Management of the Urban Environment
The DSS-maker's script
Christiane Böhner

VRIJE UNIVERSITEIT

MANAGEMENT OF THE URBAN ENVIRONMENT
THE DSS-MAKER'S SCRIPT

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. T. Sminia,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de faculteit der Economische Wetenschappen en Bedrijfskunde
op donderdag 12 september 2002 om 13.45 uur
in de aula van de universiteit,
De Boelelaan 1105

door
Christiane Böhner
geboren te Keulen

promotoren:	prof.dr. H.J. Scholten
	prof.dr. P. Nijkamp

Index

CHAPTER 5 A NOVEL APPROACH TO INTRODUCING THE DECISION-MAKERS TO THE DSS DEVELOPMENT PROCESS

CHAPTER 6 TEST 1 OF THE DSS-MAKER'S SCRIPT - MATADOR

CHAPTER 7 TEST 2 OF THE DSS-MAKER'S SCRIPT – UTOPIA

CHAPTER 8 LESSONS LEARNED AND NEEDS FOR FURTHER INVESTIGATION

"Because you do not live of the things,
but of the sense of these things"
Antoine de Saint-Exupéry

PREFACE

In 1997 I was offered the opportunity to initiate my first original DSS application design within an EC-funded research project. Thanks to the DESIA team at the Joint Research Centre (JRC), Ispra, I always had an experienced team to consult. Thanks are especially due to Donald Bain, who answered my questions about urban transportation and was always available to answer all kinds of technical and administrative questions even after I left the JRC; without his support and continuous encouragement I would probably never have finished this work. Thanks are due, as well, to the technical and practical support of Massimo Paruccini and his unlimited connections, to Marina Mattarelli, Francesco Mazzeo, Angela Perreira and Silvio Funtovicz for their stimulating comments, and to Lia Trovelli and Pamela Guiduzzi for their programming support. I'm also grateful to Nuria Castells for providing a good example by finishing her thesis and to Karen Fabbri for continuously providing me (as I did her) with the motivation to continue.

My background in information technology development, urban planning and transport system analysis seemed adequate for me to develop an application, to be used by urban managers, which would assist in an analysis of the consequences of introducing of alternative means of transport. I thus started searching for DSS applications and their implementation methods. I also began trying to understand what the tool would be used for and what the user was accustomed to working with. The result was astonishing: the presumed users stated that they did not need this kind of tool at all!

Thanks to those who continuously supported me, especially Prof. Maria Antonietta Esposito of the University of Florence, I did not give up at this stage. As an urban planner, she was able to assist me in resolving this dilemma from a very practical point of view, enabling me to find out who wanted the system and who paid for its development. I thus discovered a figure not described in the literature: the client. This client was not the end-user of the tool. He, however, was the one who noticed a barrier within the process of introducing alternative means of transportation in European cities, which he presumed was due to the difficulty of understanding the technical and non-technical aspects of these technologies. Thus the client had a clearly defined goal on a strategic level, which was to be implemented within a political setting by the presumed end-user. The client would contract an external team to develop a multi-criteria evaluation tool to support the end-user with this new task.

This meant that as a DSS designer, I not only needed to design a tool, but also needed to convince the end-user of its ability to represent that user's decision environment in order to facilitate the decision-making process. In this case, the major difficulty lay in training the user to provide input to the system and, ultimately, to use it. This was made possible only through an understanding of the user's background and decision-making process and through teaching the user about the capabilities of the methods and tools at hand within the process: the user had to understand his role in the development process.

The practical need for the development of an application was the basic idea that gave rise to this thesis. I was tirelessly supported in my determination to find a solution by Professors Peter Nijkamp and Henk Scholten of the VU in Amsterdam.

There have been many moments when I've wished that I had never started this project, or when pressure from the loneliness that comes along with doing research discouraged me almost to the point of giving up. But I always found support and encouragement to continue, as I did when I left the JRC to go back to Germany to follow my private interests, and my new colleagues there offered me the opportunity to use the equipment in our workplace to finish the thesis. Then even more strongly, when I started my new job as (personal referent) to the chair of transportation at the German Aerospace Centre, my boss, Prof. Jürgen Blum, never failed to emphasise the importance of completing my thesis and my colleague, Andrea Kuhn, was always available to help out when I needed time for writing.

A very special thanks for all those years goes to my family, who have always accepted the lack of time available for them and who always were patient and at my side during the more difficult periods. During this time I found the strongest support I could ever have wished for, from the one who was always there to give me a good word and a reason for going on, my best friend and partner, Till Rümenapp.

