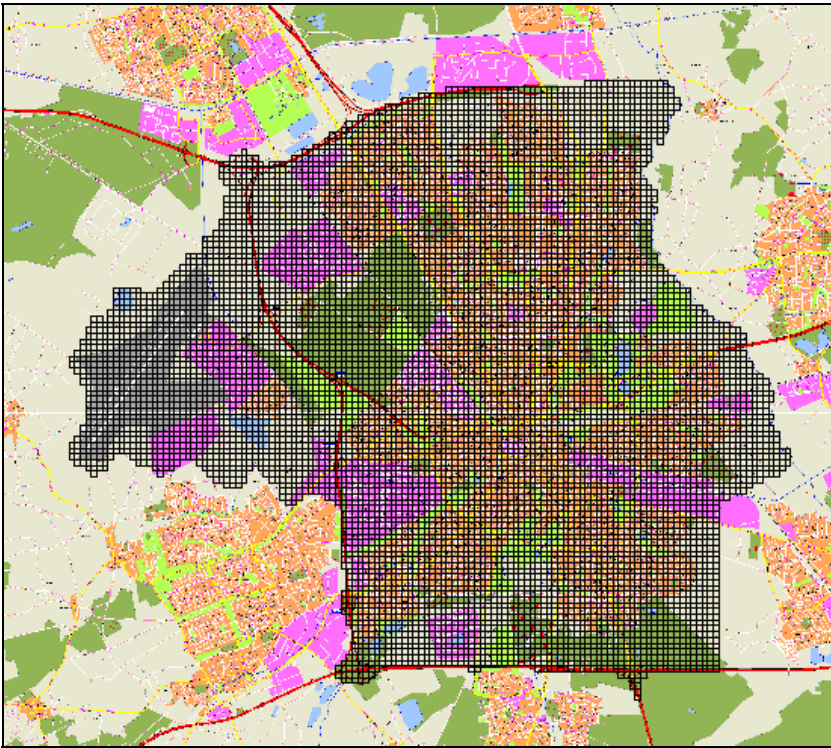


Figure 6-1. Cell layer overlaying a georeferenced raster image of the study area.

The greenspace attribute of each cell was defined by the attribute value of the greenspace object (of the greenspace layer) that contains the centroid of the cell when these layers are spatially interpolated.

Next, “non-greenspace” cells were spatially interpolated with the zonal system layer to receive the socio-demographics data. In this sense, zone socio-demographic data will be shared between the cells within the zones and that are not taken by greenspaces. For instance, if a cell belongs to a greenspace, it is likely to have nobody living in that cell. Thus, we can say that socio-demographics data are not completely uniformly distributed within the cells in the zone. Different interpolation techniques were used to assign socio-demographic data to the cell layer. Proportion sum interpolation technique, i.e. a sum calculation that is adjusted based on how many “non-greenspace” cells are within a neighbourhood unit, was used for raw data (e.g. population, housing units, etc.). In the case of categorical data (e.g., percentage of family with children, percentage of individuals younger than 14 years, etc.), the value of each “non-greenspace” cell was defined by the value of the neighbourhood unit that contains the centroid of the cell when these layers are spatially interpolated.

A six-digit postcode address is assigned to every cell given the closest postcode address to the centroid of the cell, as shown in Figure 6-4(a). Spatial interaction between cells is established via the road network linked to cells centroid, as shown in Figure 6-4(b).

Figure 6-5 illustrates part of the table containing tabular information of the cell layer. In total, the cell layer includes 301,243 cells, covering the whole region of Eindhoven (a total of 13 towns and villages).

Up to now, we have described, collected and treated the baseline data. These data feed the DBMS, that from now on takes the responsibility to keep these data save and consistent, by managing storage, manipulation and retrieval. Baseline data is required to compose the “greenspace scenarios developments”. In other words, different scenarios may be elaborated as potential evolutions of the baseline situation.

Having the baseline data ready, the next step consists of collecting the data that describe individual behaviour, to estimate the models that predict awareness, preferences and behaviour within the system. The next section describes the methodology used to collect the data for model estimation.

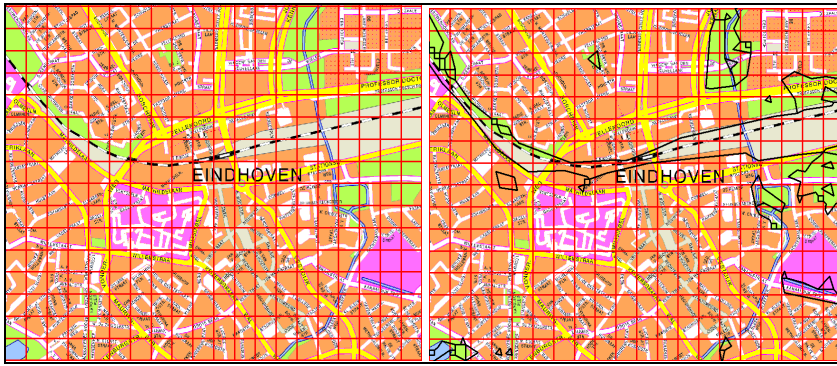


Figure 6-2. (a) Zoom in cell layer; (b) Add land use coverage layer.

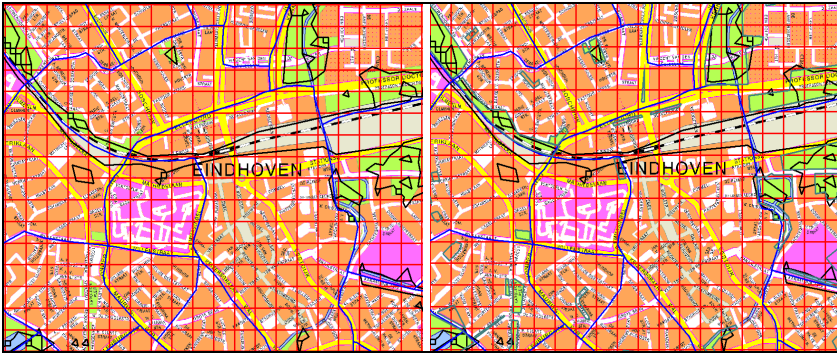


Figure 6-3. (a) Add zonal system coverage; (b) Add green space coverage

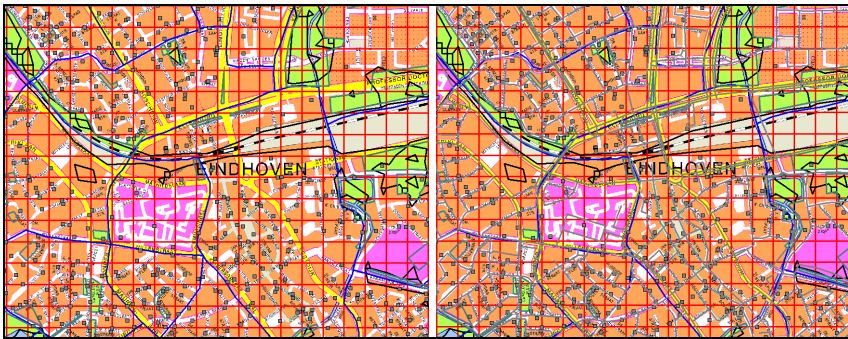


Figure 6-4. (a) Add postcode address; (b) Cell and Road Network layers

YNEA	LAND	TYF	URBA	POPDE	NUMBI	NUMB	NUMB	00_14	15_24	25_44	45_64	OLDI	NON	NUMF	PER	AVG	AVGIN	AVGIN	PERC	PERC	PER	NUMB	MUNH	MUNIC	PARK	HEC
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	25	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	1	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0
03500	43	0	5	82	0.81	0.42	0.39	17	15	23	36	10	7	0.24	66	3	21900	32000	41	24	16	0.27	758	Breda	0	0

Figure 6-5. Cell layer database

## 6.2 Calibrating the Models: Surveying and Questionnaire Administration

As indicated in the conceptual framework discussed in Chapter 4, and the conceptual model (described in Chapter 5), three models were estimated using empirical data: the *Awareness* model (Ponjé *et al.*, 2005); the *Preference* model (Ponjé and Timmermans, 2003); and, the *Trip Making Propensity* model (Kemperman *et al.*, 2005). The conjoint *Preference* model required a special data collection effort: an experimental design was created and implemented on the Internet. The other two models were estimated on the basis of a traditional surveying/questionnaire administrated by mail and Internet.

Based on the above discussion, this chapter is organized as follows. First, we describe the main questionnaire survey. To that end, we start with the delineation of the study area, followed by the design and administration of this questionnaire and report the relevant response rates and sample characteristics and finally report the analysis and parameter estimation of the *Awareness* and *Trip Making Propensity* models. During this analysis, greenspace attributes and characteristics were also needed but not available. Hence, a park inventory was prepared to collect the information on the greenspaces attributes, topic described next. This information was also used to feed the spatial greenspace database. Next, we report the design, administration and analysis of the conjoint analysis, an experiment conducted to estimate the parameters of the *Preference* model implemented within GRAS. The chapter ends with some conclusions and discussion.

### 6.2.1 Main questionnaire

This section describes the data collection procedures and statistical procedures used to estimate the parameters of the awareness and trip propensity models. We start with the delineation of the study area, followed by the design and administration of this questionnaire and report the relevant response rates and sample characteristics. Next, we describe the park inventory prepared to collect the information on the greenspaces attributes. Finally, Subsection 6.2.1.1 reports the analysis and parameter estimation of the *Awareness* and *Trip Making Propensity* models.

#### *Study area*

Respondents were recruited from the City of Eindhoven and 3 smaller neighbouring towns: Best, Son en Breugel, and Waalre, located in the South of the Netherlands. The sampling frame was build up as follows. First, for the City of Eindhoven, 16199 street addresses were sampled at random from their database weighted according to the number of households per neighbourhood. People received an introduction letter, explaining the goal of the research project and a small questionnaire to collect household information. In addition, they were asked whether they would be willing to participate in the research project. Questionnaires and diaries were sent to those who were willing to cooperate. Among those respondents who participated, fifteen coupons in a range from euro 100 to euro 1000 cash were raffled.

#### *Questionnaire design*

The first questionnaire of the data collection consisted of two parts (see Appendix E). The first part was used to collect data about the experience and use of green spaces and the second part was used to collect some additional household information.

The first part started with a question to get insight into user awareness of green spaces. Respondents had to mention up to five parks they best know. Next, respondents had to identify up to five parks they used most during the last twelve months. For the parks they used most, respondents were also asked to give information by season about the number of times they had visual contact with the parks, the number of visits, the time of day during the week and in the weekends of the visits, the duration of the visits and the transportation mode usually used. Furthermore, respondents had to report with whom they visited the parks, which activities they performed, what reasons they had for the visits, how satisfied they are with the parks and

whether they would like to have something changed to one of the reported parks and if so, what the change would be.

The questionnaire continued with a question about the perception of safety. More specifically, respondents were asked to mention up to five parks they avoided during certain hours or always and whether one of the reasons was vandalism, the presence of certain people or a feeling of insecurity. To get insight into the amount and variety of parks respondents were asked to give a ranking between 1 (very bad) and 7 (very good) to indicate how they assessed and how important they found the amount and variety of parks in the Eindhoven region. The last question of the first part related to the greenspace outside the own neighbourhood respondents had visited most during the last 12 months. For a whole list of uses and benefits, respondents had to give a ranking between 1 and 7 to indicate how they assessed and how important they found the uses and benefits of the park they visited most.

The second part of the questionnaire was used to collect some more household information. The introduction questionnaire brought already the following information: day of birth, gender, position in the household, main occupation, number of working hours, highest education and ability to drive a car or motorbike for up to six household members.

First, some questions were asked about the property they live in. More specifically, respondents were asked in what kind of property they live, what the type of tenure is and what kind of facilities their property has (balcony, lean-on, garage, garden, roof garden and own parking place). Furthermore they were asked how long they have been living in their current neighbourhood and city and to what extent their decision to move to this neighbourhood was influenced by the proximity to green space. Because we expect a relation between visiting green spaces and owning a dog, respondents were asked whether they own a dog.

Second, some questions were asked about the use and availability of transportation modes. Respondents were asked whether they had a handicap, which limits them to use certain transport modes. Respondents could indicate the transportation modes concerned. Furthermore, the availability of bikes, mopeds, cars and motorbikes was asked and the number of these transportation modes respondents owned. Last, respondents could indicate whether the household was engaged in official car sharing and whether they had a public transport season ticket and, if so, of what kind.

Finally, three more questions were asked. First, respondents were asked to indicate their annual household income. Second, they were asked what option they would most prefer if the Council had money left over at the end of the budget period: spend the money on greenspace, spend the money on something else, no opinion, don't know and other. Third, to end the

questionnaire, respondents were asked whether they had any questions, suggestions or comments with regard to the questionnaire.

#### *Administration*

In the introduction questionnaire respondents could indicate whether they would be willing to cooperate by mail or by Internet. Dependent on their responses, the questionnaire was administered through Internet or through the mail. Distribution through the Internet was handled by the City of Eindhoven. Unfortunately, to reduce the complexity and amount of effort of translating the questionnaire into an Internet-based format, the version distributed through the Internet was slightly different. Especially, multiple answers were avoided. This means that some analyses were based on the mail questionnaire only, whereas other analyses were based on the pooled data.

#### *Response rates*

Table 6-1 reports the response rate for the first questionnaire. In total, 3240 people indicated that they were willing to participate in the research. In total 1110 people were invited to participate in the study through the Internet. Ninety six (96) e-mails returned due to errors in the e-mail address. In the case that people also gave their home address, questionnaires were sent by mail. In total, 529 respondents completed the questionnaire, representing a response rate of 52,2%, which is quite high. To pay for expenses respondents received a coupon of 5 euro. In total, 2158 people were invited to participate in the study through the mail. Of these, 1124 completed the questionnaire, representing a response rate of 52.1%. To complete the 3240: 57 people were too young to participate. In the introduction letter we invited all household members older than 12 years of age. 11 People could not be reached through the Internet or by mail.

Table 6-2 provides further information about the kind of people, who were willing to cooperate by kind of survey instrument. A number of interesting observations can be made.

Table 6-1. Selection of respondents and response rat

	People willing to cooperate	Number of respondents	Rate
By mail	2158	1124	52.1
Through the internet	1014	529	52.2



Table 6-2. Distribution of people willing to cooperate according to some selected characteristics

	Sample mail		Sample internet		Total	Eindh
	Number	%	Number	%	%	%
<b>Gender</b>						
male	939	43.5	570	56.2	47.6	50.1
female	1184	54.9	432	42.6	50.9	49.9
unknown	35	1.6	12	1.2	1.5	
<b>Age</b>						
0 -24 years	143	6.6	108	10.7	7.9	28.8
25-39 years	508	23.5	334	32.9	26.5	25.7
40-54 years	480	22.2	287	28.3	24.2	20.0
55+ years	708	32.8	162	16.0	27.4	25.4
unknown	319	14.8	123	12.1	13.9	
<b>Household composition</b>						
1 person with children	146	6.8	68	6.7	6.7	5.3
2 persons no child	688	31.9	326	32.1	32.0	31.9
2 persons with children	451	20.9	322	31.8	24.4	23.2
1 person no children	758	35.1	253	25.0	31.9	34.5
Other	80	3.7	34	3.4	3.6	5.0
unknown	35	1.6	11	1.1	1.5	
<b>Working hours</b>						
no and a few hours (< 8 h)	1027	47.6	321	31.7	42.5	
part-time (>=8 & < 32 h)	388	18.0	191	18.8	18.3	
full time (>= 32 h)	743	34.4	502	49.5	39.2	

First, it shows that women were more willing to participate in the mail questionnaire. In contrast, men were more willing to return the email questionnaire. This finding suggests that men use the Internet more. Secondly, a similar effect can be observed for age. Table 6-2 shows that the willingness to participate for the 55+ age cohort is significantly lower than the corresponding willingness to participate through the mail questionnaire. Overall, willingness to participate is rather independent of age cohort, except for the younger than 24 years of age category, which shows a significantly lower rate.

Table 6-3. Number of parks per type in total, with information and used in the inventory

Type of park	Number of greenspaces	Information available	Inventory
Local park	1062	68	30
Neighbourhood park	136	13	123
District park	92	20	72
City park	50	24	26



Thirdly, there is less of a difference between the two means of administration for household composition, although two-person households without children have a higher response rate to the Internet survey than 1 person households without children, compared to the mail questionnaire. Except for the 1 person with children category, the response rates are more or less the same for different household composition categories.

### *Park inventory*

As already mentioned in the beginning of this chapter (spatial data collection), an inventory was organized to collect data on the description of the green spaces on the attributes listed in the Appendix B (Table 1) in order to explore the nature of the assumed relationships between awareness, preference, and choice and the locational and non-locational attributes of green spaces.

There are about 1340 greenspaces in Eindhoven, our study area (see Table 6-3). We needed to collect the data for all greenspaces of the study area except for the local parks, which are basically small grass field with playgrounds. Hence, 251 greenspaces had “unknown” information in the system database, requiring data collection. To decrease the amount of work, the data of these 251 greenspaces was collected in two steps. First, we used the respondents’ judgements and characterisations of the greenspaces they visit most during the last twelve months, instead of collecting the data for these green spaces. As said before, in the main questionnaire, respondents were asked to give a rank between 1 (very bad) and 7 (very good) to indicate how they assessed the characteristics of the park they most visited in the last twelve months (see Appendix E, questions 15 and 16). Because the information we needed had dichotomous variables, we had to recode the ranked information. For each variable and each green space, the mean was calculated. Means greater than 4 were recoded into “available or possible” and means lower and equal to 4 were recoded into “not available or possible”. This inventory assembled data for 125 greenspaces in total. In the second step, data of the other 126 greenspaces of the study area with unknown information was collected through fieldwork.

#### **6.2.1.1 Analysis and results**

Having described the data collection, the statistical procedure used to estimate the parameters of the Awareness and Trip Making Propensity models are now described.

*Awareness*<sup>3</sup>

A Partially Exploded Logit Model was estimated to describe the level of awareness of green spaces. As mentioned before, the concept of awareness was defined as the probability that respondents know a particular green space. It is assumed that the probability that a respondent is aware of a park is a function of park attributes, distance and a set of socio-demographic variables. This choice of model was driven by the fact that respondents did not indicate for all parks in the study whether or not they knew it, but only indicated in sequence the three parks they knew best.

To estimate these probabilities, first the total number of green spaces that were used to estimate the model has to be determined. To that effect, we first created a frequency distribution of the number of times that a green space (park) was mentioned. A total of 456 parks were mentioned. Only those parks that were mentioned at least three times were included in the final analysis. This resulted in a total of 162 parks/green spaces that were finally used for analysis.

The construction of the choice sets, used for model estimation, involved the following steps. If a respondent only indicated one of the 162 parks used for analysis, 10 additional parks were randomly selected from the remaining 161 parks. If two parks were mentioned, two choice sets were created. The first choice sets consist of the two parks plus a random selection of the remaining 160 parks. For this choice set, it was indicated that the first park was the known one. The second choice set consisted of the park that was listed second, plus the same random selection of parks. In case of three listed parks, three choice sets were created using the same principles. Using this procedure, a total of 5499 choice sets, involving 68497 cases were created. Effect-coding was used to represent the explanatory variables.

The results of the estimated model are shown in Table 1 Appendix F. The rho-square of the estimated model is .3778, which is a satisfactory result, keeping in mind the large number of cases. It suggests that awareness level constitutes a relatively stable concept. Table 1 Appendix F indicates that the probability of green space being known decreases with increasing distance. It also shows that awareness is systematically increasing from a local park to a city park. Most of the facility attributes were also significant at the 5 percent probability level, except for sport facilities, dustbins and playing facilities.

To investigate the effect of gender on awareness, gender specific contrast parameters were estimated (e.g., Kmenta, 1986; Oppewal *et al* 1994). These

<sup>3</sup> Ponjé *et al.*, 2005. "Factors Influencing Awareness Levels of Urban Greenspaces: A Partially Exploded Logit Analysis", to appear in the *Journal of Applied Psychology*.

parameters represent the effect of respectively male (+1) and female (-1). A significant parameter indicates a significant difference between male and female respondents in the contribution of the corresponding park attribute on awareness level. The results are presented in Table 2 Appendix F.

A number of interesting conclusions can be drawn from Table 2 Appendix F. First, it shows that women are more aware of parks with sport facilities more than men are. This may reflect that women use parks more often for exercising than men do. Secondly, men are more aware of parks with playing facilities than women are. This supported other findings in the larger project that on average men are more involved in active types of recreation compared to women. Thirdly, women are more aware of parks at a small distance from their home while men are more aware of parks that are farther from their home. This finding seems to support the finding related to the size of the parks: women tend to have a more local orientation in the conduct of their daily activities.

The next analysis concerned the effect of age. To investigate the effect of age on awareness, age specific contrast parameters were estimated. These parameters indicate the effect of young respondents (younger than 40 years: \* +1) and older respondents (40 and older than 40: \* -1). A significant parameter shows a difference in the effect of the corresponding park attribute between younger and older respondents. Table 3 Appendix F lists the results. It shows that none of the contrast parameters is significant at conventional 5 percent probability level: the one for picnic facilities however comes very close. The positive contrast parameter suggests that younger people are more aware of parks with picnic facilities. In contrast, older people tend to be less familiar with parks with playing facilities, but this effect is not significant at the conventional 5 percent probability level.

Finally, we analysed the effect of household composition on awareness, again by constructing contrast parameters. A distinction was made between households with children (+1) and households without children (-1). The results of the estimated values for this contrast effect are listed in Table 4 Appendix F. It shows that two contrast effects are significant at the conventional 5 percent probability level. The impact of footpaths on awareness is higher for household without children, suggesting that these facilities are more important for these households. Moreover, the effect of distance is larger (more negative) for households without children.

*The Trip Propensity Model Estimation<sup>4</sup>*

A mixed logit model was estimated to describe residents' trip making propensity for urban parks. The data for estimation were prepared as follows. First, the dependent variable indicating the number of trips per park per season was recoded. A daily visit was recoded as 90 trips per season; a few times per week as 36 trips; weekly as 12 trips; once every two weeks as 6 trips; monthly as 3 trips, once every three months as 1 trip; and never as 0 trip. The five (or less) parks visited most often were considered to constitute the choice set and in total a respondent could make 450 park trips (5 parks and a maximum of 90 trips per park) per choice set. For each respondent and each season (spring, summer, autumn and winter) a separate choice set was included in the estimation data file.

A base alternative 'no park visit' was artificially created for each respondent and added to each choice set for reasons of model estimation. This base alternative was defined as follows: the maximum number of 450 trips minus the trips made to the five (or less) parks in the choice set. The constant included in the model was coded as 1 for all parks and 0 for the constant base alternative 'no park visit'. In addition, for all other variables the base alternative was coded 0.

Secondly, all parks included in the choice set were recoded to four park types: local park, neighbourhood park, district park and city park. The main distinction between these four types is the size of the park, from small to large in the order as mentioned. In the estimation data set, dummy variables (1, 0) were used to represent the park types, and one park served as the base (city park).

Thirdly, the other variables, the temporal aspects (season, time of the week, time of the day), and some socio-demographics (gender, working hours and household type), were effect coded (1, -1). An overview of the variables, their levels and the specific coding is provided in Table 1 of Appendix G.

Simulated maximum likelihood estimation, using Halton draws, was used to estimate the parameters of the choice model. The number of Halton draws was set to 50. Parameters were estimated for the constant, the park types, the seasons, weekday/weekend trip in the morning, afternoon and evening, gender, working hours and household type. Also the standard deviation of unobserved heterogeneity specific to park types, and the unobserved covariance between the park types were estimated.

<sup>4</sup> This discussion follows Kemperman, A.D.A.M., Ponjé, M.M.W., and Timmermans, H.J.P., 2005, 'Analyzing heterogeneity and substitution in trip making propensity to urban parks: A mixed logit model', paper accepted for publication in *Tourism Analysis*.

The log likelihood value of the estimated model  $LL(B)$  was compared with the log likelihood of the random choice model  $LL(0)$  (i.e., the log likelihood that arises when the choice for each alternative is assumed to be equally likely) to test if the estimated choice model significantly improved the null model. This was tested using the likelihood ratio test statistic  $G^2 = -2[LL(0)-LL(B)]$ , which tests the hypothesis that all parameters are equal to zero. This statistic is asymptotically chi-squared distributed with degrees of freedom equal to the number of free parameters in the model. McFadden's rho square =  $1-LL(B)/LL(0)$  was used to indicate the goodness of fit of the estimated choice model.

Table 2 of Appendix G presents the parameter estimates and their significance for the constant, the type of park, seasonal effects, time of visit (weekday/weekend and morning/afternoon/evening), gender, working hours, household type, interactions between park type and the other variables mentioned, and the standard deviation specific to the park type parameters and unobserved covariance between park types. The log likelihood value of the estimated model is also shown.

The overall fit of the model is good, with McFadden's rho-square value of 0.72. Most of the parameter values are significant at the 95% confidence level. The log likelihood value of the estimated mixed logit model is -986323.9.

The constant of the estimated choice model indicates the average difference in utility between the park alternatives and the base alternative of 'no park visit'. The parameter value of the constant is very negative. This suggests that the average probability of making a trip to a specific park is lower than the probability of staying at home. However, it has in fact no significant meaning because the negative constant is mainly caused by the definition of the base-alternative. The base alternative was artificially defined by taking the maximum number of 450 trips minus the trips made to the five (or less) parks in the choice set. Understandable, only few respondents made 90 trips to a park per season, on average the respondents paid 17.8 trips per park per season. Therefore, for many respondents the frequency of the base was quite large compared to the number of trips to the parks in the choice set and the parameter value of this constant is negative.

Table 2 of Appendix G shows the parameter values, their standard deviation and the unobserved covariance for the park types. The results show that the respondents prefer the local park most for a leisure trip, followed by a neighbourhood park type. This means that the respondents prefer the smaller parks to the larger parks for a trip. This was expected because the smaller parks are often closer to home and are visited more often for a small period of time than the larger parks that are visited less often, but for a longer period of time.

The standard deviations of the parameter distributions of the park types are all significant at the 95% confidence level (note that the city park served as the base for the park types). This indicates that respondents do differ in their propensity to make a trip to a particular park type. Specifically, the standard deviation for the district park parameter is quite large, and residents seem quite diverse in their propensity for making a trip to a district park type. This result could be explained by the fact that the district parks are the larger parks and therefore they provide a more unique environment that residents specifically like or do not like. The local parks are smaller and have less and probably more similar features, and therefore residents might be more similar in their preferences for this type of park.

The three estimated covariances between the park types are all significant at the 95% confidence level. The local and district park are highly positively correlated. This estimate implies that residents who prefer to make a trip to a local park type also prefer to make a trip to a district park type. These types of parks complement each other. This can be explained by the fact that respondents who often visit a small local park also like to make a trip to the larger district parks; in general they like visiting urban parks. This explanation also applies for the positive, although smaller, correlation between a neighbourhood park type and a district park type. The opposite holds for the correlation between a local and a neighbourhood park type, the parameter indicating the covariance is negative. This shows that local and neighbourhood parks are more substitutes in terms of leisure trip making. This is not surprising as these two park types are about the same size and located at relatively close distance of the respondents' residences.

The results also suggest significant seasonal differences. At first sight, it seems that the respondents have the propensity to visit most parks in the summer season, followed by the autumn and winter, and that spring is the least preferred season to make a trip to a park. However, the actual order of preference is different when the interaction effects between season and park type are also taken into consideration. Especially for the spring season, the interaction effects are large and positive, while for the other seasons they are lower and sometimes negative. Thus, when these interaction effects are also taken into account, the order of preference becomes different. In this case, summer is still the most preferred season to make a park trip, followed by the spring season, while the autumn and winter are the least appreciated seasons to visit a park. The reason for this seems clear, respondents have the propensity to make a trip to a park and like to go outdoors when the weather is good.

Table 2 of Appendix G also lists the parameters indicating the effects of timing: day of the week (weekday or weekend), and time of day (morning, afternoon and evening). Note that because of their questions the parameters

do not indicate the trade-off between a weekday or weekend trip or between a morning, afternoon or evening trip. For example, a resident could make a trip to the same park 45 times during a weekday and 45 times during the weekend in the spring season. However, the parameters indicate that during the week the morning is most preferred for a park trip followed by the evening and the least preferred time of the day for a trip is the afternoon. But also for this variable, the interaction effects should be considered. Then, during the week, the morning is by far the most preferred time to make a trip to an urban park, followed by the afternoon and least preferred for a park trip is the evening. During the weekend the propensity for trip making remains unchanged.

Finally, Table 2 of Appendix G presents the results of the parameters for the socio-demographics. The positive parameter for gender suggests that men make more trips to parks than women. However, the interaction effects indicate that men pay more visits to the local parks whereas women have the propensity to make trips to the neighbourhood parks more frequently.

Not surprisingly, the negative parameter for working hours indicates that respondents who work more hours, make less trips to the parks, while respondents who work less hours make more trips to urban parks. However, the interaction effects between working hours and park types show that the parks closer to home (the local and neighbourhood parks), are visited more often by the respondents who work more hours, whereas the parks farther away are visited more frequently by respondents who spend less hours at work. Making a trip to a park that is closer to one's home takes less time than making a trip to a park that is located further away, and people who work more hours have probably less time for leisure trips.

The positive parameter for household type suggests that families with children have a higher propensity to make a trip to a park than families without children. However, all interactions of household type with the park types are negative; so in the end it seems that families without children have a higher propensity to make a park trip. It could be that households with children more often make a trip to the larger city parks where more facilities are available for the children to enjoy themselves.

The parameters estimate with this model and presented in Appendix G are then inputted in the user interface of the *trip making propensity model* implemented in GRAS.

### 6.2.2 Conjoint choice experiment<sup>5</sup>

As said before, the estimation of the *preference* model requires a dedicated second data collection effort. Conjoint preference and choice experiments focus on stated responses of subjects who are requested to express their preference for a set of attribute profiles which are varied according the principles underlying the design of statistical experiments. Preference designs differ from choice designs in that subjects are shown sequentially the hypothetical profiles and are asked to rate each profile on some scale of preference. In contrast, when using choice experiments, the utility function and choice model are estimated simultaneously. In this case, profiles are placed into choice sets and respondents are requested to choose the alternative in each choice set they like best.

The application of a conjoint choice experiment implies that one has first to elicit the attributes that are deemed relevant to the problem of interest, in this case the choice of greenspace. In addition to selecting the influential attributes, one also has to characterize each attribute in terms of attribute levels. Next, these attribute levels are combined according to some experimental design, which allows one to estimate the preference or choice model of interest. In many applications, a multinomial logit model, which can be derived from random utility theory, is used. The design of the experiment for choice analysis implies that the attribute profiles are placed into choice sets. Having constructed the experimental design, one has to decide on the task for the respondents. Finally, the attributes varied in the experiment need to be coded and the user responses need to be analysed to estimate the choice model of interest. The operational decisions made in the present study are described in Chapter 5.

This section is organized as follows. First, we describe the sample and report the relevant response rates. Next, we describe the experimental task followed by the experimental design. Finally, we report the analyses and results.

#### *Sample and response rate*

The sampling frame consisted of two parts. First, people were randomly selected from a database of addresses from the city of Eindhoven and asked whether they were willing to participate. A total of 750 respondents were recruited in this way. The email addresses of these people were obtained.

<sup>5</sup> Ponjé, M.M.W. and H.J.P.Timmermans, 2005, “*Development of a conjoint choice model to predict trips to urban parks in Eindhoven*”, Greenspace Project, European Commission, Fifth Framework Programme. Final Report, pp.33-37.



Secondly, members of a panel, organized by the city of Eindhoven, were invited to participate. An additional 778 respondents were recruited. In total, 1628 people were invited to participate in the study through the Internet. Potential participants were given the link to the web site where they could complete the experiment. In total, 111 respondents completed the experiment, representing a response rate of 7.3%, which is a typically response rate for this mode of administration without incentives, pre-screening and reminders.

Table 6-4 describes the sample in terms of a number of socio-demographic characteristics. It shows that the majority of the respondents were male (59.5%). In terms of age, Table 6-4 demonstrates that the majority of the respondents were between 25 and 54 years of age, 15.3 percent were older than 55. The majority of the respondents had no children.

Table 6-4 also shows some evidence of sampling bias, which seems rather typically for Internet questionnaires. Females are underrepresented in the sample. The elderly and the young people are also underrepresented. As for household composition, 2 person households with children are over-represented. The analyses reported in this paper relate to the sample. If the results are used to say something about the Eindhoven population at large, the data should be weighted accordingly.

Table 6-4. Distribution of sample

	Number	Sample Percentage	Eindhoven Percentage
<b>Gender</b>			
Male	66	59.5	50.1
Female	45	40.5	49.9
<b>Age</b>			
0 -24 years	5	4.5	28.8
25-39 years	46	41.4	25.7
40-54 years	43	38.7	20.0
55+ years	17	15.3	25.4
<b>Household composition</b>			
1 person with children	6	5.4	5.3
2 persons without children	35	31.5	31.9
2 persons with children	54	48.6	23.2
1 person without children	16	14.4	34.5
<b>Other</b>			<b>5.0</b>
<b>Working hours</b>			
No and part-time (< 32 h)	46	41.4	
Full time (>= 32 h)	63	56.8	
Unknown	2	1.8	

*Experimental Task*

Choice sets consisted of two hypothetical urban parks. Usually respondents were requested to choose from each choice set the alternative they like best. In the present study, however, respondents were asked to allocate 10 trips among these two hypothetical parks. This allows them to take into account the different reasons they might have for visiting the parks.

*Experimental Design*

Table 1 in Appendix B shows that we selected two attributes with four levels each, and twenty attributes with two levels each. Hence, the full factorial design involves  $4^2 2^{20} = 16.777.216$  profiles. From these, an orthogonal fraction, consisting of 128 profiles was selected. These 128 profiles were combined at random to create 128 choice sets, ensuring that the same profile did not appear twice in the same choice set. Next, these 128 choice set were divided at random into blocks of 8 choice sets. Respondents were shown a randomly selected block of 8 choice sets. This design strategy allows the estimation of a linear additive utility function and the multinomial logit model.

*Analyses and results*

The Table 2 in Appendix B reports the estimated part-worth utilities and the derived relative importance of the attributes. The overall fit of the model is satisfactory, with rho-square value of 0.271. The results demonstrate that, on average, distance to the urban park is the most influential attribute, followed by size/type of park. The part-worth utilities for distance indicate that utility decreases more or less at an increasing rate with increasing distance. as expected, the part-worth utilities for type of park indicate that utility increases with the park size. All estimated parameters for those two attributes are significant at the conventional 5% probability level.

Next in importance are respectively possibility to walk, availability of café, place to eat, kiosk, type of green, possibility to walk the dog, possibility to enjoy a wonderful view, accessibility by public transport and possibility to organize something. All estimated parameters are significant at the conventional level. Moreover, all signs are in anticipated direction, except for accessibility by public transport. Upon reflection, the negative sign might reflect the fact that public transport in the city is rarely used for visits to parks, and only by particular segments of the population. Regarding vegetation type, individuals prefer greenspaces with trees and bushes to greenspaces with grass and flowers.

All remaining attributes are not significant at the 5% probability level. This implies that either these attributes are considered not very important or that diverging preferences cancel out at the aggregate level within the sample. Within this group of attributes, safety and maintenance are slightly more important. The availability of many facilities and attributes, such as playground and sport facility, toilet, trash bins, and lighting, are deemed not very important. The two least important attributes are ecological value of the park and the presence of benches with tables.

The estimated part-worth utilities shown in Table 2 in Appendix B are inputted in the *preference* model in GRAS, via the user interface.

### 6.3 Conclusions and Discussion

Because GRAS is heavily dependent on data, and having the objective of making the system operational to apply in a case study of the city of Eindhoven (to be described in Chapter 7), this chapter was dedicated to issues regarding data collection and model estimation.

First, the spatial representation (cell system) that describes the study area in GRAS (introduced in Chapter 4, section 4.3.1) requires a variety of spatial (and non-spatial) data, obtained from different data sources and with different spatial representation. Based on that, in this chapter we described a procedure to spatially disaggregate and then aggregate the relevant spatial data to compose the *cell system* (intermediary database infrastructure).

Secondly, based on the conceptual framework discussed in Chapter 4, the type of models integrated in GRAS (see Chapter 5) to predict the spatial and non-spatial factors influencing individual behaviours towards urban greenspaces, required a multitude of data collection to calibrate these models. Two models, the *awareness* and the *trip propensity* models, were estimated on the basis of a traditional surveying/questionnaire administrated by mail and Internet. The *preference* model, on the other hand, required a special data collection effort: an experimental design was created and implemented on the Internet. Aspects of questionnaire administration, and design, and the conjoint choice experiment were reported in this chapter. In addition, appropriate statistical procedures to parameter estimation were described. A report on the analysis and models' parameters estimation is the outcome of this chapter. Such parameters were then inputted in the respective models of GRAS, making the system operational and ready to be applied for the greenspace planning, design, and maintenance in the region of Eindhoven. In the next chapter, we apply the system to a case study in this region.

## CHAPTER 7

### 7. CASE STUDY

This chapter describes a case study that employs GRAS, the SDSS developed in this research project, to illustrate the system's capabilities to support decision-making problems in the planning, design and maintenance of greenspace. The Eindhoven city is the study area used in this case study. Eindhoven is the fifth largest city of the Netherlands, located in the Southern region of the country. The objective of this study is to investigate and assess a proposal to develop new greenspace in the city centre of Eindhoven.

As a consequence of national spatial planning and spatial development principles, the city centre of Eindhoven as part of the *red contour* (described in Chapter 3), has insufficient greenspace to support primary work, residential and recreational functions. Being the most important commercial centre of the entire region of Eindhoven, this densely built space attracts people from several villages in its surroundings, coming mostly for shopping and leisure activities (e.g., shopping, restaurants and movies). As a result of a "compact city" planning philosophy, many open spaces have been developed, not leaving that much greenspace. The lack and need of greenspace in this area is clearly noticed by the overuse, especially during lunchtime, of a small grass field around the train station, which is in the heart of the city centre.

In line with the spatial strategy to improve greenspace in the city of Eindhoven ("Visie Groenbeleidsplan", October, 2000), we study the possibility of developing new local greenspace for recreational use in the city centre of Eindhoven to support its primary work and residential function. To this end, we deploy the SDSS developed in this research project to assess and evaluate the benefits that such greenspace would bring to the community.

The operation of GRAS is based on the concept of scenarios. A scenario is defined in terms of an appropriate database that represents the urban system in terms of greenspace amenities, the transportation network, the land use configuration, the zonal system and the work facilities of the entire study area. At the starting point, the user, having certain aspiration levels or goal states for the urban area being monitored, can modify the actual scenario. As

suggested by Arampatziz *et al.* (2004), this “reference” or “zero-state” scenario corresponds to the baseline situation, which is always present, serving 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”. Scenario analysis corresponds to the application of appropriate domain models and presentation of computational results through appropriate thematic maps and tables. Finally, the multicriteria evaluation tool is used to support the selection of the best scenario, given a set of potentially conflicting criteria; scenarios are ordered from most to last desirable.

The objective of this case study is not to give a best solution to the decision problem at hand. This is a task that involves decision makers’ knowledge and personal judgment. Rather, the objective here is to illustrate how the system can support decision-makers to explore the problem more objectively, with tangible measures from different perspectives.

This case study is presented as follows. We start with a brief description of the study area (“zero-state” scenario) in terms of some socio-demographic distributions. Next, the assessment of the “zero-state” scenario using a set of models and performance indicators, such as accessibility, pressure, greenspaces utility, quality of life, and so on, is performed. Results are shown through appropriate thematic maps and/or tables for a better diagnosis of the greenspace weaknesses in the target area, i.e., the city centre area. Then, a new scenario is created by strategically positioning a new greenspace in a suitable cell within the city centre. Different designs are tried for the new greenspace in order to optimise the relationship between people’s interests and greenspace costs, i.e. social welfare. The same set of performance indicators used to assess the “zero state” scenario is then used to assess the new scenarios and their different design facets. Finally, we compare the scenarios using the multicriteria evaluation tool. For these spatial scenarios, GRAS uses the spatial choice models. In addition, the current version of Aurora can be used to assess temporal scenarios. This is illustrated as a second temporal scenario.

## 7.1 “Zero-state” scenario

In line with the system concepts to assess and evaluate greenspace provision and maintenance, we observe the difference between the present and future state of the system being monitored. The difficulty in assessing greenspace benefits comes from the lack of understanding of the non-economic value that individuals place on greenspaces. We propose an approach associating greenspace location and attributes, individual’s demographics, and

individual’s behaviour towards greenspaces as instruments to provide indicators of the system state.

Figure 7-1 shows a map of the city of Eindhoven representing the zero-state scenario. The representation of scenario within the system is given by a raster image, overlaid with the vector cell-based layer of the area, which composes the basic instrument to represent the spatial and non-spatial aspects of the decision making process. The raster image does not provide attribute data, but it is essential to spatially reference the users and allow them to visually understand the spatial dimension of the problem. It is a digital map of the city, where different land uses are finely represented in different colour patterns. For instance, work facilities are highlighted in pink; road network is highlighted in: (i) yellow for high-speed roads; (ii) white for low speed roads; (iii) grey to pedestrian areas (shopping streets); (iv) dash style for railways; and, (v) red for highways. Greenspaces are highlighted in different shades of green, varying from light green for greenspaces with landscape value and dark green for greenspaces with ecological value. Water, such as lakes and canals are highlighted in blue, agriculture areas in grey, and finally housing in sandy brown.

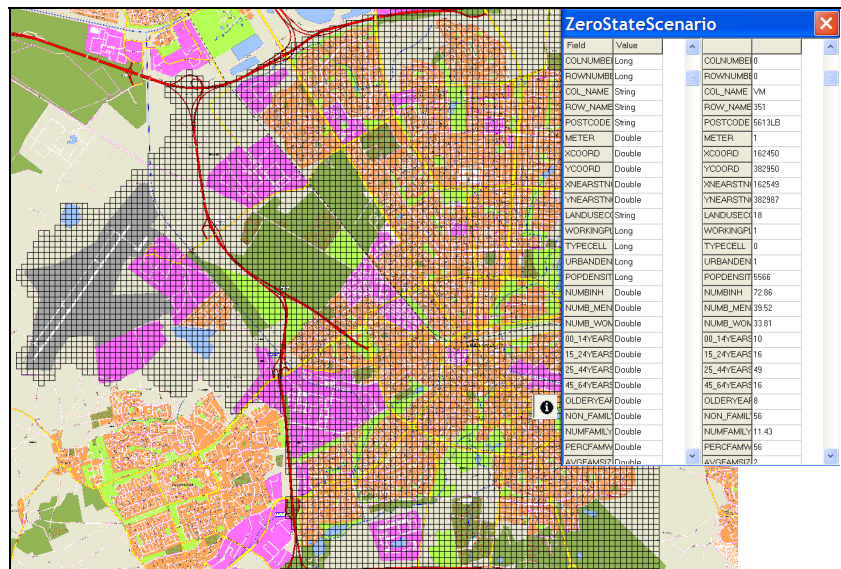


Figure 7-1. Eindhoven city map (raster and cell-based vector layers)

The cell-based vector layer on the other hand, consists of polygons (100x100m) containing georeferenced attribute data, (resulting from the spatial interpolation of different data sources, as described in Chapter 6). Therefore, raster and vector layers are complementary to each other to provide maximum visual capability and data based information to the user.

Having the system's information button enabled, the users are able to retrieve the database information with a single click on the map's object displayed in the map interface, as illustrated in Figure 7-1. Using this basic mapping instrument, the user can explore some general issues of the problem. A thematic map tool enables visual representation of information through geographic interpretation, i.e. the representation of information in themes in terms of their geographic distribution and interrelationships. For instance, Figure 7-2 shows the thematic map representing the population in Eindhoven. The black dots represent the population density across the city. Note that, Eindhoven is a typical radial city with a more dense population around the CBD<sup>1</sup>, surrounded by a circle in Figure 7-2.

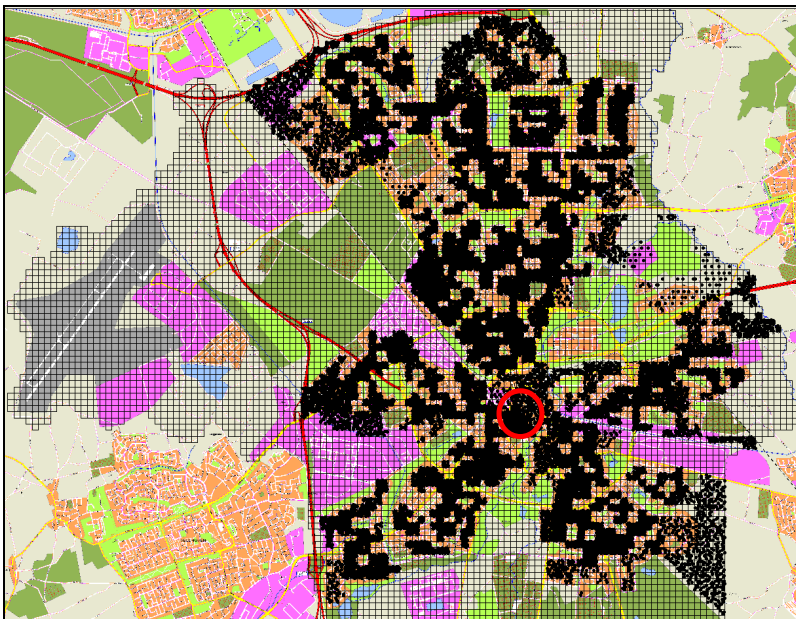


Figure 7-2. Zero state scenario population density

<sup>1</sup> The central business district of an urban area, typically containing an intense concentration of office and retail activities



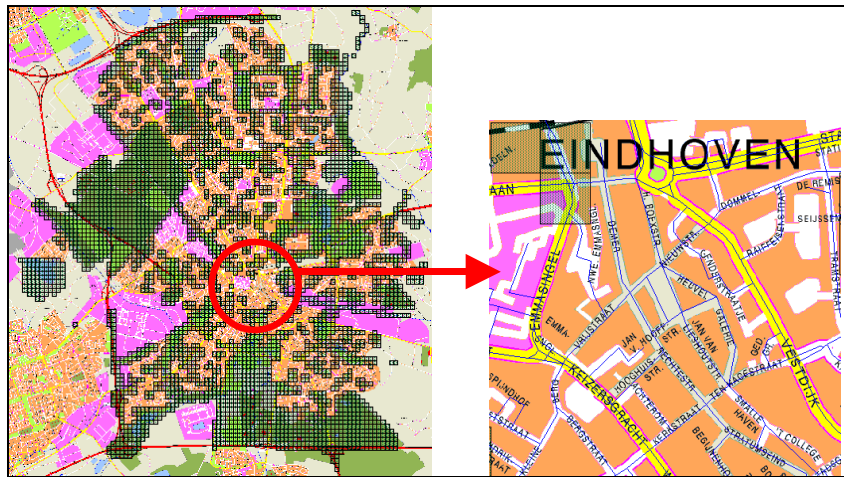


Figure 7-3. "Zero-state" (a). Greenspaces in the Eindhoven city; (b) Zooming in the city centre.

Eindhoven (as most Dutch cities) has a high population density level, up to 10.000 inhabitants per km<sup>2</sup> around the CBD.

Figure 7-3 illustrates the distribution of greenspaces in the city. The lack of greenspace in the central area is shown by zooming in on the CBD area (Figure 7-3 (b)).

Hereafter, we use the thematic map tool in the “*standard deviation*” mode to create thematic maps. The darker the colour pattern, the higher the associate attribute value.

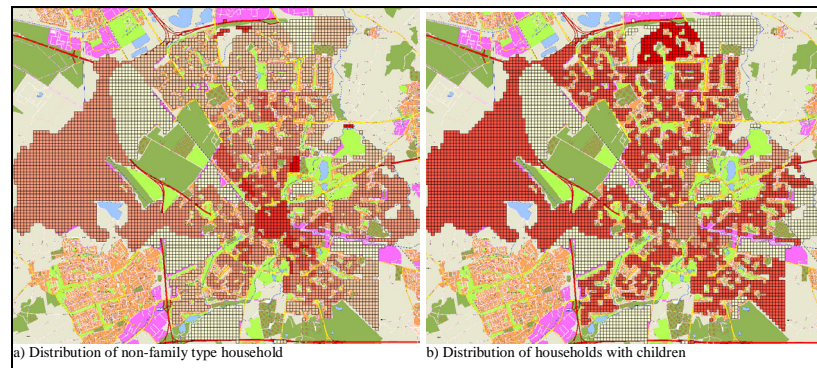


Figure 7-4. Other socio-demographic characteristics



Regarding households' characteristics, Figure 7-4.(a) shows that the higher percentage of households around the CBD is of the non-family type (individual households or households of individuals living in group quarters such as dorms).