CHAPTER 1 Urban environmental management - Introduction

1.1 INTRODUCTION

Many decision support tools have been developed during the last decades with high economic and intellectual effort. They have been implemented within different application environments, such as e.g. the European urban environmental management. Asking European urban managers for the utility within their personal application fields the practical use of these tools is often considered as scarce. But who wanted the tools and paid for their development and why do they not support the user's needs?

Decision theory usually concentrates on the definition of the decision process and a specific user to be supported. But does the definition of the decision process to be supported always correspond to the decision process followed by the final user? The author of this thesis found out, that the decision process defined through the user profile and analysis often is not the only indication for the development of the final tool, but that an actor not described in literature heavily impacts on the decision process as supported by the tool. The author calls this figure: the client, who does not correspond to the presumed end user. This client is no direct user, but has a specific interest or in making the process transparent or simply in supporting the decision-maker. Thus the client has a clearly defined goal at a strategic level, to be implemented by the presumed end-user on an operational level.

The client provides the funding for the decision tool development and impacts thus on the development process. If this actor is not described in decision theory and not even in practical instructions for the technical development of decision support systems (DSS), are there other actors impacting on the final tool? What are the dynamics of DSS development and how may a tool be developed as support to the final user while serving the client?

To support the user while being conscious of the client's requirements and translating the needs of both into a useful tool asks for a continuous dialogue and interactive process between the technical developers, the user(s) and the client. I.e. the different actors within DSS development have to form a team, conscious about the role and requirements of each other actor, the proper role, opportunities and duties and the process and modes of interaction during the tool development. The co-ordinator of the DSS developing process thus gains a very complex role.

Even though a lack of user acceptance within the DSS implementation methods has often been remarked in literature, the roles of actors have been described especially for the decision process itself. No integrated approach has been proposed instead to lead a DSS designer or a DSS developing team through the process of understanding each others role's within the tool development process.

1.2 DSS IN EUROPEAN URBAN ENVIRONMENTAL MANAGEMENT

The question of urban sustainability becomes more and more pressing regarding the scarcity of urban environmental resources such as ground, air, water etc. The change of life-style brought the available structures to their saturation, even though all European regions differ in their cultural aspects and thus may require different approaches. The traditional manners of urban management cannot face these effects, as they interpret each sub-system of the city by its own. Such as the built environment, the economic system, the social system etc. The first indicators of unsustainable urban growth belong in large part to the ecologic system, but they are caused by the effects of other aspects, e.g. the transport system, the built environment and the social system. I.e. an integrated analysis of the different sub-systems of the city is needed to reach a sustainable balance for urban development. For this integrated approach new tools are required supporting the decision-maker with the integration of multi-disciplinary aspects of the evaluation process.

The introduction of multi-criteria decision-support systems (DSS) appeared as useful approaching this situation, as they permit the introduction of multiple interdisciplinary evaluation criteria and the description of complex decision environments. An initial wave of application developments started in the United States and conquered Europe at the end of the 80s. Unfortunately many of the developed approaches finished, after a first enthusiasm, most decision-makers went back to use their traditional tools consulting from time to time disciplinary experts to gain a more inter-disciplinary view.

But why have these tools been developed though? Who were the clients funding the specific tools? Only in a few cases the presumed DSS users have been identical with the clients. Most of the time there have been other clients e.g. regional, national and international governments aiming at a more transparent integrated approach for urban environmental management, which might support them with their more strategic goals in environmental policy; parties representing a stream of interest within the population as the interest for the urban ecology or the price for immobiles etc. I.e. the client did not correspond to the decision-maker and final user.

Trying to introduce a new approach and thus trying to develop a procedure for tailoring the tool on the requirements of the user has thus to face a scepticism on the one hand due to the typical barriers to the introduction of new instruments and technologies into a traditional working environment, on the other hand very negative experiences made during the last decades with the introduction of software tools which did not respond to the operators practical needs or technical background.

In literature this problem is called the "lack of user-orientation" [Sprague, Watson 1989] within application development. Two different paths have been followed to face this problem:

1) Human interfaces have been proposed between tool and user: the tool operators or consultants;

2) User assessment and other phases of direct user-developer interaction have been introduced. This way the tool development becomes a try-and-error process with user-testing phases at all major DSS development stages.

The first path faces the problem of tool complexity and the user's background in using such a tool. The intensified use of digital interfaces in every day's office life makes the use of such tools more familiar to the user and thus this barrier is expected to vanish in future.

The second path introduces the user to tool development at single moments, without defining the exact role of the user within these steps and without defining the rules of interaction between the different actors involved in the tool development.

1.3 RESEARCH QUESTIONS TO BE ANSWERED

This thesis aims at improving the application of decision support systems and their usefulness to the decision processes in European urban environmental management through the development of a structured method for introducing all actors involved in the DSS development process to their proper parts and responsibilities and the rules of interaction with the other users towards understanding their different impacts and allowing the development of a tool corresponding to the designated user's needs.

To develop a structured methodological approach to meet the user needs and expectations in terms of tools to support their decision process, a sequence of structured and logically linked questions have been answered. The first question is:

> *How can DSS utility and use for decisions in European cities be increased?*

This thesis aims at answering this question through introducing all actors in DSS funding, development and use into the DSS development process right from the beginning.

Until now the different roles within the development process, apart from the software designers and developers, have not been defined into detail and thus the actors where not conscious of their responsibilities. Therefor the second question will be:

> *What instrument can support the actors in formulating what they expect the DSS to support?*

To develop and use any common instrument for DSS technical developers and actors in the decision process an answer to two more questions will be approached:

> *How can DSS technical developers better understand the needs of actors in European urban environmental management?*

and

> *How can European urban environmental managers understand the services that could be provided by decision support methods and instruments?*

Once the actors understand each others background and the available tools and methodologies a final question is answered:

> *What could support the actors during the developing process?*

I.e. to structure the interactive workflow of the tool development process.

The structured approach to answering these questions is introduced in the following paragraph and developed throughout the thesis document.

1.4 NOVEL APPROACH TO USER-ORIENTED DSS DEVELOPMENT: THE DSS MAKER'S SCRIPT

The novel approach to user-oriented DSS development proposed in this thesis consists of a support to the understanding of the different roles within the development process and a step-by-step guide for the DSS developing actors to the final tool implementation. It thus intents to improve the final tools through focusing on the impact of the tool development process on the DSS solution produced. The structure follows the logic of improvisation role-plays indicating the actors' profile, the given methods and requisites, specific milestones and a final common goal. The DSS designer assumes the role of the director and the single roles are performed through improvisation by the actors, i.e. the use of the requisites and the form of the final output depends on the performance of the actors. This thesis is thus based on the recognition, that the specific DSS implementation and its use strongly depends not only on the methods and techniques implemented, but on the development process and the role the final user(s) and customers assume. This first approach to human factor analysis in the DSS development process impacting the final DSS has been called the "DSS maker's script".

This approach focuses on European urban environmental management, because it represents a very complex environment where multi-disciplinary approaches are required to guaranty a sustainable management for the future and interdisciplinary management tools are still rare.

The DSS maker's script starts with introducing the participating parties to the special areas of expertise of all actors involved, i.e. :

- the introduction of the actors in European urban environmental management to decision theory and the related information technology;
- the introduction of the software tool developers to the roles and disciplines of actors in European urban environmental management.

After this a framework for the interaction rules and the DSS project development process is sketched. This part introduces the profiles and methodologies described before into proper roles within the DSS development process. The script has been checked step-by-step against two DSS case study implementations in the field of European urban environmental management.

An additional novelty of the thesis lies with the possibility of a double use:

1) The thesis text supports the reader with understanding each others backgrounds and introduces the DSS maker's script as a novel approach to support DSS development processes.
2) The attached CD presents the methodology using the chapters introducing the cultural background of the actors and the case study interface samples as an interactive demonstrator of the processes described.

The European urban environmental manager has been presented as the DSS user to develop the script, thus the city and its environment have supported the analysis of specific complex problems and the development of suiting applications through specific actor profiles. The resulting DSS maker's script instead might be transferable as well to other evaluation backgrounds through the detailed analysis of the single actors and the decision spaces involved. The approach itself, i.e. the definition of the steps for the profiling and preparation of the different actors within the DSS development process, the workplan definition and the DSS implementation might be used as well for other evaluation processes. How portable they are would have to be proved through further studies.

1.5 THESIS STRUCTURE

The DSS maker's script aims at preparing the different actors to their part within the DSS development process. Therefore the technical preparation for the methodology of the script is introduced through two binaries of technical introduction: The introduction to the real world of the decision-maker is meant for the technical tool developers, who's background instead is introduced to the decision-makers.