Figure 7-5. Distribution of population by age

Figure 7-4.(b) shows that households with children are distributed more or less equally across the city, except around the CBD. This could be an indicator of the lack of greenspace in the CBD area, as demonstrated in some studies that individuals with children migrate to greener areas of the city (e.g., Nicol and Blake, 2000; Herzele and Wiedemann, 2002).

Figure 7-5 shows the spatial distribution of the population by categorical age groups in a thematic map. Observe that individuals between 15 and 44 years old are predominantly located in the city centre; the group between 25 and 44 years is most dominant in this area.

To conclude the demographic analysis, we can say that the population group directly affected by the lack of greenspace in the city centre of Eindhoven is the group of individuals between 25 and 44 years old, belonging to non-family households, without children.

#### *Cell level zero-state scenario evaluation*

One of the most basic and important greenspace performance indicators is the concept of accessibility. Although there is no universal accepted standard for this measure, access to green areas is recognized as essential for healthy local communities and local sustainability. The judgment/preference of decision makers is essential to determine an appropriate equation to measure accessibility. Nevertheless, we employ all the nine equations implemented in the system to explore accessibility issues in our case study. The nine equations implemented within GRAS to measure accessibility are broadly grouped into three types: the container measure, the cumulative opportunity measure and spatial interaction measures.

The container measure is concerned with the number of greenspaces available within a certain distance from an origin, which in our case is the home location of individuals. The container measure simply counts the number of greenspaces available within a specific distance from an origin. It can also output the minimum distance measure, which finds the distance to the nearest greenspace amenity. Based on the local policy, which says that individuals must be able to reach local greenspaces within 400m from their home, we analyse accessibility to greenspaces based on this threshold.

Figure 7-6 illustrates the thematic map of the computational results of the container measure. The “*standard deviation*” mode is used to generate the colour patterns in the maps. In Figure 7-6, darker colours reflect higher accessibility levels. Observe that the central area of the city (highlighted with a circle) has relatively poor accessibility level. The disadvantages of the container measure are: (i) the influence of distance is the same within the selected threshold (400m); and, (ii) the size/type of the greenspace does not play any role in this measure.

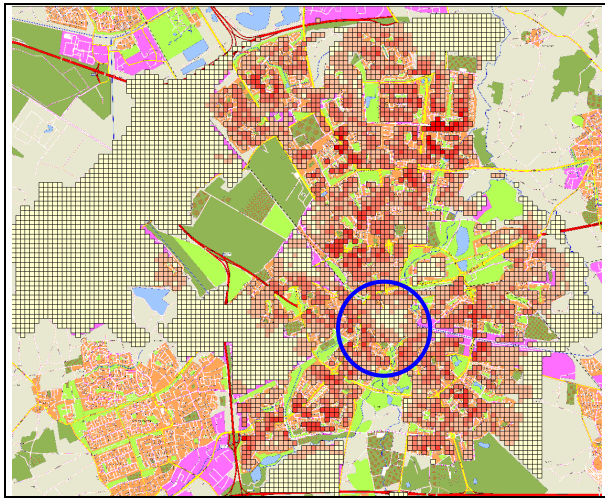


Figure 7-6. Accessibility to greenspaces as function of the number of opportunities

Figure 7-7 shows the computational results of accessibility as a function of minimum distance (using the road network) to greenspaces. In this case, the longer the distance, the darker the colour pattern in the thematic map and therefore, the lower the accessibility level.

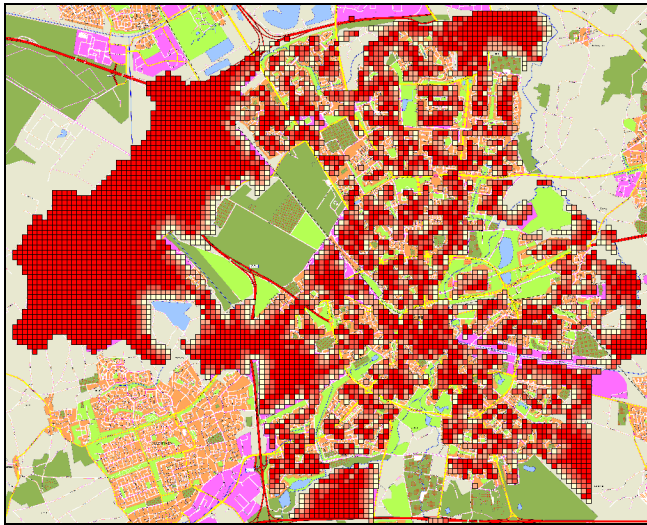


Figure 7-7. Minimum distance accessibility measure

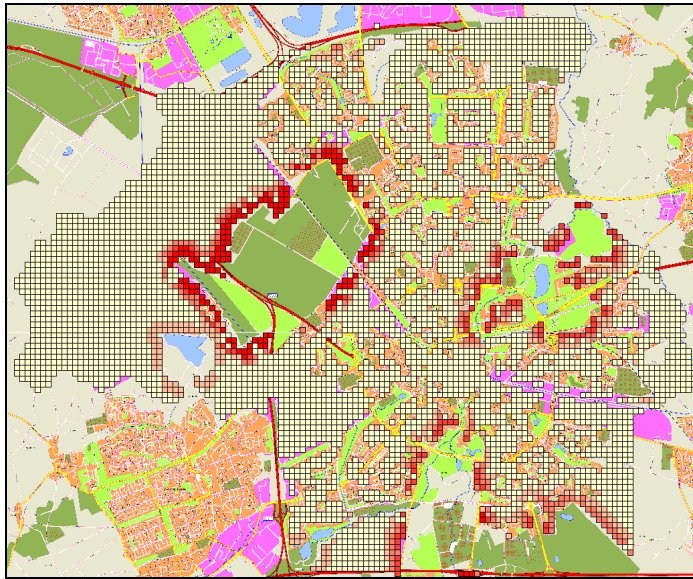


Figure 7-8. Accessibility number of opportunities as function of distances

Once again, this measure indicates a relatively low accessibility in the city centre area, as well in most of the study area. The disadvantage of this measure is that it never includes more than one facility (only the closest one) to measure accessibility. As in the case before, this measure does not take into account the size of the greenspace facility in measuring accessibility.

In order to overcome the weaknesses of the container and minimum distance measures, the so-called cumulative measures (Ingrim, 1971; Helling, 1998; Black and Conroy, 1977; Kwan, 1998) can be used. In this case, accessibility is measured by the sum of opportunities, where opportunity is given by greenspaces size and distance.

Figure 7-8 shows the computational results of the cumulative opportunity measure. This accessibility measure accumulates a score given by the size of greenspaces multiplied by a distance factor. As a distance factor, distance is standardized to a negative scale, such as  $(D-d)/d$ , where  $D$  is the threshold value given by the user and  $d$  is the distance to greenspace. Thus, in Figure 7-8, higher scores (dark colours) reflect high accessibility levels. The cumulative-opportunity measure presents low accessibility scores for the entire city, except the cells surrounding the larger greenspaces.

Accessibility analyses using spatial interaction measures are shown in Figure 7-9, where the distance friction parameter is based on the distance effect parameter of the trip propensity model ( $\beta = -0.0001$ ) and the threshold value is set to 400 metres. Note that user could also decide to derive the

parameter from different and perhaps more consistent models with this accessibility measure.

Figure 7-9(a) shows accessibility scores using the well-known *gravity potential* expression. The gravity type measure suggests that accessibility is positively related to the size of the attractiveness and negatively related to the travel impedance, which is the inverse power function,  $d^{-\alpha}$ . In the *entropy maximizing model* (Figure 7-9(b)) on the other hand, the travel impedance function has a negative exponential function,  $\exp(-\alpha d)$ . For both cases, the computed accessibility score for each cell characterizes the potential supply of greenspace within a certain threshold value (catchment area). For these measures, the higher the score, the better the accessibility level. As in the cumulative opportunity measure, accessibility scores in Figure 7-9(a) and (b) are relatively low for a great part of the city, because of the impact of the distance decay factor, which increases either to the power of the friction parameter in the case of the gravity potential measure, or exponentially, in the case of the entropy maximizing measure.

Figure 7-9(c) and (d) show accessibility scores using expressions that incorporate the probabilistic (or choice-based) notion of greenspaces visits. Figure 7-9(c) estimates the probability of a individual located in cell  $k$  selecting a given greenspace  $j$  by dividing the *gravity potential* accessibility score of that site by the sum of all the (*gravity potential* accessibility) scores from the individual's greenspace choice set (greenspaces within the threshold). On the other hand, the *probability entropy-based measure* (Figure 7-9(d)) estimates the same probabilities using a entropy maximization model. In both cases, the accessibility score is the given by the sum of probabilities multiplied by the respective distances. Lower scores reflect better accessibility, because the goal is to minimize the average travel distance. Note that, there is a methodological problem in the calculation of the probabilistic accessibility measures. When the threshold value (or catchment areas) is not large enough to include at least one greenspace per cell, biases results will appear. In other words, if there is no greenspace within the catchment areas, the distance is automatically set by the computer programming to zero, because no special action has been taken (e.g., a methodology to convert missing distance values into a "maximum" accessibility score, which in this case means low accessibility). However, small scores (tending to zero) reflect high accessibility (imagine the case when the distance to greenspace is very small, approximately zero). For this reason we dismiss the probabilistic accessibility measures from our scenario evaluation and made sure the system returns a warning message and does not allow the user to use this accessibility measure when the action space (catchment areas) is not large enough to hold at least a greenspace per cell analysed.



Finally, Figures 7-9(e) and (f) shows accessibility scores derived from the *consumer surplus* approach, i.e. individuals derive utility from each greenspace from the choice set.

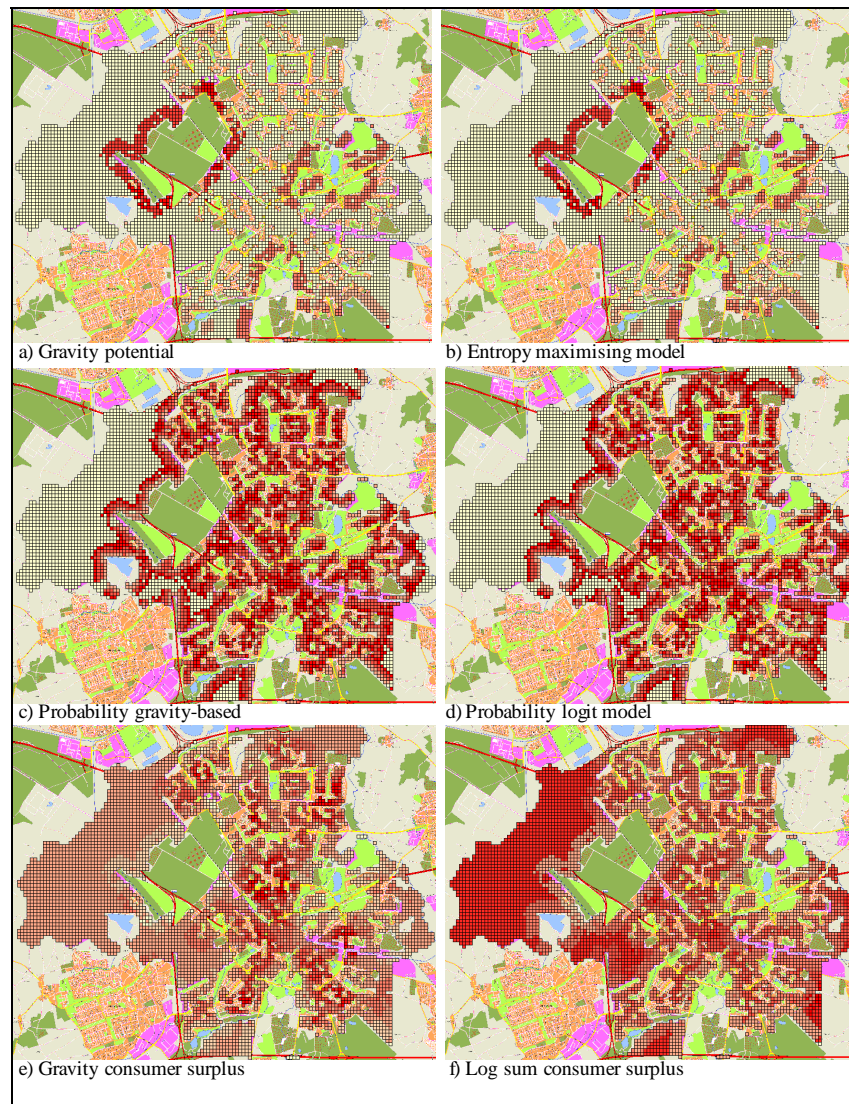


Figure 7-9. Spatial Interaction Methods

The average utility value of the individual greenspace choice set is then the accessibility measure. The *gravity-based consumer surplus* measure assumes a combination of a linear negative function of distance and a logarithmic function of size to derive greenspace utility (Figure 7-9(d)). According to the *log sum consumer surplus* measure (Figure 7-9(e)), greenspace utility is measured with an exponential negative distance function multiplied by the size of the facility. The accessibility score is then given by a logarithmic function of the sum of greenspaces attractiveness. In these cases, a higher score reflects a better accessibility. Because the *log sum consumer surplus* accessibility measure has a negative index, a darker colour reflects worse accessibility.

Each accessibility measure implies a different treatment of spatial externalities associated with greenspaces. Both the container measure and the minimum distance measure mostly ignore these externalities, but in a slightly different manner. When there are multiple facilities in the catchment area, the container measure will include them all, whereas the minimum distance index will count only the distance to the closest facility. The cumulative opportunity measure, gravity potential and entropy maximising measures capture the spatial externalities of the combination of facilities within the catchment areas, but according to different travel impedance. Gravity potential and entropy maximizing measures tend to consider steeper distances decay compared to the cumulative opportunity measure. Nevertheless, the most obvious problem with these methods however is the lack of a direct relationship between individuals' choice and accessibility. Based on the notion that individuals are likely to visit greenspaces, probabilistic measures attempt to capture different competing elements (size and distance) to explain individual's choices. The consumer surplus measures, on the other hand, apply random utility theory implying that the benefit or accessibility to individuals is given by the sum of the maximum utility of greenspaces from their choice set.

The different patterns between accessibility measures suggested by the maps demonstrate that the choice of measure has to be considered very carefully when trying to analyse the accessibility of greenspaces. Depending on the goal, the primary issue to be determined is what characterization of accessibility is most appropriate/relevant. This concerns the decision how distance should be characterized, and what assumptions about travel behaviour are most appropriate. Beyond the differences among the accessibility measures as explained before, we hope to have shown that the system is prepared to support decision makers with different methods for empirical accessibility analyses. The range of options can help users to gain an understanding of the sensitivity of the conceptualisation and measurement

of accessibility in order to diminish a too narrow interpretation of accessibility.

Based on the notion that individual behaviour is assumed to be spatially driven and greenspace choice preferences are dependent of: (i) individual spatial location; and (ii) greenspace attributes and characteristics (as shown in Appendix B), we applied the *preference* model to estimate greenspace utilities and preferences.

The *preference* model is the simplest model of choice behaviour within the system. Indeed, this model assumes utility-maximizing choice behaviour implying that the preferences of an individual living in cell  $z$ , for greenspace  $j$  among  $J_i$  possible alternatives (greenspace choice set) depend on the greenspace attractiveness (attributes and characteristics) and distance.

In this application, we use Rule 2 of the model to specify the action space choice set. Hence, based on the general principle that individuals may be willing to travel longer distances to reach larger greenspaces, individuals choices are defined as the set of greenspaces located within 400m from the individual residence location, if the greenspace is a local park; 800m if the greenspace is a neighbourhood park; 1600m if it is a district park; and 3200m if it is a city park. It should be emphasized that this definition has been made to illustrate the flexibility of the decision support system. Choice sets can be defined in various ways, including a very large set implying that spatial choices are driven only by the distance effect.

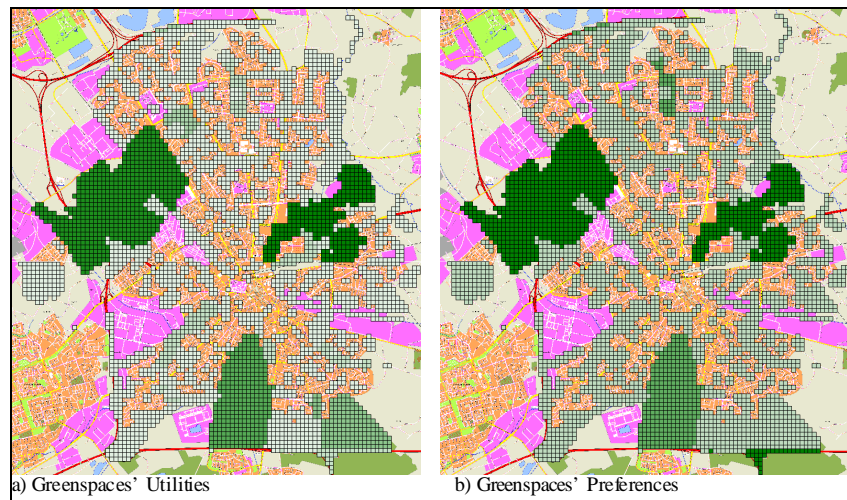


Figure 7-10. Preference Model



A visual representation of the spatial distribution of greenspaces' utilities and preferences is given in Figure 7-10 (a) and (b), respectively. Darker colours reflect higher utility and preference values. As expected, large (city) parks have a high utility score, in part because of the size and in part because they offer more possibilities for recreation.

#### *Individual level zero-state scenario evaluation*

Moving our analysis to the individual level, the next model applied to evaluate greenspaces in the study area is the *Awareness* model. Before proceeding with the application of spatial choice models at the individual level, socio-demographics information of individuals is needed. Population socio-demographics are crucial to spatial models because such demographics determine the behaviour pattern of each individual. Hence, the synthetic population model is used to create a population imitation of the study area (scenario population) with demographics closely matching those of the real population. It is the responsibility of the decision maker to define the group and parcel of individuals that will better represent the decision problem. In principle, models operate on a "100% sample" (i.e., the entire population) of individuals, even though high computational time is required. A possibility is to create a sample of individuals representing a specific group of the population. For instance, in the beginning of this chapter we have found that this case study may affect mostly individuals between 25-44 years old (see Figure 7-5), without children (see Figure 7-4) and non-family households. Therefore, the decision maker could create a population imitation of such a specific group to evaluate alternative scenarios or, compare both cases, i.e., analyse the impact of the scenario changes on the behaviour of the entire population and on the behaviour of specific target groups. In this case study, however, we create a 1% sample of individuals of the population representing the entire population.

An important facet of the greenspace problem is the notion that people act on the basis of the information they have about the environment, i.e. their cognitive space. In order to understand the cognitive space of individuals in the context of urban greenspaces, we apply the *awareness* model. The concept of awareness refers to the probability that individuals know a spatial choice alternative. We assume that the awareness level of greenspace is a function of (a) a set of relevant attributes of the greenspace, (b) a set of relevant characteristics of individuals, and (c) some measure of accessibility. The system positions the corresponding greenspace on a relative scale, where a higher value implies that people are more aware of this greenspace.

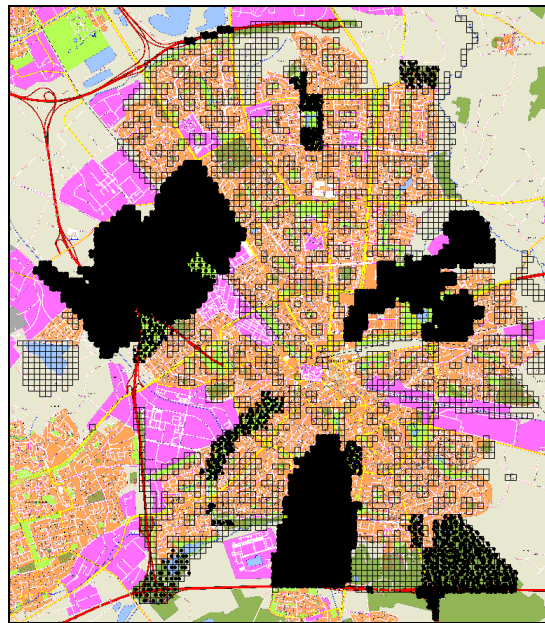


Figure 7-11. Awareness Model

Figure 7-11 shows the computational results of the awareness model. The *dot density* mode was used to display the patterns in the thematic map. A higher dot density pattern in the map reflects a higher scale value. As expected, the larger greenspaces (city parks) are the most known of the city, followed by the district parks. Empirical findings (model parameters) suggest that accessibility (distance) is the most important variable influencing the derived scale, followed by the type (size) and some attributes/facilities of greenspaces.

The next model applied is the *trip making propensity* model, which can be used to predict the number of trips to the various parks. Besides individual's socio-demographics, distance and greenspaces' specific attributes, this model tries to capture temporal variation (time of the day, day of the week and season of the year) on individual choice. As a final output, the aggregate number of individuals going to the various greenspaces, given the day of the week, time of the day and season of the year, is generated.

Figure 7-12 shows the computational results of the trip-making propensity model to greenspaces during weekends, in the morning, across different seasons. The *standard deviation* mode was used to colour the map; darker colours reflect higher trip propensity. Note that, individuals show different trip making propensity to greenspaces across seasons.

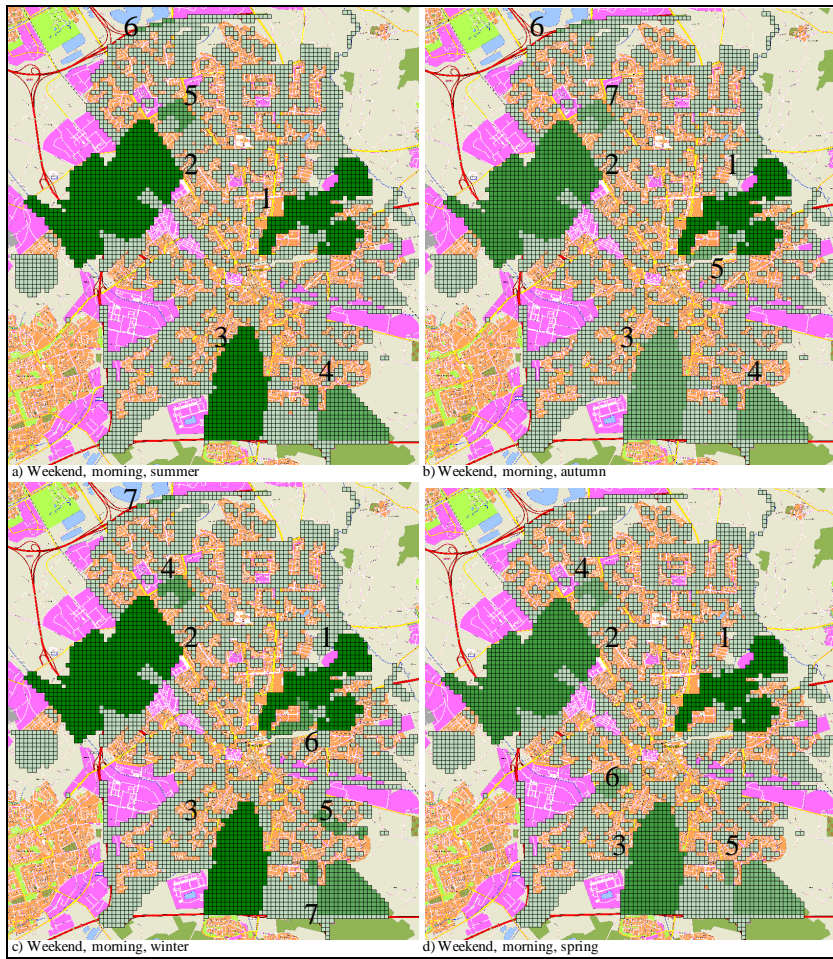


Figure 7-12. Zero state scenario, Trip Propensity Model

Table 7-1. Trip propensity to greenspaces across season during weekends, in the morning

Season	Most visited greenspaces (% of visits)					
	1	2	3	4	5	6
Summer	6.30	5.95	4.79	3.12	3.00	2.48
Autumn	6.76	5.66	2.94	2.83	2.36	2.19
Winter	5.78	5.66	4.79	2.77	2.71	2.54
Spring	7.16	4.97	4.39	3.35	2.36	2.13

Table 7-2. Percentage of visits during weekends in the morning, across seasons, aggregated by greenspace type (%).