These two souls of the acting group are at the basis of an initial conflict in understanding. The DSS maker's script presents a solution to this conflict introducing the actors to their own parts and the role and cultural background of each other actor, to their rules of interaction and the framework structure of a DSS development process. As a proof of concept during the script composition two application cases have been developed. Their implementation steps are reported after the description of the methodology to serve as illustration for the process of a DSS maker's script implementation. I.e. first the actors learn about each other's background, than about their roles within the DSS development process, about the steps of the process itself and the way of translating their requirements into a tool. After this two application cases illustrate the process of putting theory into practice.

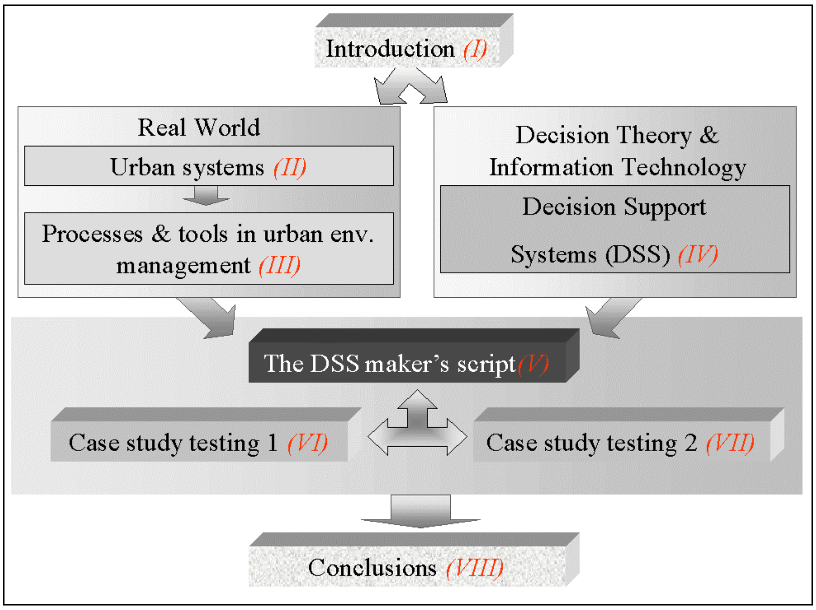


Figure 1.1: Thesis structure

The following paragraph summarises the specific contents of the single chapters within the framework described above and sketched in figure 1.1:

Chapter 5 is the core chapter including the role assignment and the framework of the development process. All other chapters are sources of information focusing on the understanding and development of this core chapter.

Chapter 2 and 3 introduce the decision theory or software specialist to a selected number of disciplinary approaches, models of the city (II) and tools (III) in decision making within the current real world situation of European urban environmental management. This introduction to *who* acts and reacts *how* with *what* and *whom* within the European city, i.e. to the complexity in decisions within this space aims at inducing the experts in decision theory and software development to the background of the users, clients and other stakeholders of the decision and tool development process. These experts are responsible for the translation of the user's needs for support to DSS functionalities, therefore they need to understand the DSS user's view of the problem to solve and its context, to create a corresponding model within the digital projection of the user's "Image" of the real world represented within the DSS and to create an interface able to gather the user's questions and to produce the desired type of response. I.e. chapters 2 and 3 aim at tuning the technical tool developers on the user's *language* and *imaginary* model of the real *world*.

On the other hand the experts in European urban environmental management, i.e. the clients and users asking for tools to support their decision-making process need to formulate *what* they need to represent *how* to answer *which* questions. I.e. they need to gain a general feeling for how decision processes can be modelled and/or supported by methods and tools and where their responsibilities within the decision process are, i.e. how tools can support the process without replacing the decision-maker. To be able to choose the type(s) of support desired a general introduction to the theory of decision-making in complex environments and the methods and information technology developed to support it (chapter 4) are provided on the basis of selected sets of examples.

After introducing the actors reciprocally to the other's field of expertise each actor the DSS developing process is described to allow the different experts to understand the proper role within the process. After this the reader is lead through a framework of the DSS development process from the problem and goal definition through the development workplan, the software development to the testing and implementation phases.

The DSS maker's script has been developed on the basis of the parallel development of two application cases, which are reported in chapters 6 and 7. These cases are reported after the script. They represent an illustration of each step of the DSS maker's script, thus, they have served for the fine-tuning of the script, and they also serve for the understanding of the script implementation. The lessons learned within these applications are reported as loops to the script.

A verification of the thesis' goals, a summary of the lessons learned and an outlook of which lessons have still to be learned concludes the work (*9*).

The structure thus introduces first the multidisciplinary theoretical background and the methods and tools for simulation and decision support (chapters 2 to 4) to introduce a methodology for the design and implementation of a tool based on the merging of the competencies of all actors involved (chapter 5). This methodology is tested against a set of case studies starting with a rather linear application case (6) and concluding with a more complex situation (chapter 7). The complete approach represents the DSS-maker's script.

The two case studies reported have been considered as particularly indicated for the aims of this thesis, because:

1) they represent first a more linear problem case application and after this a rather complex situation both on the same general question of the introduction of alternative propulsion systems to European urban transports. This permitted the development of the general structure of the tool following a clear structure defined for the simple case application and refining of the method on the complex case;
2) The role of the author of this thesis within both project developments was that of the DSS designer and prototype developer of the technical interface concept. The final digital implementation has been worked out by a programmer (toolsmith), whereas the end-user profile analysis, the model implementation and the data

capture and generation have been due to other members of the project development team. Possible end-users were represented within the project group and thus have contributed to the tool development and given direct feedback on the methodology developed.

1.6 GUIDELINE FOR THE READERSHIP

The paper version of this thesis serves as a first introduction to the process of DSS development for European urban environmental management, it is meant to prepare the actors in DSS development for their role in the development process. A digital version of the document is contained on the attached CD-ROM. This version is meant as on-line script for the different roles and steps within the DSS development process, thus a script for the DSS makers. In this digital version chapter 5 represents the guide itself, chapter 6 and 7 are used as illustrations to the single steps and possible occurring problems and chapters 2 to 5 are used as illustrations to the different parts of the decision space to be modelled within the DSS application, a kind of toolbox.

The DSS maker's script should be used in three phases:

1. all actors read the book to understand the roles and the rules and steps of interaction within the DSS development;
2. the roles within the DSS application development are assigned to specific persons and thus the proper responsibilities are studied into detail through chapter 5 ;
3. the digital version of chapter 5 is used as on-line support for the DSS development using the rest of the book as toolbox.

This is the key for reading the following chapters. The actors, tools and methods described in chapters 2 to 4 represent a selected set of elements of the European urban environment and the tools applied and developed for decision-making. They are meant to introduce to the complexity of problem solving in this environment and the multitude of tools and approaches, but do not aim at representing a complete glossary of tools.

CHAPTER 2 Urban systems

2.1 INTRODUCTION

This chapter introduces the concept of "Urban Environmental Management", which leads to different approaches to representing the European urban environment as a system. This type of modelling approach has been used within a number of disciplines involved in urban environmental management and is employed here as a means to better understand the different disciplinary backgrounds of its actors. The second part of this chapter introduces multi-disciplinary approaches to an integrated analysis and simulation of the urban environment as a complex system. This perspective on multi-disciplinary planning and decision-making is required in order to design a consistent set of criteria for evaluation within urban environmental problem solving as proposed in chapter 5.

More than 80% of the residents of Europe live in urban areas. But what are cities and how do they work? All existing approaches to this problem describe urban systems as complex and are constrained by the limits of their disciplines in their approach to describing these systems. This seems to have arisen suddenly: why hasn't this question been addressed earlier? All these questions arise during the observation of problems in urban areas and during spirited discussions about how to solve them. This thesis tries to illustrate some of the basic dynamics of the urban system in order to enable actors to understand the elements to be considered within their specific problem analyses and to understand the possible methodologies that can be used to describe these elements and their interaction.

The urban system is composed of three functional parts: the physical form, the organisational structure and the system dynamics. The urban form, at a specific instant in time, is the result of the efforts of the organisational structure to direct the system dynamics towards specific goals, defined on the basis of a pre-existent physical form. Thus changes in the urban form follow impulses generated at the organisational level, which are intended to produce a certain trend in system dynamics. Traditionally, the three functional parts are analysed within several distinct research disciplines. System dynamics are analysed in economics and, in relation to human behaviour, in the social sciences; the organisational level is at the focus of political science, law and the social sciences. The physical level is a subject for environmental and civil engineering and for architecture.

Real difficulties arise in describing and analysing the interaction between functional parts of the system. System dynamics may be analysed by observing their physical aspects, e.g. mobility is analysed through observation of the transportation network. System dynamics may require, for example, the transportation of goods and actors from one point to another at a certain time. The physical system permits certain modes of transport and transit paths at specific speeds. The importance assigned to system dynamics and to the physical environment by the organisational level influences the measures taken that favour certain specific transport modes and routes. A route through a public park may be the shortest one. This may be the solution adopted in a case where the park has been abandoned or where the system dynamics grant much importance to that organisation, e.g. it is the emergency road to the main factory situated in a small town. On the other hand, a route that makes a less violent impact on the existing urban context may be chosen in order to avoid a chain of events which also impacts the surrounding neighbourhood. The organisational level sets boundary conditions for both the physical environment and system dynamics, trying to achieve the best possible compromise as a solution for all stakeholders concerned, according to specific goals.