	Local Parks	Neighbourhood Parks	District Parks	City parks
Summer	46.70	9.43	20.31	23.55
Autumn	48.81	9.60	19.38	22.21
Winter	47.60	10.12	19.90	22.38
Spring	46.48	11.16	20.78	21.60

Table 7-1 shows the percentage of trip for each of the most visited parks numbered in Figure 7-12. Table 7-2 relates the percentage of visits with greenspace type, during weekends in the morning, given different seasons.

Table 7-2 shows that, on average, individuals show a higher propensity to visit local parks (small greenspaces), followed by city parks, district parks, and finally, neighbourhood parks. Note however that, in Figure 7-12, city parks (large greenspaces highlighted) are shown as the most visited. This is because Table 7-2 and Figure 7-12 illustrate different perspectives of the model output. Figure 7-12 describes individual's trip propensity to each particular greenspace of the study area. Having only few greenspaces in the study area that fall into the city park category, a lower percentage of individuals showing trip propensity to city parks are distributed across few greenspaces, while a larger percentage of individuals showing trip propensity to local parks are distributed across thousand of local parks within the study area.

Observe in Table 7-2 that during weekends in the morning, individuals show a higher propensity to visit local parks during autumn and lower during summer and spring. As would be expected, during summer individuals show a higher propensity to visit the larger greenspaces (city parks) than in any other season. District and neighbourhood parks are mostly visited during spring. During winter the trips are more distributed across the various greenspaces of the city. Notice that such seasonal patterns vary across time of the day and day of the week.

One could argue that the effect of season is not very significant on the individual trip propensity to greenspaces. This may be true when the focus is on the greenspace type (classification). However, Figure 7-12 shows that the season does affect the choice on the particular greenspace (not only type, but also size and location).

An interesting observation can be made when looking at the estimated parameters (see Chapter 5, Figure 5-9). On the most aggregate level, i.e. not considering individual socio-demographic characteristics and geographic location, one could argue that during summer, autumn and winter during the weekends in the morning, individuals would express a higher trip propensity to neighbourhood parks over district parks. However, the socio-demographic characteristics of individuals and the geographical position of the different

greenspace types in the study area (distance/type effect) switch individual preferences to district parks over neighbourhood parks, as shown in Table 7-2. Another consideration is the choice set of individuals that, many times, does not include every type of greenspaces to be chosen from during their decision making process.

Derived from the trip making propensity model, aggregated to season level, the *pressure* model estimates the pressure on greenspace. Greenspaces pressure is defined as the number of individuals visiting (a hectare of) a particular greenspace, per day, given a particular season of the year. This is a useful performance indicator in the sense that authorities are able to measure the pressure on greenspace in any particular season, or to clarify issues regarding maintenance priorities and budget allocation. In addition, it is also possible that authorities develop plans or norms taking into consideration the ecological sensitivity of greenspaces or the maximum crowdedness that should ideally be adhered to, such that individuals will be able to conduct particular green activities.

Figure 7-13 shows the computational results of the pressure on greenspaces, across different seasons. Darker colour patterns in the map reflect higher pressure. Notice that, according to the adopted approach small greenspaces have a higher pressure: the number of visits/hectare is higher. Spring is the time of the year that city parks are mostly under pressure, followed by summer, winter and autumn. Local greenspaces are more difficult to generalize, because there are variations across each particular local greenspace. However, local greenspaces have higher pressure during summer and spring and lower pressure during autumn and winter. By enabling the information button and clicking on the computer mouse on any greenspace of the study area, users are able to get the pressure value across the seasons.

The analyses presented until now use models of spatial choice behaviour, where individuals are assumed to trade-off the characteristics of the choice alternatives against the distance to reach these destinations. These models are originally based on a *static* approach to single purpose behaviour where greenspaces are considered in connection with the place where people live.

The potential weakness of this approach is that it does not capture, simultaneously, the spatio-temporal context of the problem. In other words, although individuals may express utility maximization behaviour and preferences to certain type/location of greenspaces, the time pressure of individuals lifestyle do not give them enough time to reach such locations or to stay there as long as they ideally wish. That is, various spatial and temporal constraints act on spatial choice, implying that choice may be context-specific.

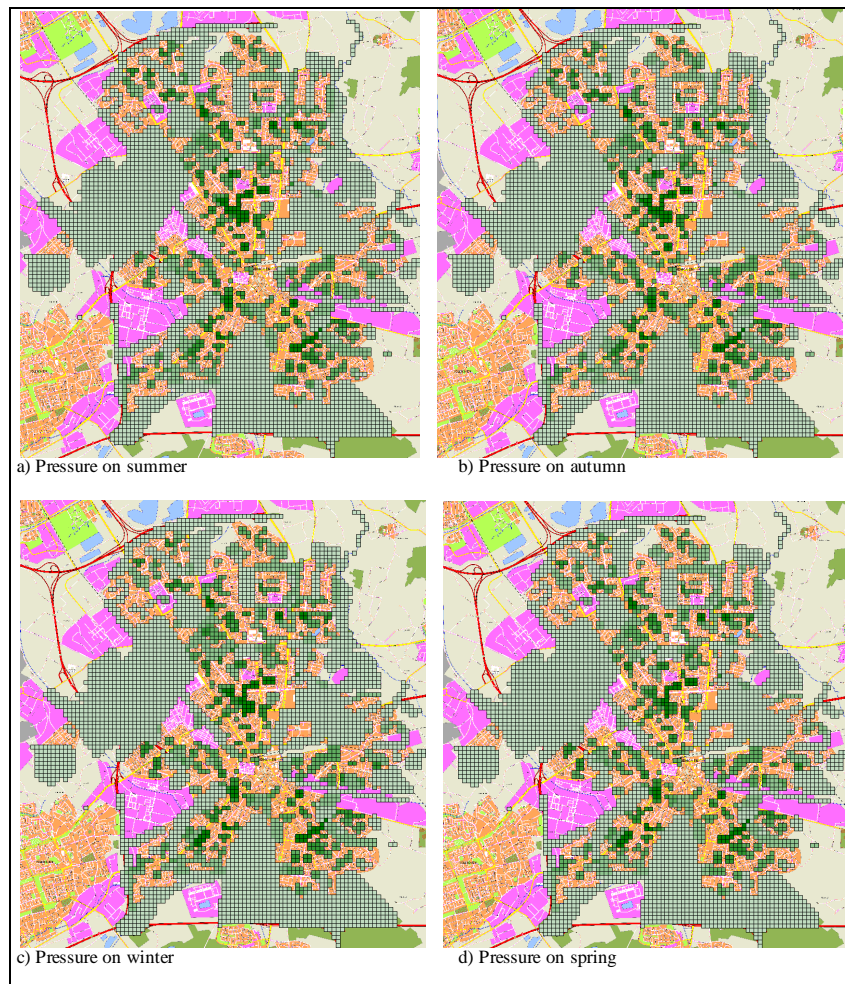


Figure 7-13. Pressure Model

To capture the effect of time pressure (or, ideally, the larger space-time context) on greenspaces usage, we applied the Aurora activity-based model. This model provides users with additional information on frequencies with which individuals participate in green activities, their duration, timing, combination with other activities, and so on. As output, the Aurora model generates individuals' schedules of activities, for a given day. Individuals' generated schedules are an essential ingredient to capture some important performance indicators for scenario-based evaluations, as described in Chapter 5.



To keep the scenario evaluation consistent, the Aurora model was executed for the same synthetic population used for the spatial choice models at the individual level. Thus, individuals represent 1% of the population of the study area.

Figure 7-14 shows the activities parameters settings used to run the simulation model. Frequency tables of some of the results of the simulation are shown in Tables 7-3 to 7-7.

Table 7-3 shows the number of individuals of the synthetic population with green activity scheduled for the simulated day. Note that 30,3% of individuals of the synthetic population have scheduled a green activity for the simulated day. From these 30,3%, 48,0% also have scheduled a work activity.

Table 7-4 shows that individuals spend between 21 and 120 minutes on green activities. Indeed, 37,6% of individuals with a scheduled green activity spend between 21 and 60 minutes on green activities. The majority, i.e. 47,7% of individuals with a scheduled green activity, spends between 61 and 90 minutes in the greenspace.

Table 7-5 shows the frequency of green activity duration as a function of start time. Observe that green activities are mostly conducted in the morning (before 12 a.m.) or late in the afternoon (after 4 p.m.).

Activity Type	U <sub>x</sub>		U			Work Activity	
	$\alpha_x$	$\beta_x$	U <sub>x</sub>	$\alpha$	$\beta$	$\gamma$	
Green recreation	7	1	20	10	0.07	1.5	
Other activities			60	600	0.0065	1	

Green Activity Settings		Transport-mode Parameters		Work Activity		
Minimum Starting Time	420 hrs	Marginal Utility of a minute travel time by car	-0.2	Full Time		
Starting Time1	540 hrs	Marginal Utility of a minute travel time by bike	-0.1	%	Start Time	
Starting Time2	1440 hrs	Set Values		40	540	
Maximum Starting Time	1440 hrs			35	510	
				15	480	
				10	450	
				Part Time		
				Freq	%	Start Time
				1	30	540
				2	20	720
				3	20	300
				4	30	540

Memo1

Figure 7-14. Parameters setting used in this case study

Table 7-3. Frequency of green activity and work activity scheduled

Schedule has green	Schedule has work		Total
	No	Yes	
No	347	859	1206
Yes	273	251	524
Total	620	1110	1730

Table 7-4. Activities duration

	Activity duration (minutes)							Total	
	0-15	16-20	21-60	61-90	91-120	121-240	241-480		481+
Work	10	0	21	23	10	81	831	134	1110
Green	0	0	197	250	77	0	0	0	524
Total	10	0	218	273	87	81	831	134	1634

Table 7-5. Activities start time

	Activity start time				Total
	< 12	12-2	2-4	>4	
Work	1110	0	0	0	1110
Green	306	32	77	109	524
Total	1416	32	77	109	1634

Table 7-6. Trip travel duration

	Trip travel time (minutes)						Total
	0 min	1-10	11-20	> 40	21-30	31-40	
green	93	420	11	0	0	0	524
work	1	528	518	38	6	19	1110
home	94	948	529	38	6	19	1634
Total	188	1896	1058	76	12	38	3268

Table 7-7. Trip transport mode

	Trip mode		Total
	Fast	Slow	
green	92	432	524
work	982	128	1110
home	1074	560	1634
Total	2148	1120	3268



Table 7-6 shows that 98,00% of the individuals with a scheduled green activity travel less than 10 minutes to reach greenspaces. Over 80% of the individuals travel between 1 and 10 minutes to reach greenspaces. Moreover, as shown in Table 7-7, approximately 82% of the greenspace trips are made by slow mode (bike or foot), against 18% by car.

The Aurora model may bring about slightly different outcomes from run to run, for the same case study (and parameters settings), as a consequence of the stochastic processes introduced in this microsimulation model. For instance, the working hours and start time of the individual's work activity (work schedule) may differ from run to run because they are drawn from a distribution given by the decision maker (user) via user interface (see Figure 7-14). Green activity history is also another stochastic element of the microsimulation model, as described in Chapter 5, section 5.5.2.

It is important to emphasize here that changes in parameter settings may bring about different results in the schedule of individuals (as will be noticed in section 7.4 of this chapter). Thus, the decision maker could try different parameter settings to understand changes in individual behaviour. Although not pursued in this illustration, the parameters could be based on an empirical estimation of the model. This could capture and reflect current conditions. By changing parameters, user can simulate possible future scenarios. For instance, change of season will reflect the time window that green activities can take place as a consequence of the sunset/sunrise, or even the utility value of green activities. Changes in the utility values could be a consequence of the competition with other recreational activities.

To conclude our zero-state scenario assessment/diagnosis we estimated the costs related to greenspace provision and maintenance. To this end, we use the *Cost Estimate Spreadsheet*, another tool provided within GRAS. The values used to estimate the costs are stated in Figure 7-15. Although some of the unit costs considered here are fictional, they will be kept constant in the assessment of alternative scenarios. Hence, comparisons can be made on the basis of marginal budget allocation.

Decision makers must be aware that maintenance costs are calculated on an annual basis, per hectare of greenspace. The frequency with which greenspace maintenance services are provided per year is inputted in the user interface (*number of maintenance/year* – see Figure 7-15) and used to calculate the final maintenance costs. In case that different maintenance services are provided in different frequencies per year, it is the responsibility of the user to make these numbers consistent. For instance, suppose that most of the maintenance activities are provided once per season (four times per year), except gardening, which is provided once per year.

Enter Average Maintenance Costs		Enter Average Provision Costs	
Number of Maintenances / year 1	Shrub/Trees (cost/hectare-maint) Herbicides 1000 EU Weed out 4000 EU Pruning/trimming 600 EU Cultivation 2700 EU Refill 45 EU	Land - Price/hec Region1 100000 EU Region2 2000000 EU Region3 3000000 EU Region4 4000000 EU	
Lake (cost/park-maint) 0 EU	Grass/Flowers (Euro/hec) %flower 50 Herbicides 0 1000 Weed out 8000 11000 Pruning/trimming 1021 4000 Cultivation 4500 6000 Fertilization 0 4000 Set up ground 1500 3000 Refill 1500 3000	Lake (cost/park) 300000 EU Sport Facility (cost/park) 30000 EU Paths (cost/hectare) 20000 EU Table/Benches (cost/hectare) 80000 EU Playground (cost/park) 100000 EU Toilet (cost/park) 30000 EU Lighting (cost/hectare) 60000 EU TrashBins (cost/hectare) 10000 EU	
Sport Facility (cost/park-maint) 300 EU			
Paths (cost/hectare-maint) 1000 EU			
Cleaning (cost/hectare-maint) 1000 EU			
Tables (cost/hectare-maint) 0 EU			
Playground (cost/park-maint) 1000 EU			
Toilet (cost/park-maint) 700 EU			
Lighting (cost/hectare-maint) 400 EU			
TrashBins (cost/hectare-maint) 200 EU			
Update Costs			

Figure 7-15. Cost estimation spreadsheet

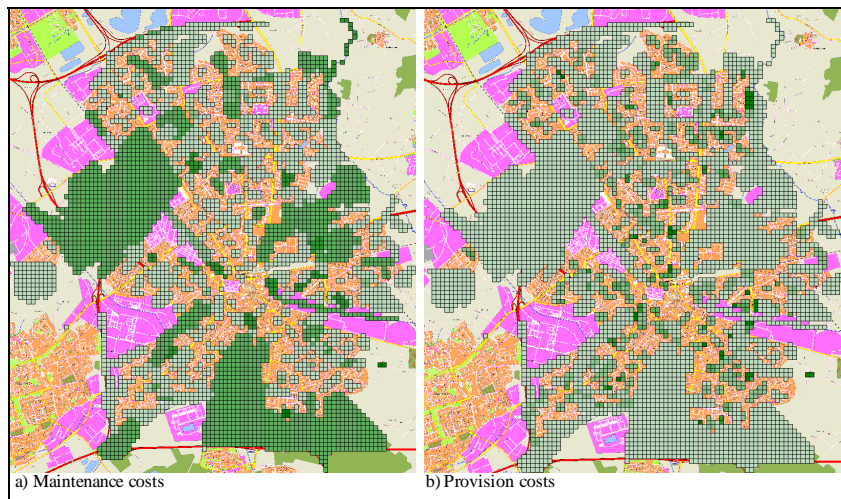


Figure 7-16. Costs estimate

Then, the user can choose setting the number of maintenances per/year equal to 4 and input gardening costs divided by 4; or set the number of maintenance/year equal to 1 and input other costs multiplied by 4. In the case of self-maintained greenspaces, this information is part of the characteristic of the greenspace in the database and therefore the system will not address maintenance costs. Costs are then computed as the costs per hectare of particular greenspace. In this application, we use the default values to calculate greenspaces maintenance and provision costs, as shown in the user interface of Figure 7-15.

The results are displayed in Figure 7-16. A dark colour pattern reflects higher costs. Although small (local) greenspaces demonstrates relatively high provision costs, they show low maintenance cost. As expected, city parks show high maintenance costs.

Having finished the assessment of the zero-state scenario, in the next section we describe the procedure to create alternative scenarios. The goal of these scenarios is to improve the provision of greenspace in the city centre area. The alternative scenarios are then assessed and evaluated.

## 7.2 The “New-Park” scenario

The development of a new scenario is an interactive process between the system and the user. Generally speaking, scenario development involves a sequence of steps that starts with the exploration of possible target cells (green or non-green cells) and evolves to the choice of a theme and then, changes in the scenario.

The user, being familiar with the study area, has already some clues about possible/reasonable changes in urban design that may bring about the desired effect to the built environment. The GIS-based user interface will support the user to explore particularities of the urban design, providing information at the cell level. Hence, having the zero-state scenario operational in the main user interface, by enabling the *information* button, a click on a cell will pop-up the dialog box with the cell’s information, as shown in Figure 7-17.

After looking at the information of possible target cells to build a new greenspace in the city centre, we have decided to transform a parking place, very close the commercial pedestrian area in the city centre, into a new “local” greenspace. The parking place target cell is highlighted in Figure 7-18, which illustrates the scenario-development user interface. The scenario development process is carried out through interactive procedures based on a set of hierarchical buttons/popup dialog boxes. Figures 7-18 and 7-19 illustrate this process.

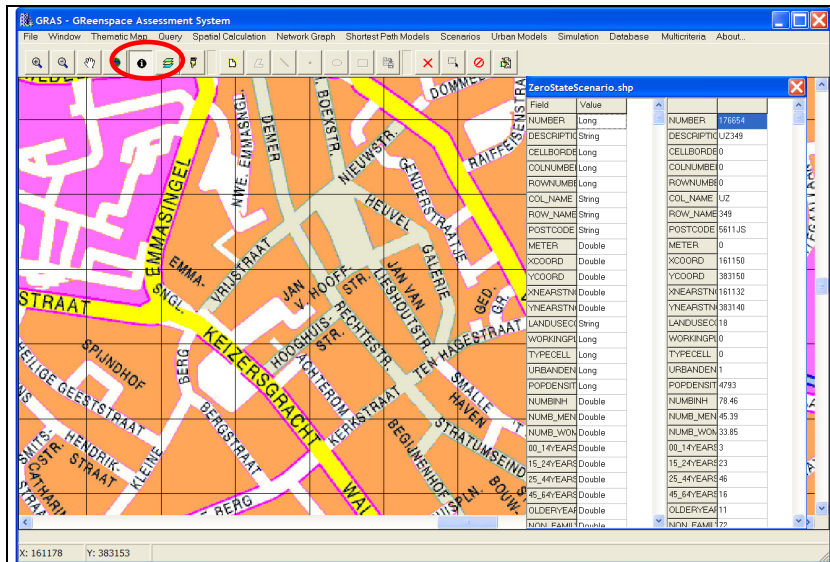


Figure 7-17. Exploring targets cells: Information button

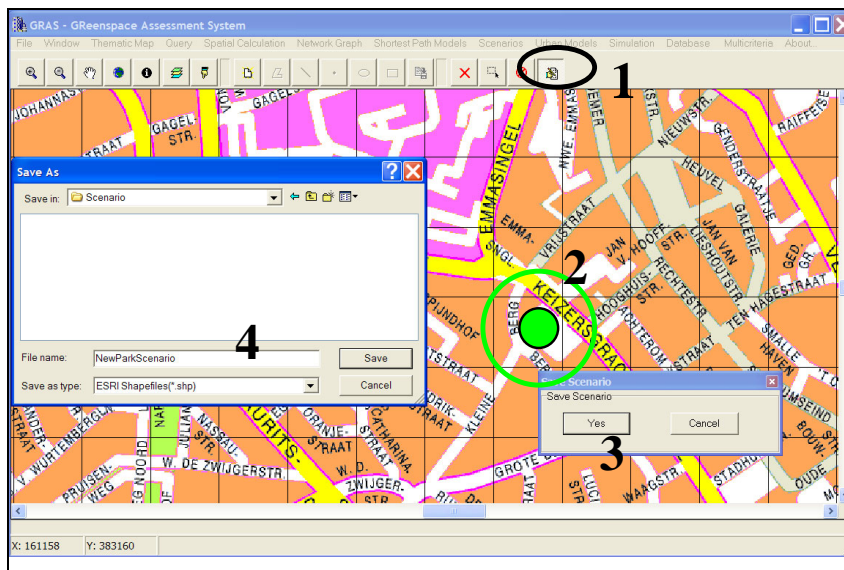


Figure 7-18. New scenario development

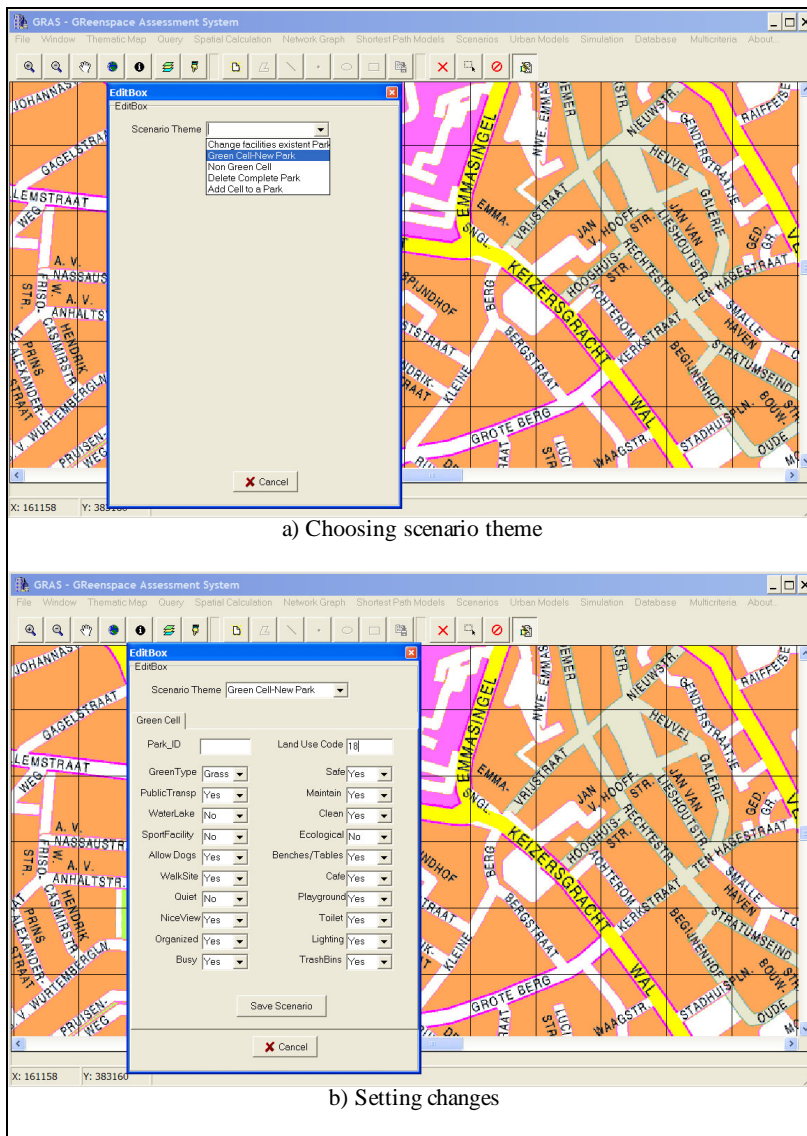


Figure 7-19. Edit box and scenario theme.

Having decided on the target cell, the user may enable the *edit* button (step1, Figure 7-18) and single click with the mouse on the target cell (step2, Figure 7-18). By doing that, the “*Save Scenario*” dialog box is immediately displayed (step3, Figure 7-18), and the user may choose between making

changes in the current scenario (button “*cancel*” of the “*Save Scenario*” box) or create a new scenario (button “*yes*” of the “*Save Scenario*” box). If the user chooses to create a new scenario (*yes* button), the reference scenario is used as the basis for the new scenario and scenario changes are made on the basis of a new scenario layer placed on top of the scenario reference. On the other hand, if the “*cancel*” button is chosen, changes are made in the current (reference) scenario. Thus, the difference is that, if a new scenario is created, user’s changes will affect the database of the new scenario (new layer), and the scenario reference file will be kept intact. However, if changes are made in the current (reference) scenario, its database will be committed to the user’s changes, which cannot be automatically reversed by the system later, in case of user’s regrets or mistakes.

Despite the user’s choice on whether creating a new scenario or making changes in the reference (current) scenario, the *edit* dialog box automatically pops-up, as shown in Figure 7-19 (a). The user may then choose the scenario development theme, which retrieves specific fields of the database object of changes, and makes other database related fields consistent with the given information. In this study case, a “non-greenspace” cell is changed into a “*greenspace cell- new park*”, which is the scenario theme. Then, the user enters the new greenspace attributes, as required by the user interface, shown in Figure 7-19 (b).

Having developed the new scenario for our case study, the next step consists of applying the models to assess the benefits of the scenario change. To that end, the same models (including same settings and parameters) applied before to assess the zero-state scenario, were applied to assess the new scenario.

#### *Cell level new-park scenario evaluation*

We start the new-park scenario evaluation with the accessibility analysis, using appropriate measures. In the zero-state scenario accessibility evaluation, we found that seven out of the nine equations are suitable for analysing accessibility in this case study. These are: number of opportunities, minimum distance, cumulative-opportunity, gravity potential, entropy maximizing, gravity consumer surplus, and log sum consumer surplus measures. The computational results displayed in thematic maps of the entire city in the new-park scenario, look very similar to those produced for the zero state scenario. The reason is that, the new neighbourhood park introduced in the scenario plays only a minor role at the city level, at which the accessibility indices are calculated. This is confirmed by the average accessibility results, shown in Table 7-8.

Table 7-8 compares scenarios in terms of the average values of the accessibility measures, in the context of the entire city of Eindhoven. Note that the introduction of a new neighbourhood park in the city centre does not result in a significant improvement of accessibility to greenspace at the city level. For instance, the number of opportunity and the log sum consumer surplus measures indicate an improvement of approximately 0,17% in the average accessibility at the city level. The minimum distance measure indicates an average improvement of 0,02%, whereas the cumulative opportunity, the gravity potential and the entropy maximizing measures indicate an improvement of about 0,06%. However, by definition, neighbourhood parks are supposed to support the neighbourhood and at the local level accessibility improve.

As our intention is to develop such a greenspace to support the CBD, we look at accessibility issues in the CBD surrounding area, as shown in Figure 7-20. Figures 7-21 and 7-22 show the computational results of the accessibility measures at the CBD neighbourhood level, for both the scenarios being studied here. The LHS of these figures show the results of the zero-state scenario, whereas the RHS shows the results of the new-park scenario. The absolute values of the various accessibility measures are compared in Table 7-9.

Moving the focus to the CBD neighbourhood area, accessibility seems to improve with the introduction of the new neighbourhood park, especially when looking at the results of the number of opportunity measure (Figure 7-21(a) and (b)), cumulative opportunity measure (Figure 7-21(e) and (f)), and of the log sum consumer surplus measure (Figure 7-22(e) and (f)). These measures indicate an increase of about 10%, 13% and 20%, respectively in accessibility of the CBD neighbourhood, with the introduction of the new park.

Table 7-8. Comparison average accessibility measures scores (entire city)

Accessibility measure	Zero State Scenario	New Park Scenario	Improvement (%)
Number Opportunities	5,603	5,613	0,178
Minimum Distance	275,307	275,249	0,021
Cumulative Opportunity	21,700	21,712	0,055
Gravity Potential	61,997	62,033	0,058
Entropy Maximizing	62,007	62,042	0,056
Gravity Cons. Surplus	22986,483	22988,445	0,008
Log Sum Cons. Surplus	-28779,903	-28827,175	0,164



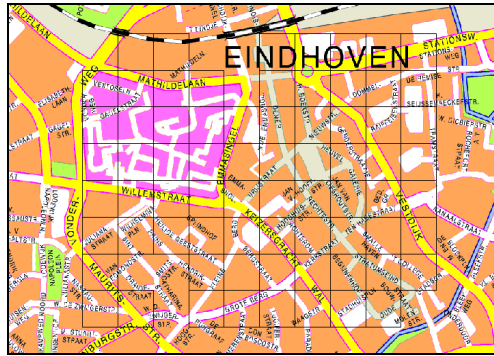


Figure 7-20. The city centre area

The gravity based measures (Figures 7-21(g) and (h), 7-22(c) and (d)) and the entropy maximizing measure (Figure 7-22(a) and (b)) indicate a less significant increase in accessibility (around 4%) with the introduction of the new neighbourhood park.

As noticed in Figure 7-21(a) and (b), no significant improvement in accessibility is observed for the minimum distance measure. This is confirmed in Table 7-9, where the absolute values of the minimum distance measure indicate an increase in the CBD accessibility of 0,36% only.

Comparing the results of Tables 7-8 and 7-9, we observe (with the exception of the number of opportunity measure) that the average accessibility measures of the CBD area are below the average accessibility measures at the city level. This confirms our preliminary concern: the lack of greenspace in the CBD neighbourhood. Moreover, although some improvement in accessibility can be achieved with the introduction of a new local greenspace in this neighbourhood, such an improvement is not sufficient to bridge the gap between city level average accessibility and CBD average accessibility. In other words, the accessibility of the CBD area remains below the average accessibility at the city level, even with the introduction of a new local greenspace in the city centre.

Figure 7-23 shows the computational results of the greenspace utility and preference in the new-park scenario, estimated with the *preference* model. A darker colour reflects higher utility and preference values. Note in Figure 7-23(a) that the new greenspace in the city centre will not have a high utility to individuals. Figure 7-23(b) shows that the average greenspace preference is not influenced by the introduction of the new local greenspace in the city centre. As before, individuals favour larger greenspaces with more possibilities for recreation.



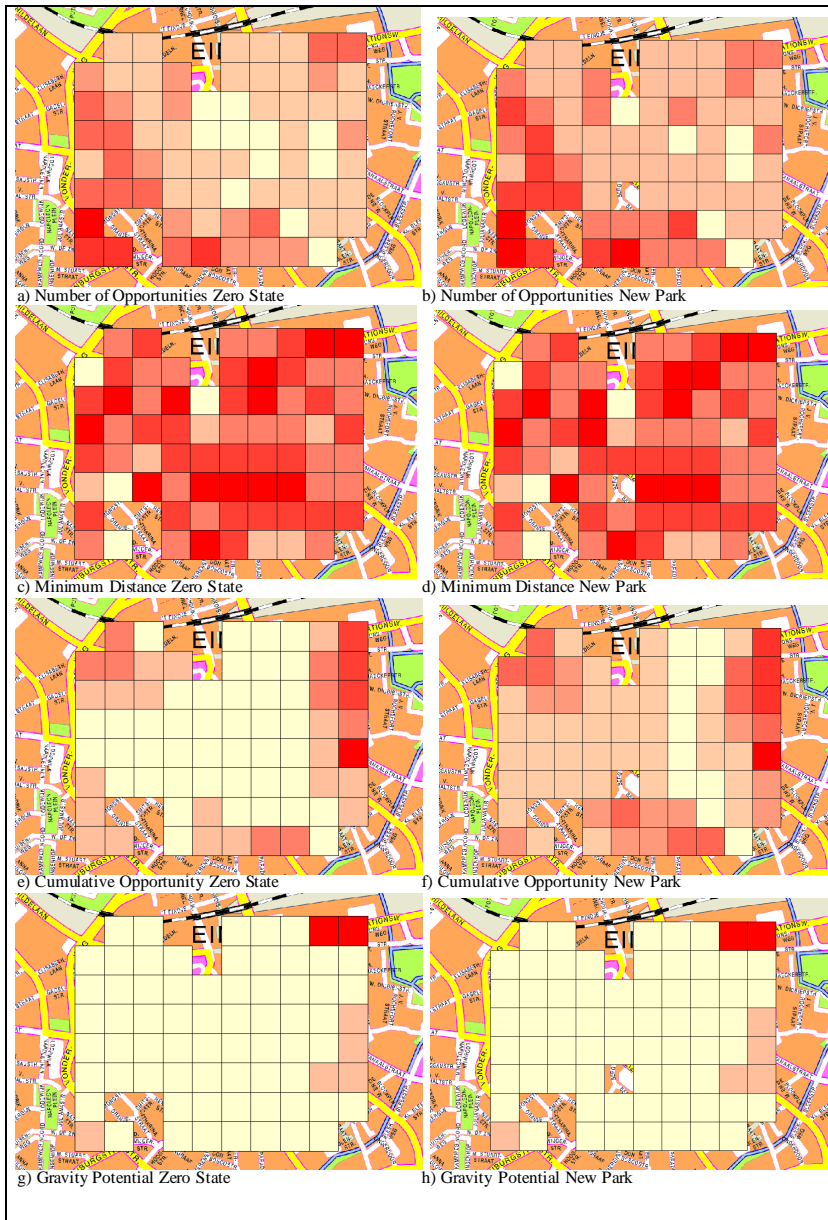


Figure 7-21. Comparison of accessibility at the neighbourhood level before and after the introduction of a new neighbourhood park



Figure 7-22. (Continuation) Comparison of accessibility at the neighbourhood level before and after the introduction of a new neighbourhood park

Table 7-9. Comparison of average accessibility measures (CBD)

Accessibility measure	Zero State Scenario	New Park Scenario	Improvement (%)
Number Opportunity	3,2222	3,5915	10,2
Minimum Distance	320,2608	317,3377	0,3
Cumulative Opportunity	0,8013	0,9216	13,0
Gravity Potential	9,7062	10,3890	6,6
Entropy Maximizing	11,3372	11,8318	4,1
Gravity Cons. Surplus	27089,3834	28054,9050	3,5
Log Sum Cons. Surplus	-9154,4859	-11442,4851	20,0

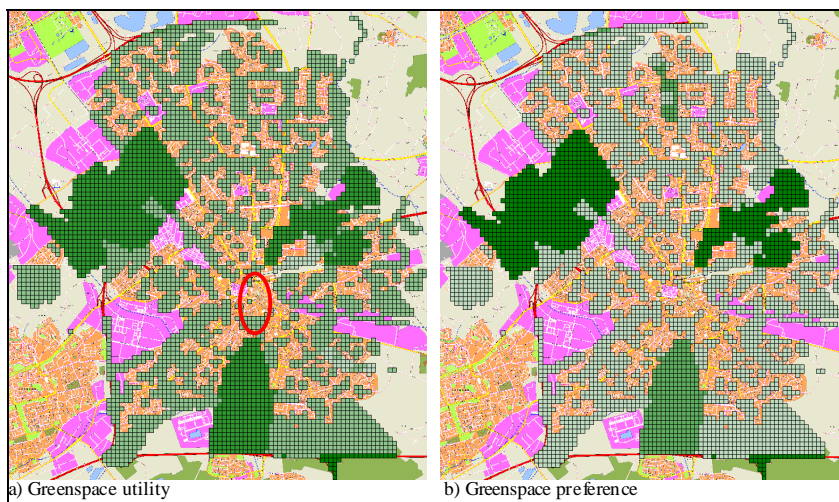


Figure 7-23. Preference model (new park scenario).

Figure 7-24 shows the simulated *trip making propensity* to greenspaces for the new scenario, during weekends, in the morning, across seasons. As before, a darker colour reflects a higher trip making propensity to greenspaces. Note that the development of the new local greenspace in the CBD will have some effect on the individuals' trip making propensity to greenspaces. This model predicts that during weekends in the morning, the new park would take 0,06% of the greenspace visits during summer and autumn and 0,17% during winter and spring. Figure 7-24(a) is very similar to Figure 7-12(a). When looking at the distributions of individuals' trip propensity as a function of greenspace type, we observe a slight increase in trips to local greenspaces and a decrease to city greenspaces. Hence, individuals located in the CBD area show a higher trip making propensity to local parks than to city parks, when a new local greenspace is developed in this area. On the other hand, during autumn, weekends-mornings, the model predicts an increase in the number of trips to local greenspaces and a decrease to neighbourhood greenspaces. Comparing Figures 7-12(b) and 7-24(b), a slightly different picture is presented for the new park. We observe that the new local park developed in the city centre would attract visitors from the neighbourhood greenspace identified by number 5 in Figure 7-12(b). Note that in the north part of the map in Figure 7-24(b), a district park that is not highlighted for the zero state scenario (compare with Figure 7-12(b)) now appears. It does not mean, however, that the development of the new local park in the CBD is affecting behaviour of individuals located that far away.

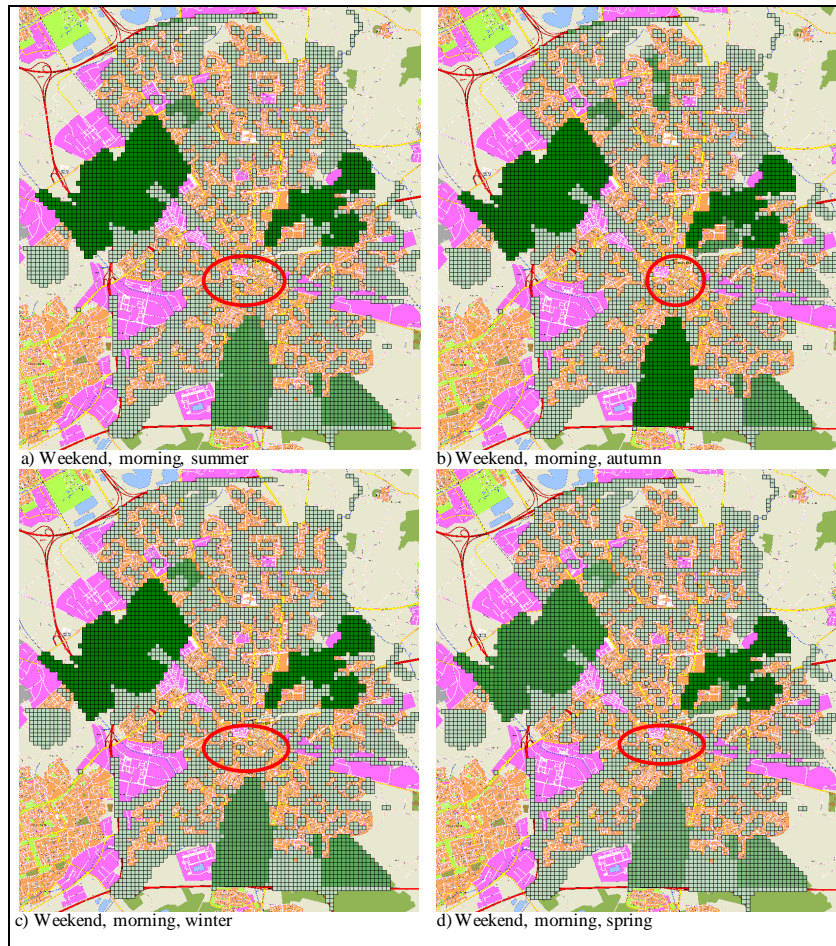


Figure 7-24. Trip propensity to greenspaces in the new park scenario.

Rather, this is just a side effect of the statistical calculations to define the boundary classes for definition of the colour patterns in the thematic map representation. Similar patterns occur during winter, weekends-mornings, however changes in individual behaviour reflect trips to the neighbourhood park located in the southeast part of the study area (identified as number 5 in Figure 7-12(c)). During spring, weekends-mornings, the development of the new park in the CBD area will decrease trips to the neighbourhood park identified as number 6 in Figure 7-12(d). Moreover, the average number of trips to local greenspaces increases to 48,95%, against 46,70% for the zero state scenario (see Table 7-2).



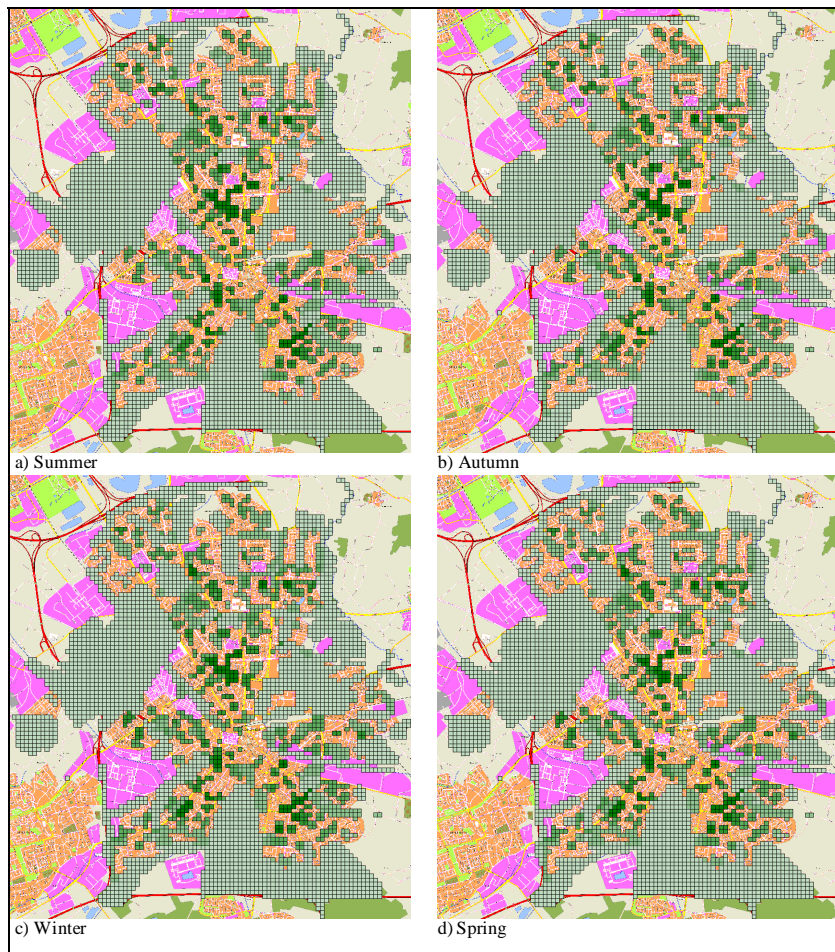


Figure 7-25. Pressure model, new park scenario

Figure 7-25 shows the computational results of the pressure model. In this figure, the darker the colour, the higher the pressure. Observe that the new local greenspace in the city centre is likely to be under relatively high pressure. Observe also that this pattern does not change very much over the year, across seasons. Indeed, the model predicts for this particular park average of 3821,74 visits per day during spring, 3329,35 during winter, 3316,30 during autumn, and 3792,39 during summer.

Figure 7-26 shows the results of the awareness model. The *dot density* mode was used to display the colours in the thematic map. The greater the number of dots, the higher the awareness level. This model indicates that the

new neighbourhood park would be ranked on the 47<sup>th</sup> position in terms of awareness. Considering that there are about 1340 greenspaces in the study area, this is a good awareness level for a local greenspace type.

Ideally, the new park scenario should be also evaluated using the Aurora model, in order to capture simultaneously the spatial-temporal context of the problem, as illustrated for the zero-state scenario evaluation. However, the actual implementation of the Aurora model in GRAS is not valid yet to predict and measure changes in individual behaviour as consequence of changes in the built environment (i.e., spatial scenarios), which is the focus of this case study. Future implementation and adjustments in the model are required to validate the Aurora model for spatial-temporal scenarios evaluation, as will be discussed in Chapter 8 of this book. Because of that, spatial-temporal scenario evaluation for scenarios comparison is left for future work. Nevertheless, the actual implementation of the Aurora model is ready to predict and measure the impact of time pressure changes (temporal scenarios) on individual behaviour, as it is illustrated in section 7.5 of this chapter.

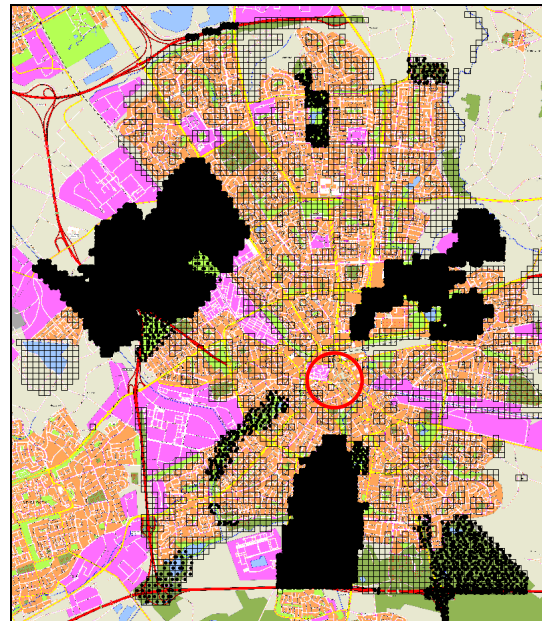


Figure 7-26. Awareness model (new park scenario)

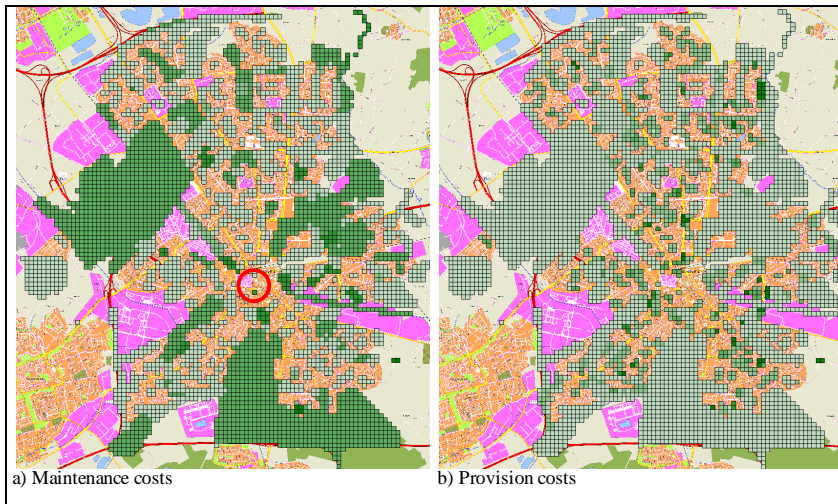


Figure 7-27. New park scenario costs

To conclude the *new park scenario* assessment, the costs related to greenspace provision and maintenance are estimated, as shown in Figure 7-27. Note that the new neighbourhood park has relatively high provision and maintenance costs. The type of vegetation (grass and flowers) chosen in the design of the new local greenspace is responsible, among others, for the high maintenance costs. Besides the type of vegetation, the land value in the CBD area is the highest in the city, reason why provision costs are also an issue in the development of such a new local greenspace.

Having found that the design of the new greenspace involves high maintenance and provision costs, a redesign of this park may be considered. To that end, the user may employ the scenario development tool to create a new scenario and evaluate the changes in the design of the new park. At this time, we use the new-park scenario as a “reference” scenario to create the new *design* scenario, following the procedure explained before. The scenario theme used in this case is “*Change facilities - Existing Park*”, as shown in Figure 7-19 (a). By choosing this theme, the *edit* box opens the same window shown in Figure 7-19 (b), with the same settings. In other words, the edit box automatically retrieves the existing design information of the greenspace, stored in the database and allows the user to make further changes. The following changes were then made: (i) instead of *grass and flowers* in the “*Green Type*” field, we set to *trees and shrubs*; (ii) the walkpath is eliminated, based on the assumption that people do not visit local parks for active walking; (iii) the cleaning service is eliminated (note that maintenance and trash discharge are services apart); (iv) lighting and

toilet are eliminated. Considering such a new design, provision costs decrease by 3%, whereas maintenance costs decrease by 89%. In general, we can say that provision and maintenance costs are a consequence of the planning and design of greenspaces. The user can develop as many alternative scenarios as needed/desired.

To evaluate the impact of the design changes, the same urban models were once again employed to assess the *design scenario*. Some of the models in GRAS, such as the accessibility measures, the trip making propensity model and the pressure model, do not capture changes in individual behaviour caused by changes in park design. Results of the preference model indicate that the above redesign of the new local park would decrease the average utility of this park from 0.98 in the new park scenario to 0.96 in the new design scenario.

Regarding the awareness model, the redesign of the CBD local park would change the position of this park at the city level from the 47<sup>th</sup> position to the 70<sup>th</sup> position. As before, considering a total of 1341 greenspaces in the city, the 70<sup>th</sup> position still rather good. To avoid a redundant and exhaustive description of the scenarios evaluation, the results of the “new design scenario” assessment are not illustrated in maps.

In the next section, we compare the three scenarios developed here using the multicriteria evaluation tool. The scenarios are compared in light of different criteria and ordered from the most desirable to the least desirable.

### 7.3 The scenarios evaluation

The role of the *Multicriteria Evaluation Tool* is to evaluate the alternative scenarios in terms of a set of criteria, derived from the spatial and non-spatial models implemented within GRAS. The criteria definition and equations involved were explained in detail in Chapter 5.