This chapter starts with descriptions of the urban system that are typical of the different disciplines involved in urban systems research in order to consider the role of the system in individual and social life as well as to consider the dynamics explained by different disciplines. The descriptions from different disciplines illustrate the cultural and methodological background of the actors in the DSS development process and thus they serve as input in the assignment of the actors' parts in chapter 5.

After this, existing integrated approaches are described and, finally, a hyper-linguistic scheme of possible logical integration of the different approaches is proposed.

For a better understanding of the logic of this chapter, see figure 2.1, which shows its structure.

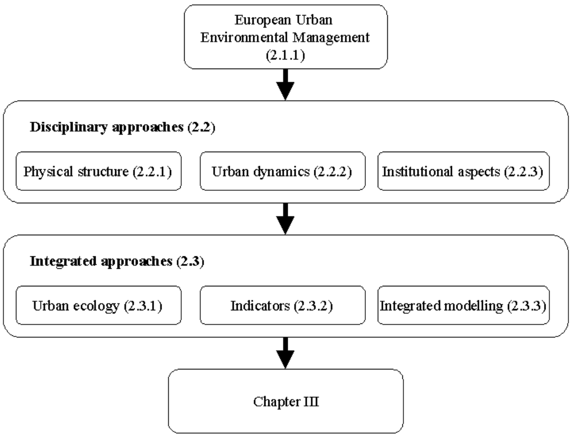


Figure 2.1: Chapter 2 logical structure

2.1.1 European urban environmental management

Before describing different approaches to urban system analysis, this paper defines the related subject of "urban environmental management". What is urban environmental management?

The expression is composed of the following terms [Academic Press Dictionary of Science and Technology, on-line version, active in 2002]:

Urban:	Within this thesis "urban" means the context of the densely populated man-made physical and social structures called cities or metropolitan areas. Many definitions have been given to describe the urban context; some of these are presented in chapter 2.
Environment:	biologically: "The specific surroundings necessary for the survival of a species, which is observed as a *recognised world* (the whole of its characteristics) and which influences the behaviour of the members of the species as an *action world* (the whole of its interactions). The human being is the only being not dependant on a specific environment." culturally: "The human habitat, which has been adapted to the specific living requirements of the human being ..."

Management: "Leadership and guidance of business and other social systems. Management incorporates leadership functions and indicates activities including company/institutional politics such as planning, strategic decision-making, the implementation of these decisions through delegation and the control of the implementation process."

Within this thesis, *Urban Environment* defines the city as a multi-functional complex system composed of interacting sub-systems. *Urban Environmental Management* is thus leadership within the evolving processes of this system. *Urban Environmental Management* is not the task of one single actor, but of different actors, groups and their interactions. To reduce conflicts and tensions within the system, the actions of those responsible have to be co-ordinated. The different groups involved must compromise in choosing final goals that favour the functionality of the whole system. The introduction of DSS is intended to enable such compromises to be found.

2.2 DISCIPLINARY APPROACHES

This chapter tries to offer an overview of the basic disciplinary approaches to defining and analysing urban systems in order to understand how they work and what they represent to their individual inhabitants. This comprehensive view of the approaches from different disciplines is necessary to model the interactions of the actors in the DSS development process as it is described in chapter 5.

2.2.1 Physical structure

2.2.1.1 Urban geography

Geography models space, defining a reference system for physical objects and surfaces based on their geometric location in relation to the origin of the system through a set of co-ordinates. The geographic concept of the city describes the physical occupation of the urban soil. The geographic concept of the city structures the densely built urban ground into areas of homogenous land use. It takes into account physical aspects of the surface as well as the structures upon it, assigning specific importance to areas or individual locations. Man-made structures are considered elements of the landscape and are modelled as distinct types of land use, usually in a two-dimensional cartographic representation, but sometimes with an additional indication of the how far the areas extend in height (2 ½ dimensions). Specific symbols are used for development and for linear networks, depending on their impact on the surrounding tissue.

The city may be modelled in different ways, depending on the scale of what is being considered. A map of the world represents London as a point, but its urban dynamics may, for example, be analysed in terms of the climatic area. A national map may represent Greater London as a surface displaying high building density or showing the administrative borders of the city, depending on the specific subject that is being represented. It may also continue to represent the city as a point, for example, in order to represent international railroad connections. The geographic model is thus a thematic representation of certain elements of the urban system as they relate to a specific aim that it attempts to communicate. In more detailed urban geographic representations spatial objects may be modelled as linear or polygonal objects or the total area of the city could be divided into cells, each of which is would be characterised by primary land usage. Geographic models might compare sets describing land use in the spatial units, as observed during different periods of time. Sources of information in urban geography include existing cartography, remote-sensing imagery and direct ground measurement.

From a geographic point of view, the history of European urban evolution started with the concentration of dwellings into small villages and the growth of a resulting distinction between development, open space and paths of communication. The agglomerations later grew, within structural frameworks that were more or less regular, related to their need for defence and their geographic limits, such as riverbeds, coastlines, mountain slopes, etc. Defensive boundaries were drawn around the nucleus of the city. Once the space within the walls had been filled, the building density increased and extensions were built around the walls. Wealthy towns built secondary defences around these extensions, producing a repetition of the process that has been documented at different moments in time.

After the 15th century, when administrative structures became more stable, the defensive character of the town was abandoned and the former defences were broken down. They are often still recognisable within the urban environment as open spaces, the "belt(s)" used as the transport arteries or the green area around the ancient centre. The elimination of the need for defence reduced the original requirements for organised patterns of urban growth to the rules dictated by the local natural geography and by man-made structures consisting of the historic urban agglomeration and the transport network, which began to receive growing attention. The urban patterns that followed the newly integrated path of the railroad demonstrate this impressively: the railroad stations became important centres of communication, commerce and modal shift and the railroad itself represented a new type of geographic barrier, similar to the natural barriers influencing the growth of the city. Centres of production and railway stations rose almost contemporaneously, causing the development of urban satellites in direct communication initially by way of the railroad, and afterwards via road-network and motorway connections. These satellites originally consisted of more or less organised dwelling blocks extended later on with the addition of service structures.

By the 1960s the city had begun to resemble an octopus with polyps on its legs: the city centre continued growing diffusely with satellite agglomerations attached to the transport arteries. Close to the satellite agglomerations and to the city borders, large areas had been allocated for industrial use, followed by an extension of the transport and communication networks. The increasing demand for housing was met by assigning specific areas for the construction of high-density dwelling satellites, not always equipped with service and recreational areas. This growth pattern produced clearly defined geographic clusters in the urban land use. Industrial areas were well distinguished from residential areas, services and recreational areas. The density of construction was variable and did not correspond to the texture of the historical city.

Based on the historic development pattern described above, the geographic character of the European city can be represented by a geometrically compact historic centre, with spider-like extensions along the road-network and more highly concentrated agglomerations around transport nodes and important centres of production. The compactly built areas in the extensions are divided into geometric zones designed for particular activities (production, services, recreation, dwellings) with no apparent relation to the surroundings. Even though the historic centre may have been destroyed, and a new town may have arisen, built upon the ruins of the Second World War, the general structure derived from a central agglomeration and expanded during the 1960s remains the same.

2.2.1.2 The demographic concept of the urban system

Models of demographic migration generally analyse the movement of individuals from one well-defined geographic area to another over certain periods of time or sequences of time periods, usually corresponding to the official census. The geographic units taken into account are chosen according to the scope of the analysis and the composition of the available information, which, in general, depends on the national definition of which demographic elements make up the urban municipality. The models treat the geographic boundary areas as containers for a certain number of inhabitants and compare their numbers over different time periods, trying to determine tendencies and to analyse them on the basis of socio-economic information.

These types of migration models have been refined in attempts to achieve “continuous” representations of the geographic areas by interpolating demographic information and visualising flows and time intervals, e.g. for periodical fluctuations such as that of the day/night population.

The demographic concept of the European city has not yet been standardised [Pumain et al. 1992]. Each member state defines statistical urban boundaries and elements of the urban texture based on some definition of population and building density or simply upon the assignation of the title “municipality” to an agglomeration of buildings. This makes it difficult to collect information for parallel studies on European cities and highlights the need for research that develops guidelines for the search and integration of information characteristic to common European urban problems.

Table 2.1 summarises the definitions of the demographic concepts of “municipality” and “urban population” in use within European member states in 1990 based on Pumains study for EUROSTAT.