Comparisons among the *zero-state* scenario, the *new-park* scenario and the *design* scenario involve 16 out of 21 evaluation criteria available in the system. The five criteria left out in this evaluation consist of those derived from the accessibility measures that were found not suitable to this particular case study, i.e. the criteria derived from the probability gravity based and probability logit model accessibility measures, and those derived from the Aurora model (average quality of life, average duration of green activities, and average travel time to greenspaces). As explained before, the Aurora model in its actual implementation is not ready to predict and measure the impact of spatial modification of scenarios on individual behaviour patterns.

Table 7-14 lists the criteria selected to evaluate the alternative scenarios. The criteria’s raw scores found with the multicriteria evaluation tool for each



scenario are also presented in this table. Some of the criteria are positive measures, i.e. a higher score reflects better performance while others are negative. Positive measures are hectare of greenspace per inhabitant, accessibility measures such as number of opportunities, cumulative opportunity, gravity-potential, entropy maximising and gravity-based consumer surplus; average greenspace awareness; and average greenspace utility. Negative measures are minimum distance and log sum consumer surplus accessibility measures, average greenspace pressure, and costs. All the measures were rescaled if necessary to indicate that a higher score implies a better evaluation.

Observe in Table 7-12 that accessibility measures remain the same with the changes made in the design of the new park scenario (design scenario). This is because the accessibility measures implemented within GRAS do not take into consideration the characteristics (or type of facilities) of greenspaces to calculate accessibility. The only non-locational attribute considered by the accessibility measures is the size of greenspaces, which remains the same in the design scenario. The same is true for the greenspace pressure performance indicators, which acknowledge trip making propensity to greenspaces as a function of greenspace type (or size), distance, and other socio-economic factors to calculate greenspaces pressure. Hence, greenspace facilities are not relevant to estimate individuals' trip propensity to greenspaces in this model. Note that average greenspace pressure increases from the *zero state* scenario to the *new park/design* scenario, because the new local greenspace presents a relatively high pressure during every season, increasing the average pressure.

The awareness measure captures some attributes of greenspaces to describe the level of awareness (see Appendix F). In the *new park* scenario, the development of the new local greenspace would have a relatively high awareness level (47<sup>th</sup> position in the rank of 1341 greenspaces of the city). Because the awareness level is a relative measure, increasing the awareness level of a particular greenspace will automatically decrease the awareness of other greenspaces in the city. The decrease in the average greenspace awareness observed for the *new park* scenario is related to the fact that the new local park in the city centre would show an awareness level that is not substantial enough to overcome the decrease in the level of awareness of other greenspaces in the city, caused by the introduction of this new local greenspace. The same analogy can be made for the *design* scenario. Observe that the decrease in the average awareness level for the design scenario is smaller than for the new park scenario. This is because the relative poor attractiveness of the new local CBD park in the design scenario would stimulate individuals to look for alternative, more attractive, greenspaces in

the city, and contribute to a higher average greenspace awareness at the city level.

As expected, the development of a new local greenspace will contribute to a higher average utility of greenspaces. The new park scenario presents a higher average utility because the new local greenspace is designed to be more attractive to individuals than in the design scenario. The more attractive the greenspace, the higher the greenspace utility.

The maintenance costs of the *new park* scenario would increase by 0,0007% while in the new design scenario will increase by 0,00008%. Although this percentage does not seem substantial in the overall greenspace costs, the maintenance costs of the new neighbourhood park in the new design scenario will decrease in 89% when compared to the *new park* scenario. Provision costs would increase by 0,015% in the new park scenario and by 0,014%.

Table 7-10. Criteria's raw score

Criteria	Zero State Scenario	New Park Scenario	New Design
1 Hectare			
Green/Inhabitants	0,664	0,777	0,777
2 Minimum Distance	275,307	275,249	275,249
3 Acc. Number of Opportunities	5,603	5,613	5,613
4 Cumulative Opportunity	21,700	21,712	21,712
5 Acc. Gravity-Potential	61,997	62,033	62,033
6 Acc. Entropy Maximising	62,007	62,042	62,042
7 Acc. Gravity-based Consumer Surplus	22968,483	22988,445	22988,445
8 Acc. Log Sum Consumer Surplus	-28779,903	-28827,175	-28827,175
9 Avg. Pressure in Summer	1875,355	1908,443	1908,443
10 Avg. Pressure in Autumn	1660,074	1685,969	1685,969
11 Avg. Pressure in Winter	1824,145	1845,460	1845,460
12 Avg. Pressure in Spring	2036,020	2067,036	2067,0369
13 Avg. Awareness level	40257,009	40129,569	40147,580
14 Avg. Greenspace Utility	3554,031	3554,451	3554,431
15 Total Maintenance Cost (annual basis - in euros)	2.997.494.746,93	3.523.531.781,5	3.523.506.766
16 Total Provision Cost (in thousand euros)	25.768.131.339,3	29.643.817.435	29.643.724.635

To give a final score to the alternative scenarios, the multicriteria evaluation tool uses a compensatory approach, i.e. high performance of an alternative on one or more criteria can compensate for a weak performance of the same alternative on other criteria. In other words, the high score of an alternative is traded off against low scores on other criteria. The multicriteria analysis requires the decision maker to specify criterion priorities expressed as cardinal weights.

The additive technique is used to aggregate criterion scores to an overall evaluation score, but first the criterion scores must be standardized to enable inter-criteria trade-offs and to allow the comparison of alternative scenarios performance on a common scale.

The total (final) score of each alternative is calculated according to the weighted summation technique: the total evaluation score is calculated as the weighted sum of the standardized criteria scores. Because all scores are automatically normalized, the alternative with the highest score is recommended as the best scenario.

Keeping this in mind, we arbitrarily assign criteria weights such that their sum equals 1. The accessibility and hectare of greenspace per individual criteria receive equal weights of 0,025 each, summing to a total of 0,2 (8\*0,025). Criteria derived from the pressure model sum to 0,4 in weight, thus average greenspace pressure in winter, spring, summer, and autumn receive weights of 0,1 each.

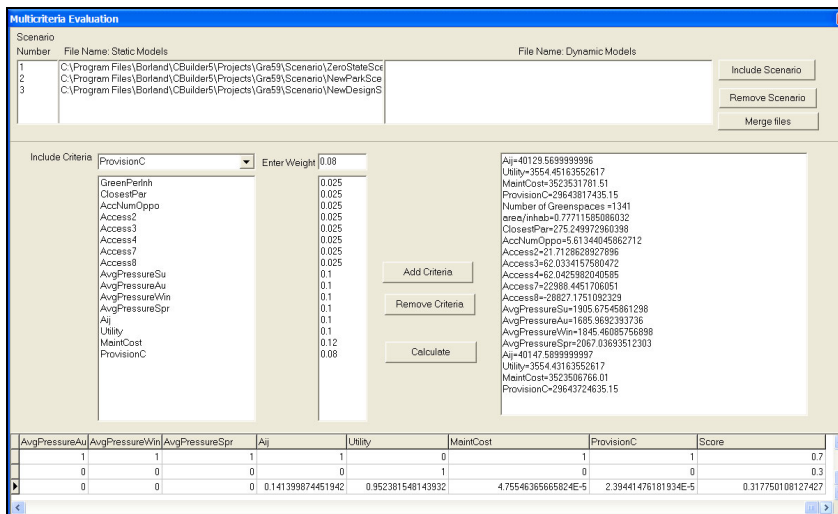


Figure 7-28. Muticriteria Evaluation Tool

Table 7-11. Scenario evaluation, final score

Criteria	Weight	Zero State Scenario	New Park scenario	New Design Scenario
1 Hectare Green/Inhabitants	<b>0,025</b>	0	1	1
2 Minimum Distance	<b>0,025</b>	0	1	1
3 Acc. Number of Opportunities	<b>0,025</b>	0	1	1
4 Cumulative Linear Negative	<b>0,025</b>	0	1	1
5 Acc. Gravity-Potential	<b>0,025</b>	0	1	1
6 Acc. Entropy Maximising	<b>0,025</b>	0	1	1
7 Acc. Gravity-based Consumer Surplus	<b>0,025</b>	0	1	1
8 Acc. Log Sum Consumer Surplus	<b>0,025</b>	0	1	1
9 Avg. Greenspace Pressure in Summer	<b>0,100</b>	1	0	0
10 Avg. Greenspace Pressure in Autumn	<b>0,100</b>	1	0	0
11 Avg. Greenspace Pressure in Winter	<b>0,100</b>	1	0	0
12 Avg. Greenspace Pressure in Spring	<b>0,100</b>	1	0	0
13 Avg. greenspace Awareness level	<b>0,100</b>	1	0	0,141
14 Avg. Greenspace Utility	<b>0,100</b>	0	1	0,952
15 Avg. Maintenance Cost (annual basis)	<b>0,120</b>	1	0	$4,75 \times 10^{-5}$
16 Avg. Provision Cost	<b>0,080</b>	1	0	$2,39 \times 10^{-5}$
<b>Scenarios Score</b>	<b>1,00</b>	<b>0,700</b>	<b>0,300</b>	<b>0,317</b>

The average utility and average awareness criteria receive also a weight of 0,1 each. Finally, costs sum to another 0,2 in weight, implying that 0,12 is assigned to maintenance and 0,08 to provision costs.

Figure 7-32 shows the result of the multicriteria evaluation. Note that the raw criterium scores are displayed in the *Memo* window, in the left hand side of this figure. Table 7-12 shows the overall scenarios scores. According to the criteria considered and weights assigned, the most desirable situation is the actual (actual scenario), and the least desirable is the new park scenario. Note that different weights assigned to the criteria will result in a different order of scenarios.

## 7.4 The temporal scenario<sup>2</sup>

To illustrate the type of results one can obtain from the actual implementation of the Aurora model in GRAS, we compare the outcomes of two runs of the model on several performance indicators. The runs considered are based on the activity parameter settings, shown in Figure 7-14 (except for those related to green activity start-time, which were set to *minimum start time*= 540, *start time*<sub>1</sub>= 620, *start time*<sub>2</sub>= 1440 and *maximum start time* = 1440), and a scenario where the alpha parameter of the Home (read Other) activity category has a higher value, i.e. from 600 (baseline situation) to 700. The latter setting simulates a scenario where the average individual experiences a higher time pressure, i.e. where there is less flexibility to substitute other activities by the green space activity. The performance indicators considered include: average frequency of green activities, average duration of green activities, and the total utility derived from executing the activities (i.e., quality of life).

For the baseline situation, the model predicts that, approximately, 25% of individuals of the synthetic population have scheduled a green activity for the day simulated. From these 25%, 47% also have scheduled a work activity. The average duration of green activities for an agent without a work activity is 82 minutes with a standard deviation of 11.4 minutes. For the agents with a work activity, the average duration of the green activity is 55 minutes and the standard deviation is 10.3 minutes. Although the standard deviations are approximately the same, agents with a work activity spend on average almost 30 minutes less on green activities than agent without a work activity.

Under the increased time-pressure scenario, the model predicts that 22% of the individuals in the synthetic population would include a green activity in their schedule, i.e. 3% less than in the baseline situation. In this case, 58% of the agents with a green activity in their schedule do not have a work activity scheduled for that day. In the new situation only 6.9% of the individuals having a workday scheduled a green activity, against 12.2% in the situation before. Hence, we observe a drop in the number of working individuals conducting green activities. As expected, individuals with a work activity are more affected by the higher pressure situation than individuals without a work activity. We also observe a drop in the average duration of green activities. Individuals with work and green activities in the schedule spend, on average, 49 minutes (with a standard deviation of 10.3 minutes) on green activities, compared to 55 minutes in the situation before. Individuals without a work activity show a drop in the green activity duration as well. In

<sup>2</sup> This example is also illustrated in Arentze *et al.*, 2005

the scenario, these individuals would spend, on average, 74 minutes on green activities, i.e., about 8 minutes less than before.

As a final performance indicator, the average utility individuals derive from their schedule is 53.12 for the baseline situation against 49.33 in the increased time pressure situation. It is noted that the decrease in average schedule utility is not only caused by the decrease in frequency and duration of green activities. Increasing the alpha parameter means that for a given duration of the home activity the utility level will be lower especially in schedules including a work activity. In other words, the scenario assumes that the extra activities causing the increase in time pressure do not generate a utility themselves.

## **7.5 Conclusion and discussion**

The aim of this chapter was to demonstrate how GRAS can be used to support the decision making process related to the planning, design and maintenance of greenspaces. To that effect, a case study in the city of Eindhoven was conducted and discussed. Models and tools within GRAS were used to identify and diagnose potential weaknesses and/or problems of the greenspace subsystem within the actual or “zero-state” scenario. Based on such preliminary analysis and diagnosis, changes in the greenspace scenario were suggested and incorporated in the development of two new scenarios, focusing on planning, design and maintenance issues. The alternatives were then evaluated and compared using the performance indicators generated by the system.

We have shown that: (i) the GIS-based user interface supports suitability analysis and the search process for feasible alternatives (potential problem solution); (ii) a wide range of state-of-art spatial (-temporal) choice models integrated under a common framework support decision-makers in taking different perspectives to evaluate a multi-objective conflicting decision problem; (iii) the system is capable of supporting decision makers in identifying significant improvements in the alternative scenarios, and the best alternative, given multiple and possibly conflicting objectives.

To conclude this chapter, we can say that GRAS is a robust framework, capable of supporting every stage of the greenspace decision-making process. Moreover, it can be deployed and used at any regional and local level of governance. However, the system at its present state of development also has some limitations. These will be discussed in the final chapter.



## CHAPTER 8

### 8. CONCLUSIONS AND DISCUSSIONS

The aim of this research project has been to develop a prototype Spatial Decision Support System to assist local/regional authorities in the planning, design and maintenance of urban greenspace. The system has been given the acronym GRAS, Dutch word for grass, which stands for Greenspace Assessment System in the context of this project.

This study was motivated by increasing concerns of urban greenspace as an important contributor to the urban quality of life. Urban greenspace is strongly linked with social aspects (e.g. recreation and relaxation) and physical aspects (e.g. open space, water structures, clean air) of the quality of life. Whereas the relationship between urban greenspace and the physical aspect of the quality of life has been associated with problems in the field of transportation and has extensively been explored under the umbrella of urban ecology and the environment (e.g., Flores *et al.*, 1998; SPARTACUS project<sup>1</sup>; Randall and Baetz, 2003; Arampatzis *et al.*, 2004; Breuste, 2004), the study of the social aspects of urban greenspace in the context of quality of life has received relatively minor attention. There are just a very few published guidelines, explaining how to assess the provision of greenspace at an intra-urban level.

Quality of life in this context can be seen as a balanced combination of physical and social aspects, which are linked to location, time and culture. The social value of greenspace depends on peoples' values: it is what they perceive it to be. However, very little is known about the social value of greenspace and as a consequence, the benefits of greenspace appear intangible and so sustainable funding often suffers in relation to other priorities in the urban context.

Based on these considerations, in this research project, efforts were undertaken to provide:

<sup>1</sup> <http://www.vtt.fi/rte/projects/yki4/spartacus.htm>



- 1) A robust conceptual framework and methodological help to support decision makers and planners to understand and articulate the social values of urban greenspaces.
- 2) Relevant information for the problem solving process;
- 3) The right tools, models, methods and methodologies to gather and evaluate the relevant information so that uncertainties can be reduced.
- 4) A framework to integrate information, tools and models and represent the decision making process in a structured way.

The conceptual framework underlying the models and methodologies implemented in GRAS adopts elements of research on spatial choice behaviour. Although we use a more elaborate framework of context-dependent and time sensitive choice behaviour, the key notion underlying these models is that individuals derive some utility from greenspaces, which can be derived from choice behaviour and hence, measured. In line with this conceptual framework, GRAS considers two types of choice behaviour: non-temporal and temporal. The former refers to the approach in which greenspaces are conceptualised in terms of their attributes and facilities that will induce some utility for socio-demographics segments of the population. The results provide information on preference for different greenspace attributes and location and the effect of these preferences on their use. The latter, spatio-temporal (activity-based) approach, is based on a richer conceptualisation in that in addition to individual's preferences for certain types of greenspace, individuals needs or desires to pursue other activities in space and time are also considered. In particular, it allows addressing scenarios related to temporal planning (changing time use; planning with temporal context; etc). The results provide additional information about the intensity of greenspace use. These models are able of clarifying and quantifying the relationship between greenspace provision and use. In addition, these models identify interdependencies among planning, design and maintenance elements of the greenspace problem to integrate these three levels of decisions effectively, although not necessarily fully. Consequently, the right portfolio of urban parks can be arranged and monitored, given population needs and preferences.

More specifically, GRAS is a GIS-scenario-based micro-simulation multicriteria decision support system, with a range of domain-specific models using the conceptual framework of spatial behaviour, operating at the individual level. Especially the models of spatial choice behaviour incorporated in the system are all state-of-the-art and have not found much, if any application, yet in recreation and leisure research.

Inspired by the technological framework proposed by Sprague (1980), we followed an approach where "*DSS Tools*" (programming language, GIS

developer toolkit) were used to develop the “DSS Specific” (GRAS). GRAS is a windows application developed using Borland Cbuilder5 programming language embedded with an ActiveX control (MapObjects 2.0 for windows) to add GIS functionalities and capabilities. Indeed, we started from the modelling side, where urban models within the system were developed from sketch in C++ Builder 5 programming environment and GIS functionalities were added. This approach eliminated issues regarding overhead and limitations of standard GIS packages. The advantage is flexibility and full integration of GIS technology, domain models, data and tools. It is important to reiterate that our focus was not to improve technological aspects of spatial decision support systems, although we did use state-of-the-art technologies. The scope of the system and its contribution to the state-of-art in greenspace planning is to bring together a number of domain models, data and tools to provide and facilitate an objective, recursive and interactive decision-making process. This specific combination is to the best of our knowledge innovative in this field of application and research.

Regarding the system’s technical capabilities, we can identify three major components in GRAS: the database management system (DBMS), the model base management system (MBMS), and the dialog generation and management system (DGMS). The DBMS is a hybrid composition of the Borland Database Engine and the MapObjects development tool. The full integration of these two technologies allows the DBMS to be the heart of the spatial and operational information system, because spatial and non-spatial data from different sources can be easily co-processed with appropriate spatial interpolation techniques. It also allows communication and intermediate storage between the various submodels without user intervention. A very important characteristic of the MBMS component is its ability to integrate data access and urban (decision) models. It does so by using the database as the integration and communication mechanism between models. Consequently, the user only intervenes in the system to control the decision process and not to conduct the basic operations needed for modelling. The dialogue generation and management system is the component for managing the interface between the system and the user.

The Model Base Management System consists of seven major integrated modules: the Scenario Management, the Population Synthesizer, the Network Model, the Spatial Component, the Spatio-temporal Component, the Cost Estimative Spreadsheet and the Multicriteria Model. The *Spatial Component* consists of a family of discrete choice models (with different degree of complexity and behavioural realism) and accessibility performance measures. This component includes five models: 1) The Awareness model; 2) The Preference model; 3) The Trip Making Propensity model; 4) The Pressure model; 5) The Accessibility model. These are static (or spatial non-

temporal) models for the predicting individual choice behaviour and preferences, which in turn is used to derive a set of performance indicators, assumed relevant for the planning, design and maintenance of urban greenspace. Accessibility indicators can be derived from nine different accessibility measures. The *Spatio-temporal Component*, represented by the micro-simulation model named Aurora (Joh *et al.*, 2004) is meant to offer an alternative to the static (non-temporal) characteristic of the spatial models. In principle, this model describes individuals choices with respect to which activities to conduct (activity participation choice), where (location or destination choice), when (choice of timing), for how long (duration choice), and the transport mode used.

The several domain models mentioned above were implemented and integrated under a common GIS-based environment. This makes the system a powerful tool to support decision makers in all phases 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 alternative scenarios, and to the assessment/comparison of alternatives. The system uses the conceptual model proposed by Mintzberg *et al.* (1976) to represent the relationship among system's elements, and give structure to the decision making process. Note however that the system offers a generic process to guide decision makers, but no fixed structure is enforced by internal dependencies between models and tools during the decision making process. This means that users are able to execute models and use tools (for instance thematic maps, query, etc.) at any time of the decision making process they wish. GRAS is highly interactive and user driven (controlled) user interface. Many models require users to add their knowledge and judgment to evaluate different decision types (decision levels), increasing system flexibility and usability. In this sense, the system is flexible enough to support decision makers with different cognitive styles.

GRAS strongly depends on data. Spatial and non-spatial data coming from internal and/or external sources are required for the description of the study area (spatial representation) and for model estimation. The urban system is represented in terms of a grid system (here called cell-based management system). Many different spatial elements in this urban system are relevant to GRAS models. These include:

1. Land Use;
2. Post Code addresses;
3. Road Network;
4. Zone system (census tract);
5. Greenspace amenities;
6. Work facilities.

Hence, spatially aggregate data from the subsystems enumerated above and must be compiled into a singular spatial source defined as cells of 100 x 100 meters. Although the cell size is arbitrary and can be easily changed by the user, the 100 x 100m cell resolution was experimentally adopted as the optimum size given limitations of memory, speed of personal computer technology and model sensitiveness and accuracy.

Secondly, a proper operational setting of the models in the system requires two sets of parameters to be estimated from empirical data. A first set of parameters is required for the static models estimation, and a second, for the spatio-temporal model estimation. This research project covered the parameter estimation of the static models only. As part of on-going research, the estimation of the spatio-temporal model, i.e. the Aurora model, is left to future work. For the moment, the parameters settings were manually calibrated both using data from a sample of the Eindhoven population and based on expert knowledge.

GRAS was employed in a case study, and assumptions with regard to the relationships between the system's components and functional requirements were tested and validated. We argue that this illustration demonstrates that GRAS successfully achieves the objectives of this research project. First, an *effective* spatial decision support system for planning, design and maintenance of greenspaces has been proposed, developed and applied. Based on Geoffrion (1987) arguments, there are four factors making GRAS an effective tool. The first is that the system attaches a common philosophical approach to the decision making process, using theories of human behaviour, which avoids multiple problem representation. Note that problem representation has nothing to do with decision making strategy. In other words, GRAS not only attaches a philosophical approach to the decision making process, but also acknowledges that different people when faced with the same decision problem will adopt different decision making strategies; they will place different values on variables and relationships; and they will select and use information in a variety of ways. Hence, the variety of tools and models, which require users to add their knowledge and judgment as parameters or model settings is meant to accommodate decision makers inter-personal differences, values, and reflect inherent difficulties, accommodating a range of different decision makers' cognitive styles. Secondly, to allow such cognitive differences, a complete range of state-of-art analytical domain models (from static to dynamically-oriented) is embedded into a framework to support decision makers in exploring and analyzing the problem under different perspectives.

Thirdly, the fully integrated GIS-based system environment, containing tools and domain-models, is structured to provide methodological and technical support to decision-makers and planners, without requiring

specialized skills and especially knowledge of predicting spatial choice behaviour.

Fourthly, GRAS is designed to support the user during all phases of the decision making process, i.e., from the identification of the problem through the development of alternative solutions to the selection of a solution.

This progress however does not mean that the system has been fully developed and validated. A first possible limitation of GRAS is related to the approach used to develop the system. Although the fully integrated approach has very strong advantages, such as flexibility to develop models and tools from scratch and the full integration of these models and tools, overcoming the limitations and overhead of conventional “*DSS Generators*”, it also has some disadvantages. One shortcoming is that when the available models in the system cannot fully meet users’ needs, users may have difficulties to build and integrate other decision models themselves unless they are skilful or experienced in computer programming. GRAS does not provide procedures to enable models to be created and integrated.

GRAS data dependency is also an important issue that deserves critical thought. The large amount of data and information needed to make the system operational and ready to use is not only a strength, but also a potential weakness. The strength is related to the fact that users are able to combine data and information to derive and generate more information and hence decrease the sources of uncertainties during the decision making process. On the other hand, a considerable effort is required to collect the data to feed the system, and later maintain the database up-to-date.

Especially when the system is going to be applied to a new plan area, not only a new synthetic population needs to be created, but if the user does not wish to rely on the settings of spatial and temporal models, but rather would wish to recalibrate the models on data specifically collected for this plan area, then the data collection and model estimation requires a substantial amount of effort and also specific modelling skills.

Other additional issue that need to be addressed in future work is the further development of the Aurora model. As indicated, the model implemented is still at the stage of development. Future elaborations may involve a finer categorization of activities, especially related to recreation and leisure, if the user wishes to have more detailed information about the kind of activities that can be conducted at the parks. Because of data availability, the current implementation of the Aurora model considers 3 types of activity only. They are green activities, work activity, and others. Biases may appear during the (re)scheduling procedure as a result of the aggregation of many types of activities into a unique class. The potential of the system is reduced, namely the interaction of green activities with other recreational activities cannot be captured because other recreational

activities belong to the third category of activity, which is aggregated with mandatory and other discretionary activities such as grocery shopping, social activities, service, healthy related, etc. A second subject of future research relates to activity location choice in the Aurora model. Although this extension has been solved theoretically, allowing for location-specific functions, the current implementation of the Aurora model uses a location choice algorithm that does not dynamically interact with the heuristic search method of Aurora. In other words, the location choice algorithm can be seen as a separated model that does not interact dynamically with the Aurora model. Consequently, activity locations are not dynamically chosen, given individuals space-time constraints compromising the model's strength. Although this implementation is capable to capture very well changes in the temporal scenarios, i.e. the impact of an increase (or decrease) of time pressure on the individuals behaviour, it is not very clear to what extent this model captures the impact of changes related to spatial scenarios, especially when the changes are very local and may very well have an impact on a relatively small part of the population of the study area.

The spatial representation in GRAS may also be a concern in future research. We did achieve in using a more disaggregated level of spatial representation than the traditional "zone-based" approach. The current system is based on a spatial representation of 100 by 100 meters cells. Explorations indicated that this spatial representation is computationally efficient and avoids problems of aggregation bias. However, such cells appear rather artificial sometimes. A finer scale of spatial representation would be preferable and will diminish overlays of spatial representation, which is especially important during scenario redevelopment. However, increased resolution also implies considerable higher computation times, which is a problem because one would like to use as large samples as possible, because in the end this is a micro-simulation system. Hence, with future progress in computer technology, this trade-off between type and resolution of spatial representation, the number of agents/individuals that can be simulated and computing time should be re-assessed and may lead to a different outcome.

The user interface can also be improved. As a Windows application, the graphical user interface allows the users to operate the system intuitively, i.e. with little or no instruction. However, to ensure optimal performance, usability testing must be addressed in future research. This empirical testing permits naive users to provide information about what does work as anticipated and what does not work. Only after the necessary repairs have been made, the user interface has been properly tested.



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## **APPENDICES**



## Appendix A

### Work time estimation - Stepwise regression model

*Dependent variable:* total number of working hours per person

*Independent variables:* Age  
Gender  
Family structure

*Age:*

Level 1: Younger than 25	(1 0 0)
Level 2: Between 25 and 44	(0 1 0)
Level 3: Between 45 and 64	(0 0 1)
Level 4: Older than 64	(-1-1-1)

*Gender:*

Level 1: Male	(-1)
Level 2: Female	(1)

*Family Structure:*

Level 1: Without children	(-1)
Level 2: With child	(1)

### Sample description

Table 1. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
HRWRK*	1075	0	99	31.0605	13.8727
Valid N (listwise)	1075				

\*HRWRK: Hours working

Table 2. Age classes (agecl)

Valid	Frequency	Percentage	Valid percentage	Cumulative percent
1	92	5.6	5.6	5.6
2	663	40.6	40.6	46.2
3	565	34.6	34.6	80.8
4	313	19.2	19.2	100.0
Total	1633	100.0	100.0	

Table 3. Gender (gesl)

Valid	Frequency	Percentage	Valid Percentage	Cumulative percentage
1	791	48.4	48.4	48.4
2	842	51.6	51.6	100.0
total	1633	100.0	100.0	

Table 4. Family structure (famstr)

Valid	Frequency	Percentage	Valid percentage	Cumulative percentage
1	1187	72.7	72.7	72.7
2	446	27.3	27.3	100.0
Total	1633	100.0	100.0	

### Model results

#### Model goodness-of-fit

Table 5. Model Summary goodness-of-fit

Model	R	R-square	Adjusted R-square	Std. error of the Estimate
1	0.333 <sup>a</sup>	0.111	0.110	13.0841
2	0.456 <sup>b</sup>	0.208	0.206	12.3586
3	0.574 <sup>c</sup>	0.329	0.328	11.3748
4	0.591 <sup>d</sup>	0.349	0.347	11.2090
5	0.601 <sup>e</sup>	0.358	0.358	11.1178

- Predictors: (Constant), GND
- Predictors: (Constant), GND, AG2
- Predictors: (Constant), GND, AG2, AG3
- Predictors: (Constant), GND, AG2, AG3, FSTR
- Predictors: (Constant), GND, AG2, AG3, FSTR, AG1

Table 6. Estimated Coefficients<sup>a</sup>

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. error	Beta		
1 (Constant)	31.247	0.400		78.210	.000
GND	-4.626	0.400	-0.333	-11.578	.000
2 (Constant)	27.500	0.500		55.010	.000
GND	-5.180	0.380	-0.373	-13.614	.000
AG2	7.605	0.666	0.313	11.426	.000
3 (Constant)	22.343	0.590		37.842	.000
GND	-5.082	0.350	-0.366	-14.510	.000
AG2	11.410	0.671	0.470	17.013	.000
AG3	9.697	0.696	0.383	13.938	.000
4 (Constant)	21.384	0.605		35.321	.000
GND	-4.938	0.346	-0.356	-14.270	.000
AG2	11.596	0.661	0.477	17.490	.000
AG3	10.026	0.668	0.396	14.573	.000
FSTR	-2.116	0.369	-0.142	-5.733	.000
5 (Constant)	20.799	0.616		33.785	.000
GND	-4.872	0.344	-0.351	-14.178	.000
AG2	12.407	0.684	0.511	18.133	.000
AG3	10.951	0.715	0.432	15.310	.000
FSTR	-1.933	0.369	-0.130	-5.246	.000
AG1	-5.221	1.210	-0.114	-4.315	.000

## Appendix B

### Preference Model

Table 1. Selected greenspaces attributes and their levels

Attribute	Attribute levels
Distance to the urban park	400 m 800 m 1600 m 3200 m
Type and size of the urban park	Local park, ½ ha Neighbourhood park, 8 ha District park, 20 ha City park, 250 ha
Type of green (mainly)	Grass and flowers Trees and bushes
Accessibility by public transport	Yes / No
Presence of water	Yes / No
Possibility to sport / play	Yes / No
Possibility to walk the dog	Yes / No
Possibility to walk	Yes / No
Possibility to enjoy relaxation	Yes / No
Possibility to enjoy a wonderful view	Yes / No
Possibility to organize something	Yes / No
Visited by many people at the same time	Yes / No
Is safe	Yes / No
High maintenance	Yes / No
Cleanliness	Yes / No
High ecological value	Yes / No
Availability of benches with tables	Yes / No
Availability of café, place to eat something, kiosk	Yes / No
Availability of a playground for children	Yes / No
Availability of toilets	Yes / No
Availability of lighting	Yes / No
Availability of dustbins	Yes / No

Table 2. Part-worth utilities and relative importance of attributes

Attribute	Attribute levels	Utility	t-value	Relative Importance
Base		-.180	-7.559	
Distance to urban park	400 m	.349	11.884	.73
	800 m	.109	3.979	
	1600 m	-.073	-2.616	
	3200 m	(-.385)		
Type and size of urban park	Local park, ½ ha	-.319	-10.385	.61
	Neighborhood park, 8 ha	-.115	-3.808	
	District park, 20 ha	.142	4.784	
	City park, 250 ha	(.292)		
Type of green (mainly)	Grass and flowers	-.086	-5.121	.17
	Trees and bushes	(.086)		
Accessibility by public transport	Yes / No	-.062	-3.799	.12
Presence of water	Yes / No	.025	1.592	.05
Possibility to sport / play	Yes / No	.036	2.184	.07
Possibility to walk the dog	Yes / No	.078	4.811	.15
Possibility to walk	Yes / No	.143	8.615	.28
Possibility to enjoy relaxation	Yes / No	-.005	-0.319	.01
Possibility to enjoy a wonderful view	Yes / No	.070	4.396	.14
Possibility to organize something	Yes / No	.056	3.253	.11
Visited by many people at the same time	Yes / No	-.007	-0.435	.01
Is safe	Yes / No	.028	1.618	.06
High maintenance	Yes / No	-.024	-1.462	.05
Cleanliness	Yes / No	.018	1.115	.03
High ecological value	Yes / No	-.009	-0.52	.00
Availability of benches with tables	Yes / No	.000	-0.017	.00
Availability of café, place to eat, kiosk	Yes / No	.090	5.492	.18
Availability of a playground for children	Yes / No	.010	0.593	.02
Availability of toilets	Yes / No	.020	1.277	.04
Availability of lighting	Yes / No	.015	0.937	.03
Availability of dustbins	Yes / No	.003	0.152	.01

## Appendix C

**CHAID Analysis:** Number of Cases 1107

**Dependent variable:** Number of park visits per season (separate trees for Spring, Summer, Autumn, Winter) Measurement Level Continuous

**Predictors:**

- AGE Continuous
- GENDER Nominal (0=female, 1=male)
- WORKHOUR Continuous
- CHILDREN Nominal (0=without children, 1=with children)

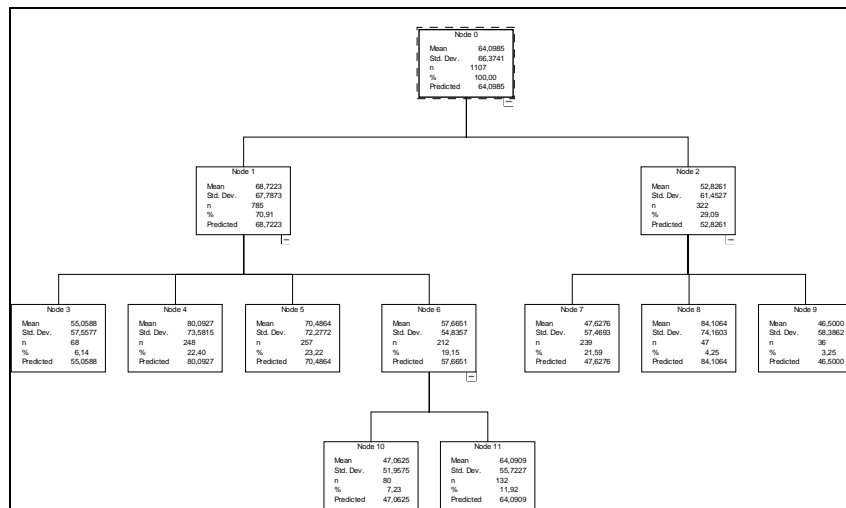


Figure 1. Spring



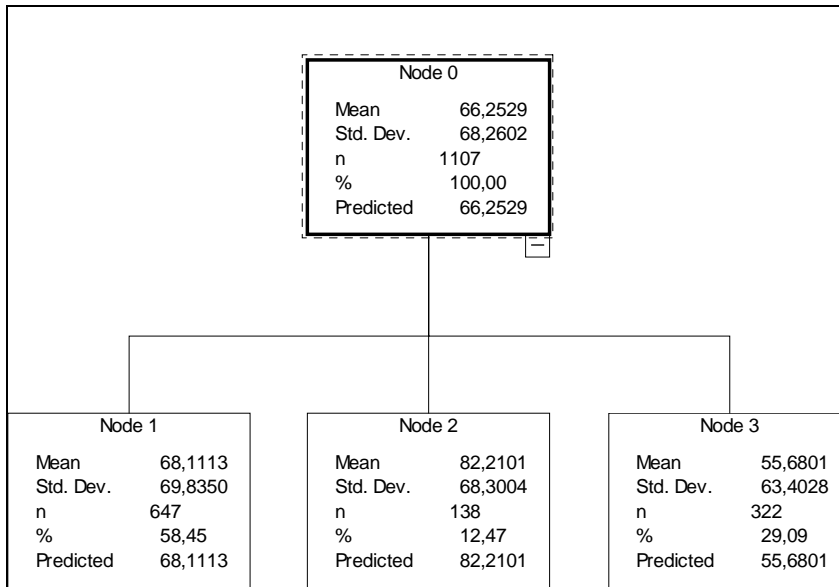


Figure 2. Summer

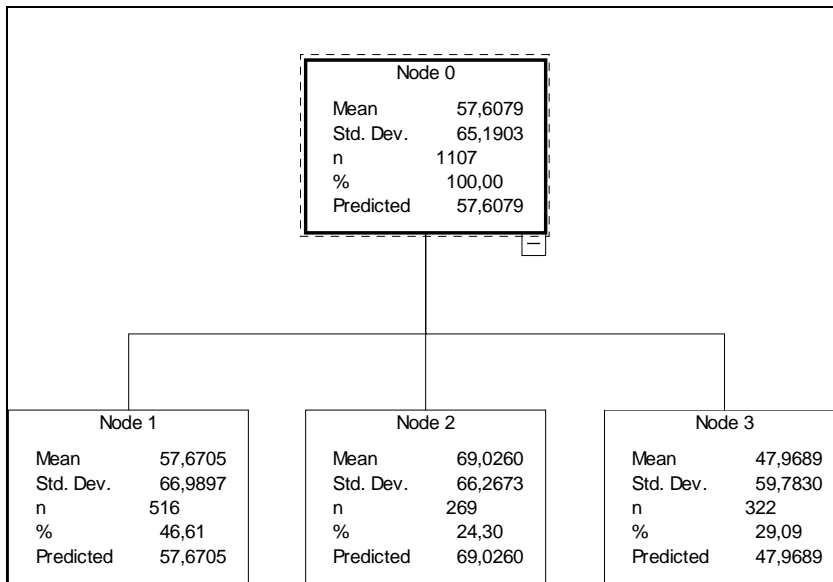


Figure 3. Fall

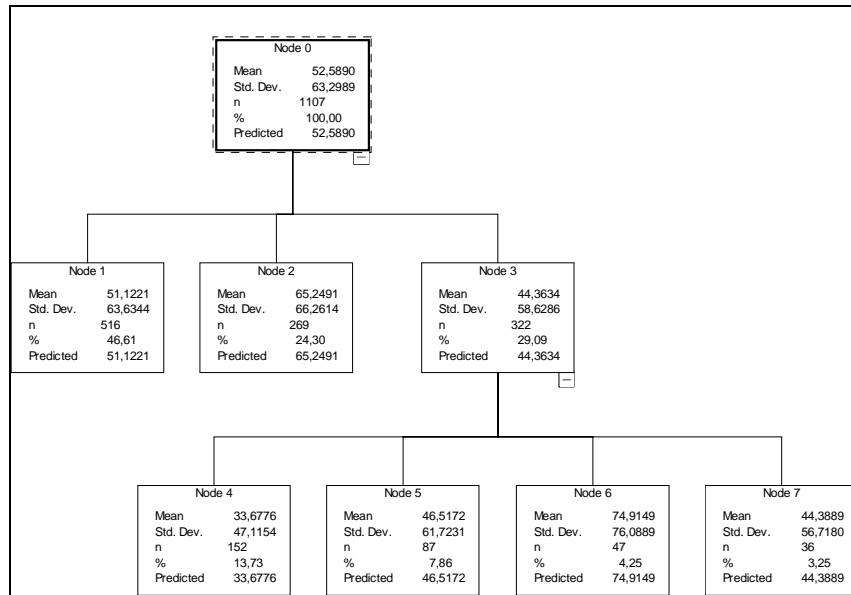


Figure 4. Winter



## Appendix D

Table 1. Land use Code

Land Use Code	Dutch Specification	English Translation
1	Agrarisch gras	Agricultural - Grass
2	Mais	Agriculture - Corn
3	Aardappelen	Agriculture - Potatos
4	Bieten	Agriculture - Beetroot
5	Granen	Agriculture - Grains
6	Overige landbouwgewassen	Agriculture - Others
8	Glastuinbouw	Green Houses
9	Boomgaarden	Orchard
10	Bloembollen	Bulb Cultivation
11	Loofbos	Deciduous Forest
12	Naadbos	Coniferous Forest
13	Droge heide	Dry Moorland
14	Overig open begroeid natuurgebied	Nature Area - Others
15	Kale grond in natuurgebied	Treeless Nature Area
16	Zoet water	Sweet water
17	Zoutwater	Salt water
18	Stedelijk bebouwd gebied	Urban Built Area
19	Bebouwing in buitengebied	Outside Urban Built Areas
20	Loofbos in bebouwd gebied	Deciduous Forest in Urban Areas
21	Naadbos in bebouwd gebied	Coniferous Forest in Urban Areas
22	Bos met dichte bebouwing	Green surrounding buildings
23	Gras in bebouwd gebied	Grass Surrounding buildings
24	Kale grond in bebouwd buitengebied	Open fields outside built areas
25	Hoofdwegen en spoorwegen	Highways and railway
26	Bebouwing in agrarisch gebied	Buildings in agriculture area
30	Kwelders	Salt marsh/ meadow
31	Open zand in kustgebied	Sand in costal area
32	Open duinvegetatie	Open Dune vegetation
33	Gesloten duinvegetatie	Close dune vegetation
34	Duinheide	Dune Moorland
35	Open stuifzand	Drift sand
36	Heide	Heather - Moorland
37	Matig vergraste heide	Moderate Heather Grass
38	Sterk vergraste heide	Intensive Heather Grass

39	Hoogveen	High moor peat
40	Bos in hoogveengebied	Forest in Moorland
41	Overige moerasvegetatie	Others wetland vegetation
42	Rietvegetatie	Sugar cane field
43	Bos in moerasgebied	Forest in swamp area
44	Veenweidegebieden	Peat meadow area
45	Overig open begroeid natuurgebied	Others open nature area
46	Kale grond in natuurgebied	Open field in nature area





<b>B</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>C</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>D</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>E</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6. Please indicate for each season, for the green spaces indicated by your answer in question 2 (A t/m E), **how long you usually stay there.**

Season	T/m 15 min	>15 min - 1 hr	> 1 - 2 hrs	> 2 - 4 hrs	More than 4 hrs	
<b>A</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>B</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>C</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>D</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>E</b>	Spring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Autumn	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>





<b>C</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	...
<b>D</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	...
<b>E</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	...

10 Please indicate, for the green spaces indicated by your answer in question 2 (A t/m E), **which are the reasons going** to these green spaces instead of others (tick all that apply).

	Dist- ance	Acces- sibility	Lay- out	Facil- ities	Kind of activity	Nature aspect	Social aspect	Feel safe	Other
<b>A</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	.....
<b>B</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	.....
<b>C</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	.....
<b>D</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	.....
<b>E</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	.....

11 Please indicate, for the green spaces indicated by your answer in question 2 (A t/m E), **how satisfied you are with** these green spaces.

	Not at all satisfied	Somewhat satisfied	Fairly satisfied	Quite satisfied	Very satisfied	Don't know
<b>A</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>B</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>C</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>D</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>E</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

12 Please indicate, for the green spaces indicated by your answer in question 2 (A t/m E), if you would like to see things changed of the green spaces

<b>A</b>	<input type="checkbox"/> no <input type="checkbox"/> Yes, .....
<b>B</b>	<input type="checkbox"/> no <input type="checkbox"/> Yes, .....
<b>C</b>	<input type="checkbox"/> no <input type="checkbox"/> Yes, .....
<b>D</b>	<input type="checkbox"/> no <input type="checkbox"/> Yes, .....
<b>E</b>	<input type="checkbox"/> no <input type="checkbox"/> Yes, .....

13 Are there in Eindhoven and green spaces you are not going to (certain points in time, always) because you do not feel safe there. Please indicate if there is vandalism, presence of certain people or whether you feel unsafe because of the layout of the green space (for example tight woods bad lighting)?

	Certain points in time		Address/neighbourhood/name of green space	Presence of certain people		
		Always		Vandalism	Presence of certain people	Social unsafety
1.	<input type="checkbox"/>	<input type="checkbox"/>	.....	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	.....	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	.....	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	.....	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	.....	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

14 What do you think about the amount and the variety of green space in Eindhoven and its neighbourhood and how important do you think this is.

	What do you think (view)							How important																									
	Very bad							Very good							Very unimportant							Very important											
The amount of green space	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The variety of green space	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

15 Please list up the green spaces, outside your neighbourhood, you **have visited** the most in the last 12 months.

Address/neighbourhood/name of green space	.....
---	-------



Sport field	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Toilets	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lighting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Garbage cans	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Part 2**

## General questions about you and your household

1. Day of birth?	..... / ..... / .....
2. Gender?	<input type="checkbox"/> male <input type="checkbox"/> female
3. Postcode + house number?	.....

1. What type of property do you live in?	<input type="checkbox"/> flat <input type="checkbox"/> apartment <input type="checkbox"/> terraced house	<input type="checkbox"/> semi-detached house <input type="checkbox"/> detached house <input type="checkbox"/> other.....
2. What is the type of tenure on the property?	<input type="checkbox"/> owner-occupied <input type="checkbox"/> rented accommodation	
3. Which facilities? (tick all that apply)	<input type="checkbox"/> balcony <input type="checkbox"/> lean-to <input type="checkbox"/> garage	<input type="checkbox"/> garden, about .....m2 <input type="checkbox"/> roof garden, about.... m2 <input type="checkbox"/> car park
4. How long have you lived in your current neighbourhood and town?	<input type="checkbox"/> neighbourhood, ..... years and ..... months <input type="checkbox"/> town, ..... years and ..... months	
5. Did green space influence your decision to move to your neighbourhood?	<input type="checkbox"/> it was a strong influence (go to question 6) <input type="checkbox"/> it had some influence (go to question 6) <input type="checkbox"/> it had limited/no influence (go to question 7) <input type="checkbox"/> don't know/don't remember (go to question 7)	
6. How did proximity to greenspace influence your decision to move to your neighbourhood?	<input type="checkbox"/> I wanted nice views <input type="checkbox"/> I wanted to be close to a natural/green area <input type="checkbox"/> I wanted somewhere close by where children could play <input type="checkbox"/> I wanted somewhere close by to relax/for peace and quiet <input type="checkbox"/> I wanted somewhere close by to walk dog(s) <input type="checkbox"/> I wanted somewhere close by to exercise/go for a walk <input type="checkbox"/> other .....	
7. Dogs? How many?	<input type="checkbox"/> no <input type="checkbox"/> yes, ..... dogs.	

**Availability of transportation modes**

8.a Do you have a handicap, which limit you to use certain transportation modes?	<input type="checkbox"/> no, go to question 9 <input type="checkbox"/> yes	
8.b Which transportation modes you can't use? (tick all that apply)	<input type="checkbox"/> car, as driver <input type="checkbox"/> car, as passenger <input type="checkbox"/> bus / tram / metro	<input type="checkbox"/> train <input type="checkbox"/> bicycle <input type="checkbox"/> other.....
9.a Do you have a bicycle?	<input type="checkbox"/> no <input type="checkbox"/> yes	

9.b Do you have a light motorbike or scooter?	<input type="checkbox"/> no <input type="checkbox"/> yes
9.c Are there any bicycles, light motorbike or scooter in your household? And yes, how many?	<input type="checkbox"/> no <input type="checkbox"/> yes, ..... bicycle(s) <input type="checkbox"/> yes, ..... light motorbike (brom-/snorfiets) <input type="checkbox"/> yes, ..... scooters
10.a Do you have a car at your disposal?	<input type="checkbox"/> no <input type="checkbox"/> yes, whenever I want <input type="checkbox"/> yes, in consultation with persons from in- and outside the household
10.b Do you have a motor at your disposal?	<input type="checkbox"/> no <input type="checkbox"/> yes, whenever I want <input type="checkbox"/> yes, in consultation with persons from in- and outside the household
10.c Are there any cars or motors in your household? And yes, how many?	<input type="checkbox"/> no <input type="checkbox"/> yes, ..... car(s) own property <input type="checkbox"/> yes, ..... car(s) lease/company car <input type="checkbox"/> yes, ..... motor(s)
10.d Is there any official car sharing in your household?	<input type="checkbox"/> no <input type="checkbox"/> yes, on average ..... days per month
11. Where do you park your car/motor at home?	<input type="checkbox"/> driveway <input type="checkbox"/> garage near house <input type="checkbox"/> parking place on the street before the house <input type="checkbox"/> parking place (walking distance of. .... min. from house) <input type="checkbox"/> own garage (walking distance of. .... min. from home) <input type="checkbox"/> collective garage (walking distance .... min. from home) <input type="checkbox"/> other .....
12. Do you have a ticket for public transport? (tick all that apply)	<input type="checkbox"/> no <input type="checkbox"/> yes, I have a week/month/year ticket* for the bus <input type="checkbox"/> yes, I have a reduction ticket for the train <input type="checkbox"/> yes, I have a pas-65 <input type="checkbox"/> yes, I have a student week/weekend ticket* <input type="checkbox"/> yes, I have a month/year rote ticket* for the train <input type="checkbox"/> yes, I have a NS/OV-year ticket*
13. What is your annual household income?	<input type="checkbox"/> less than average <input type="checkbox"/> equal to average (€ 18.000-23.000) <input type="checkbox"/> between 1 and 2 times average <input type="checkbox"/> 2 times average (€ 41.000) <input type="checkbox"/> more than 2 times average <input type="checkbox"/> don't know <input type="checkbox"/> don't tell

14. Hypothetically, if the Council had money left over at the end of its budget period, which could be put back into the community, which of the following options would you prefer?

- spend the money on greenspace (which one) .....
- spend the money on something else (what?) .....
- no opinion
- don't know
- other .....

\*delete if not applicable

**If you have any questions, suggestions or comments please write them here.**

**Thank you for completing this questionnaire.**

## Appendix F

### Awareness Model

Table 1. Estimation results of the model of awareness set

Attributes	Attribute levels	Parameter	Significance
Type of park	Local park	-1.2079	0.0000
	Neighbourhood park	-0.5632	0.0000
	District park	0.51767	0.0000
Sport facilities	Available	-0.0404	0.4032
Footpaths	Available	0.7079	0.0000
Picnic facilities	Available	0.5330	0.0000
Café and places to eat	Available	0.3623	0.0000
Toilets	Available	-0.1398	0.0000
Lighting	Available	-0.1489	0.0000
Dustbins	Available	-0.0001	0.9982
Playing facilities	Available	0.0713	0.1815
Distance from home to park		-0.0003	0.0000
Goodness-of-fit			
Number of choice sets			
Number of cases	5499		
Number of parameters	68497		
Loglikelihood null model:	12		
LL(0)	-13842.48		
Loglikelihood final model:	-8615.63		
LL(B)	10453.70		
Test statistic: $-2[LL(0)-LL(B)]$	0.3776		
Adjusted Rho-square			



Table 2. Effects of gender on awareness

Attributes	Attribute levels	Average Parameters		Gender Specific Pars.	
		Parameter	Sign.	Parameter	Sign.
Type of park	Local park	-1.2111	0.000	0.0180	0.617
	Neighbourhood park	-0.5659	0.000	-0.0207	0.669
	District park	0.5217	0.000	0.0044	0.884
Sport facilities	Available	-0.0440	0.363	-0.1031	0.033
Footpaths	Available	0.7088	0.000	0.0185	0.656
Picnic facilities	Available	0.5350	0.000	-0.0150	0.712
Café and places to eat	Available	0.3929	0.000	0.01786	0.439
Toilets	Available	-0.1404	0.000	-0.0221	0.296
Lighting	Available	-0.1481	0.000	-0.0373	0.284
Dustbins	Available	-0.0033	0.953	0.1100	0.050
Playing facilities	Available	0.0744	0.165	0.1197	0.037
Distance from home to park		-0.0003	0.000	0.00001	0.041
Goodness-of-fit					
Number of choice sets					
Number of cases		5496			
Number of parameters		68461			
Loglikelihood null model: LL(0)		24			
Loglikelihood final model: LL(B)		-13835.036			
Test statistic: $-2[LL(0)-LL(B)]$		-8599.6436			
Adjusted Rho-square		10470.784			
		0.378			

Table 3. Effects of age on awareness

Attributes	Attribute levels	Average Parameters		Age Specific Pars.	
		Parameter	Sign.	Parameter	Sign.
Type of park	Local park	-1.2068	0.000	0.0132	0.722
	Neighbourhood park	-0.5531	0.000	0.0384	0.442
	District park	0.5119	0.000	-0.0242	0.434
Sport facilities	Available	-0.0240	0.634	0.0609	0.226
Footpaths	Available	0.6998	0.000	-0.0353	0.408
Picnic facilities	Available	0.5622	0.000	0.0850	0.056
Café and places to eat	Available	0.3686	0.000	0.0202	0.399
Toilets	Available	-0.1474	0.000	-0.0251	0.256
Lighting	Available	-0.1467	0.000	-0.0030	0.935
Dustbins	Available	-0.0200	0.728	0.0446	0.440
Playing facilities	Available	0.0487	0.378	-0.0799	0.148
Distance from home to park		-0.0003	0.000	0.0000	0.913
Goodness-of-fit					
Number of choice sets					
Number of cases		5497			
Number of parameters		68474			
Loglikelihood null model: LL(0)		24			
Loglikelihood final model: LL(B)		-13837.601			
Test statistic: $-2[LL(0)-LL(B)]$		-8606.9064			
Adjusted Rho-square		10461.389			
		0.378			

Table 4. Effect of household composition on awareness

Attributes	Attribute levels	Average Parameters		Household Specific	
		Parameter	Sign.	Parameter	Sign.
Type of park	Local park	-1.2070	0.000	-0.0079	0.846
	Neighbourhood park	-0.5678	0.000	0.0116	0.827
	District park	0.5353	0.000	0.0348	0.301
Sport facilities	Available	-0.0627	0.243	-0.0427	0.426
Footpaths	Available	0.6465	0.000	-0.1523	0.001
Picnic facilities	Available	0.5312	0.000	-0.0263	0.559
Café and places to eat	Available	0.3332	0.000	-0.0661	0.012
Toilets	Available	-0.1353	0.000	0.0071	0.771
Lighting	Available	-0.1391	0.004	0.0051	0.896
Dustbins	Available	-0.0355	0.589	-0.0700	0.260
Playing facilities	Available	0.1101	0.064	0.1013	0.088
Distance from home to park		-0.0003	0.000	0.0000	0.000
Goodness-of-fit					
Number of choice sets					
Number of cases		5474			
Number of parameters		68195			
Loglikelihood null model: LL(0)		24			
Loglikelihood final model: LL(B)		-13780.275			
Test statistic: $-2[LL(0)-LL(B)]$		-8561.1978			
Adjusted Rho-square		10438.155			
		0.378			

## Appendix G

### Trip Making Propensity parameters

Table 1. Coding of the variables and their levels

Variables	Levels	Coding
Type of park	Local park	1 0 0
	Neighborhood park	0 1 0
	District park	0 0 1
	City park	0 0 0
Season	Spring	1 0 0
	Summer	0 1 0
	Autumn	0 0 1
	Winter	-1 -1 -1
Distance	Distance in meters from home to park	Meters
Time of visit	Weekday-morning--yes	1
	Weekday-morning--no	-1
	Weekday-afternoon--yes	1
	Weekday-afternoon--no	-1
	Weekday-evening--yes	1
	Weekday-evening--no	-1
	Weekend-morning--yes	1
	Weekend-morning--no	-1
	Weekend-afternoon--yes	1
	Weekend-afternoon--no	-1
	Weekend-evening--yes	1
	Weekend-evening--no	-1
Gender	Male	1
	Female	-1
Working hours	Number of working hours per week	Number
Household type	With children	1
	Without children	-1

Table 2. Mixed Logit Model: Trip Making Propensity to urban green spaces

Variables	Parameter (t-statistic)		
Constant	-2.451	(-292.615)	
Local park	.323	(20.345)	
Neighborhood park	.104	(2.676)	
District park	-.451	(-15.117)	
City park (base)	0		
Spring	-.080	(-11.539)	
Summer	.096	(13.971)	
Autumn	.042	(5.837)	
Winter (base)	-.058		
Distance	-.0001	(-131.746)	
Weekday-morning	.547	(123.561)	
Weekday-afternoon	.286	(63.513)	
Weekday-evening	.375	(65.380)	
Weekend-morning	.125	(25.142)	
Weekend-afternoon	-.072	(-16.072)	
Weekend-evening	.022	(3.231)	
Gender	.066	(15.618)	
Working hours	-.001	(-6.101)	
Household type	.039	(7.983)	
Interactions	Local Park	Neighborhood park	District park
Spring	.074 (8.304)	.090 (6.961)	.034 (3.309)
Summer	-.038 (-4.342)	-.032 (-2.473)	.010 (1.029)
Autumn	-.044 (-4.753)	-.031 (-2.278)	-.043 (-3.972)
Weekday-morning	-.043 (-19.472)	-.103 (-11.138)	.175 (25.590)
Weekday-afternoon	-.117 (-16.440)	-.045 (-4.956)	-.014 (-2.104)
Weekday-evening	-.198 (-27.037)	-.219 (-21.240)	-.211 (-24.346)
Weekend-morning	.004 (.652)	-.126 (-12.251)	.028 (3.847)
Weekend-afternoon	-.002 (-.313)	-.031 (-3.318)	-.085 (-12.905)
Weekend-evening	.071 (8.351)	.198 (16.423)	.122 (11.754)
Gender	.006 (1.092)	-.050 (-6.246)	-.015 (-2.507)
Working hours	-.0005 (-1.471)	.005 (9.925)	-.003 (-8.932)
Household type	-.078 (-12.240)	-.112 (-12.293)	-.070 (-9.369)
Standard deviation	.459 (10.720)	.453 (4.286)	.735 (14.270)
Unobserved covariance	Local Park	Neighborhood park	
Neighborhood park	-.425 (-4.272)		
District park	.712 (13.142)	.183 (2.110)	
Log-likelihood	-975967.6		

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## NEDERLANDSE SAMENVATTING

Dit onderzoek wordt gemotiveerd door het toenemende besef dat groene ruimte kan bijdragen aan het verbeteren van de kwaliteit van leven van mensen in stedelijke gebieden. Stedelijk groen is sterk verbonden met sociale aspecten (bijv. recreatie en ontspanning) en fysieke aspecten (bijv. open ruimte, waterstructuren, schone lucht) van de leefkwaliteit. Terwijl de relatie tussen stedelijk groen en het fysieke aspect van leefkwaliteit aandacht heeft gekregen in het kader van transport problematiek, stedelijke geologie en milieu (bijv., Flores *et al.*, 1998; SPARTACUS project<sup>1</sup>; Randall en Baetz, 2003; Arampatzis *et al.*, 2004; Breuste, 2004), heeft de studie van sociale aspecten van stedelijk groen in the context van leefkwaliteit relatief weinig aandacht gekregen. Er zijn slechts zeer weinig gepubliceerde richtlijnen die aangeven hoe de voorziening van groene ruimte op een binnenstedelijk niveau ingeschat moet worden.

De leefkwaliteit in deze context kan worden gezien als een uitgebalanceerde combinatie van fysieke en sociale aspecten, die zijn verbonden met plaats, tijd en cultuur. De sociale waarde van groene ruimte hangt af van waarden van mensen: het is zoals zij het beleven. Er is echter heel weinig bekend over de sociale waarde van groene ruimte en, als gevolg daarvan, lijken de voordelen van groene ruimte ontastbaar en krijgt het een lagere prioriteit bij de toekenning van duurzame financiële ondersteuning in de stedelijke context.

Op basis van deze overwegingen wordt in dit onderzoeksproject een inspanning geleverd om te voorzien in:

1. Een robuust conceptueel raamwerk en methodologische bijdrage om beslissers en planners te helpen bij het begrijpen en formuleren van de sociale waarden van stedelijk groen.
2. Relevante informatie voor het probleemoplossingsproces.
3. De juiste tools, modellen, methoden en methodologieën voor het verzamelen en evalueren van relevante informatie zodat onzekerheden kunnen worden verminderd.
4. Een raamwerk voor het integreren van informatie, tools en modellen en het op een gestructureerde wijze weergeven van het beslisproces.

<sup>1</sup> <http://www.vtt.fi/rte/projects/yki4/spartacus.htm>

Het product van dit onderzoeksproject is een prototype van een Ruimtelijk Decision Support Systeem dat locale/regionale overheden kan helpen bij de planning, het ontwerpen en het onderhouden van stedelijke groene ruimten. Het systeem heeft het acroniem GRAS gekregen – het Nederlandse woord voor gras – wat in de context van dit project staat voor Greenspace Assessment System.

GRAS is een GIS-scenario-gebaseerd micro-simulatie multicriteria decision support systeem, met een reeks van domein specifieke modellen. Het conceptuele raamwerk achter de modellen en methodologieën die zijn geïmplementeerd in GRAS incorporeren elementen van het onderzoek naar ruimtelijke keuze gedrag. Hoewel we een meer uitgewerkt raamwerk van context afhankelijk en tijdgevoelig keuzegegedrag toepassen, is het sleutelbegrip waarop de modellen zijn gebaseerd dat individuen een bepaald nut ontleen aan groene ruimten, die kan worden afgeleid van hun keuzegegedrag en dus kan worden gemeten. In overeenstemming met dit conceptuele raamwerk, onderscheidt GRAS twee typen keuzegegedrag: non-temporeel en temporeel. De eerste verwijst naar een benadering waarbij groene ruimten worden geconceptualiseerd in termen van hun attributen en voorzieningen die een bepaald nut opleveren voor bepaalde socio-demografische segmenten van de bevolking. De resultaten bieden informatie over voorkeuren voor verschillende attributen van groene ruimten en lokatie en de effecten van deze voorkeuren op het gebruik van die groene ruimten. De laatste, ruimtelijk-temporele (op activiteiten gebaseerde) benadering is gebaseerd op een rijkere conceptualisatie in de zin dat naast voorkeuren van individuen voor bepaalde typen groene ruimten, ook de behoeften en wensen van individuen om andere activiteiten in ruimte en tijd te ondernemen in beschouwing worden genomen. Dit maakt het in de eerste plaats mogelijk om scenarios met betrekking tot de temporele planning te analyseren (veranderingen in tijdsbesteding, planning in een temporele context, etc.). Deze modellen zijn in staat om de relatie tussen groenvoorziening en – gebruik te verhelderen en te kwantificeren. Daarbij kunnen met deze modellen onderlinge afhankelijkheden tussen de planning, het ontwerpen en het onderhouden van elementen van de groene ruimte worden geïdentificeerd om zo de beslissingen op deze drie niveaus misschien niet volledig maar wel beter te integreren. Hierdoor kan het juiste portfolio van stedelijke parken worden gevonden en in de tijd worden gemonitord rekening houdend met de behoeften en wensen van de bevolking. De modellen van ruimtelijk keuzegegedrag die zijn ingebouwd in het systeem zijn allen state-of-the-art en hebben nog niet veel, als dat al het geval is, toepassing gevonden in recreatie en ontspanning-onderzoek.

Technisch gezien is GRAS een windowsapplicatie ontwikkeld met behulp van de Borland Cbuilder5 programmeertaal en een daarin ingebed

ActiveX control (MapObjects 2.0 voor Windows) om GIS functionaliteiten toe te voegen. We zijn begonnen aan de modellenkant waarbij de stedelijke modellen binnen het systeem vanaf scratch werden ontwikkeld in de C++ Builder 5 programmeer-omgeving en GIS functionaliteiten werden toegevoegd. Geïnspireerd door het technologische raamwerk voorgesteld door Sprague (1980), hebben we een benadering gevolgd waarbij “DSS tools” (programmeertaal, GIS ontwikkel toolkit) werden toegepast om het “specieke DSS” (GRAS) te ontwikkelen. Deze benadering voorkomt problemen ten aanzien van de overhead en beperkingen van standaard GIS pakketten. De voordelen zijn flexibiliteit en volledige integratie van GIS technologie, domein modellen, data en tools. We benadrukken nog eens dat het niet onze bedoeling was om technologische aspecten van ruimtelijke decision support systemen te verbeteren, hoewel we state-of-the-art technologieën hebben toegepast. De beoogde bijdrage van het systeem aan de state-of-the-art in de planning van groene ruimten is om een aantal domein modellen, data en tools bij elkaar te brengen en een objectief, recursief en interactief besluitvormingsproces te faciliteren.

Ten aanzien van de technische capaciteiten van het systeem kunnen we drie hoofdcomponenten identificeren in GRAS: het database management systeem (DBMS), het model base management systeem (MBMS) en het dialoog generatie en management systeem (DGMS). Het DBMS is een hybride samenstelling van de Borland Database Engine en de MapObjects ontwikkeltool. De volledige integratie van deze technologieën maakt het mogelijk dat het DBMS het hart vormt van het ruimtelijke en operationele informatiesysteem, omdat ruimtelijke en niet-ruimtelijke data van verschillende bronnen gemakkelijk gelijktijdig kunnen worden verwerkt met de juiste ruimtelijke interpolatie technieken. Het maakt ook communicatie en tussentijdse opslag tussen verschillende submodellen zonder tussenkomst van de gebruiker mogelijk.

Het Model Base Management Systeem bestaat uit zeven hoofdmodulen: Scenario Management, Bevolking Synthesizer, het Netwerk Model, de Ruimtelijke Component, de Ruimtelijk-Temporele Component, de Kosten Raming Spreadsheet en het Multicriteria Model. De *Ruimtelijke Component* bestaat uit een familie van discrete keuze modellen (met verschillende mate van complexiteit en gedragsrealisme) en bereikbaarheid prestatie-maten. Deze component bevat vijf modellen: 1) het Awareness model, 2) het Preferentie model, 3) het Trip Making Propensity model, 4) het Pressure model en 5) het Bereikbaarheidsmodel. Dit zijn statische (of ruimtelijke, non-temporele) modellen voor het voorspellen van individueel keuzegedrag en preferenties, die op hun beurt worden gebruikt om een aantal prestatie-indicatoren te berekenen die relevant worden geacht voor de planning, het ontwerpen en het onderhouden van stedelijk groen.

Bereikbaarheidsindicatoren kunnen worden berekend op basis van negen verschillende bereikbaarheidsmaten. De *Ruimtelijk-temporele Component*, bestaande uit het micro-simulatie model genaamd Aurora (Joh et al. 2004) is bedoeld om een alternatief te bieden voor het statische (non-temporele) karakter van de ruimtelijke modellen. In principe, beschrijft dit model de keuzes van individuen met betrekking tot welke activiteiten uitgevoerd worden (activiteitendeelname keuze), waar (locatie- of bestemmingskeuze), wanneer (timing keuze), voor hoe lang (duur keuze) en welk vervoermiddel wordt gebruikt.

De verschillende bovengenoemde domein modellen zijn geïmplementeerd en geïntegreerd in een gemeenschappelijke, GIS-gebaseerde omgeving. Dit maakt dat het systeem een krachtige tool is om beslissers te ondersteunen in alle fasen van het beslisproces, dus van de identificatie van het probleem en de definitie van (meerdere) doelstelling(en), tot het toestaan van gebruikers om alternatieve scenarios te formuleren en het inschatten/vergelijken van alternatieven. Het systeem gebruikt het conceptuele model dat is voorgesteld door Mintzberg et al. (1976) om de relaties tussen systeem elementen weer te geven en het beslisproces te structureren. Merk echter wel op dat het systeem een generiek proces biedt om beslissers te begeleiden zonder dat een vaste structuur wordt opgedrongen door interne afhankelijkheden tussen modellen en tools tijdens het beslisproces. Dit betekent dat gebruikers in staat zijn om modellen te draaien en tools te gebruiken (bijv. Thematische kaarten, query, etc.) op elk moment in het beslisproces wanneer zij dat willen. GRAS is in hoge mate interactief en heeft een gebruikers-gestuurd interface. Veel modellen vereisen van gebruikers dat zij hun eigen kennis en beoordelingen inbrengen om verschillende beslistypen (beslisnivaus) te evalueren, wat de flexibiliteit en bruikbaarheid van het systeem vergroot. In die zin is het systeem flexibel genoeg om beslissers met verschillende cognitieve stijlen te ondersteunen.

GRAS is sterk afhankelijk van data. Ruimtelijke en niet-ruimtelijke data afkomstig uit interne en/of externe bronnen zijn vereist voor het beschrijven van het studiegebied (ruimtelijke representatie) en voor modelschatting. Het stedelijk systeem is weergegeven in de vorm van een grid (wat we hier cel-gebaseerd management systeem noemen). Veel verschillende ruimtelijke elementen in dit stedelijk systeem zijn relevant voor GRAS modellen. Dat zijn:

1. Landgebruik;
2. Postcode adressen;
3. Wegennetwerk;
4. Zone systeem;
5. Groenvoorzieningen;
6. Werkgelegenheid.

Vandaar dat ruimtelijk aggregate data de bovenopgesomde sybsystemen vormen en moeten worden omgezet in een enkele ruimtelijke bron gedefinieerd als cellen van 100 x 100 meter. Hoewel de celgrootte willekeurig is en gemakkelijk kan worden veranderd door de gebruiker, werd de 100 x 100 meter cel resolutie experimenteel aangenomen als de optimale omvang gegeven geheugenbeperkingen en rekensnelheid van PC technologie en modelgevoeligheid en –nauwkeurigheid.

Een juiste operationele instelling van de modellen in het systeem vereist dat twee sets van parameters geschat moeten worden op basis van empirische gegevens. Een eerste set van parameters is betrokken bij de schatting van statische modellen en de tweede set bij de schatting van de ruimtelijk-temporele component. Dit onderzoeksproject dekt de parameterschatting van alleen de statische modellen af. De schatting van het ruimtelijk-temporeel model, Aurora, wordt overgelaten voor toekomstig onderzoek. In de tussentijd zijn de parameters handmatig gecalibreerd op basis van gegevens van een steekproef van de bevolking van Eindhoven en expert kennis.

GRAS is toegepast in een case studie en aannames ten aanzien van de relaties tussen systeemcomponenten en functionele vereisten zijn getest en gevalideerd. We beargumenteren dat deze illustratie laat zien dat GRAS met succes beantwoordt aan de doelstellingen van dit onderzoeksproject. Ten eerste, een *effectief* ruimtelijk decision support systeem voor planning, het ontwerpen en het onderhouden van groene ruimten is voorgesteld, ontwikkeld en toegepast. Op basis van Geoffrin's (1987) argumenten, zijn er vier factoren die maken dat GRAS een effectieve tool is. Het eerste is dat het systeem een gemeenschappelijke filosofische benadering verbindt aan het beslisproces, gebruikmakend van theorieën van menselijk gedrag. Hiermee wordt meervoudige probleemrepresentatie voorkomen. Merk op dat probleemrepresentatie niets te maken heeft met beslisstrategie. Met andere woorden, GRAS verbindt niet alleen een filosofische benadering aan het beslisproces, maar erkent ook dat verschillende mensen, wanneer ze worden geconfronteerd met een beslisprobleem, verschillende beslisstrategieën zullen volgen; ze zullen verschillende waarden toekennen aan variabelen en relaties en ze zullen informatie op verschillende manieren selecteren en gebruiken. Vandaar dat de verscheidenheid aan tools en modellen, die vereisen dat gebruikers hun eigen kennis en beoordelingen toevoegen als parameters of modelinstellingen, is bedoeld om de interpersoonlijke verschillen in waarden en cognitieve stijlen een plaats te geven. Ten tweede, om rekening te houden met zulke cognitieve verschillen, is een complete reeks van state-of-the-art analytische domein modellen (van statisch tot dynamisch georiënteerd) ingebed in het raamwerk om beslissers te assisteren

in het verkennen en analyseren van het probleem vanuit verschillende perspectieven.

Ten derde, de geïntegreerde, GIS-gebaseerde systeemomgeving, die tools en modellen bevat, is opgebouwd om methodologische en technische ondersteuning te bieden aan beslissers en planners, zonder gespecialiseerde vaardigheden of kennis voor het voorspellen van ruimtelijk keuze gedrag te vereisen.

Ten vierde, GRAS is ontworpen om gebruikers tijdens alle fasen van het beslisproces te ondersteunen, dus van de identificatie van het probleem via de ontwikkeling van alternatieve oplossingen tot het selecteren van een oplossing.

Het is van belang om te benadrukken dat dit onderzoeksproject niet bedoeld is om een vernieuwende bijdrage te leveren aan de ontwikkeling en het ontwerp van decision support systemen. Er bestaan al veel studies die dat doen. Het is ook niet bedoeld om een geavanceerde technische behandeling van innovatieve modellen voor het oplossen van specifieke groenvoorzieningsmanagement problemen te zijn. Er is al veel vooruitgang geboekt met een breed bereik van theoretische problemen in stedelijke modelvorming. In plaats daarvan beschrijft dit project hoe methodologie, modellen en tools, die zijn ontwikkeld en geëvolueerd in de tijd op het gebied van stedelijke planning en informatie, kunnen worden gecombineerd op een innovatieve manier om te voorzien in een krachtig raamwerk voor het verkennen en extraheren van kwantitatieve prestatie-indicatoren voor een speciek stedelijke planningsprobleem: het groenvoorzieningsprobleem.

## **CURRICULUM VITAE**

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