Member State	**Urban Municipalities**	**Population or basic built-up area**		**Urban population**
		Inhabitants/ dwellings	Distance between buildings	
Belgium	All communes	Min. 200 inh.	Max. 50-100m	No definition
Denmark	No definition	Min. 100 inh.	Max. 200m	Population living in urban area

Spain	Urban zone: > 10.000 inhabitants; Intermediate zone: > 2000 and < 1000 inh.; Rural zone: < 2000 inh.	No definition		Population living in urban area
France	Population of the largest unit > 200 inh.	Min. 50 inh.	Max. 200m	Population residing in urban area
Greece	Urban zone: > 10.000 Semi-urban zone: 2000 < X < 10.000 inh.; Rural zone: < 2000	No indication	Max. 200m	Population resident in urban area
Ireland	Dublin, Cork, and aggregated towns with nucleus > 1500 inh.	Min. 50 occupied dwellings; Min. 20 dwellings along a road	Max. 200m;	Population of Aggregated Towns
Italy	> 10.000 inh.	"Kadastre" defined as composed building blocks *		Population resident in urban area
Luxembourg	> 10.000 inh.; Nucleus > 4.000 inh.; Pop. density ca. 700/sq km; - Less than 1.5% of pop. dependent on agriculture	No definition		Population resident in communes with more than 2000 inhabitants
Netherlands	- Density of pop. in built-up area min. 2000/sq km and min. 300/sq km in total territory; - Min. 70% of pop. in built-up area; - Less than 10% of active pop. dependent on agriculture - Urban services	No definition		Population resident in urban area
Portugal	No definition	Area identified by municipality		No definition
Germany (before 1990)	Legal status "Stadt"	No definition		Population of Staedte

United Kingdom - England and Wales	- Urban land min. 20 ha; - > 1000 inh. - Min. 4 Innumeration Districts (more than 50% inh. live on urban land)	Urban Land - permanent structures - public highways - transport infrastructure		Population living in urban areas
		Min. 1000 inh.	Max. 50 m	
United Kingdom – Scotland	No definition	No definition		Population in localities with > 1000 inh.

Table 2.1: Demographic concepts of "Urban Municipality" and "Urban Population" in Europe, 1990 (* addition to EUROSTAT study)

The differences between the definitions of these areas demonstrate the problem: it is necessary to define common models that are valid for the whole of Europe. The differences also serve as an example of the difficulties that arise within a single discipline and illustrate the situation that is to be improved upon through the development of inter-disciplinary approaches.

The demographic concept of the urban system is the system of geographic boundaries that identify areas of the city characterised during specific time periods by a certain population density. Urban dynamics are thus analysed as the change of the population density within these areas over time and the related flow of population from one area to another. Demographic migration simulations are at the basis of many economic models and studies as indicators of consumer behaviour and demand for transport.

2.2.1.3 Urban architecture

Architecture uses two different approaches to study the urban system: historical analysis and analysis of the current system for the development of an architectural project. Historical analysis generally describes changes in urban form that integrate aspects of the natural characteristics of the site, with aspects of socio-political and art history. Descriptions of local and general plans for the city, imagined or implemented in the relevant time-periods, are also integrated into historical analysis. The analysis often includes comparative studies that consider the impact of specific socio-economic events and decisions in urban management on the physical urban environment.

The architectural composition of the urban environment is a result of attempts to reflect the tendencies of socio-cultural evolution. Buildings were originally meant to offer shelter, but with time these shelters came to reflect the social structure of the groups that inhabited them. Grouping shelters together for defensive and productive purposes changed the social order; these changes were then reflected in architectural typology and in the definition of open spaces and physical manmade boundaries. In ancient Greek architecture the pronouncedly individual nature of each element was more important than the whole [Norberg-Schulz 1982]. The Roman tendency towards spatial integration is evident, but their system remained the sum of relatively independent sub-systems. Renaissance architecture produced a more Euclidean structure through the repetition of simple geometrical units related as a group to common geometric centres. Late baroque architecture attempted to create the illusion of dynamism by composing centres, directions and areas into spatially complex patterns. Modern architecture, with the help of new technologies, expands the composition of a continuous dynamic space into a physical composite of contiguous constructed elements that represent the directions, centres and areas of a dynamic structure. This progression shows the development of the urban system from an agglomeration of buildings to a composite dynamic structure. Along with a change in the focus of development, a focus on open spaces, as a physical expression of urban public life, evolved.

Historically the road has been a "micro-universe" that reflected the character of its neighbourhood. Tight angles and curves caused the road to be perceived on a human scale, and thus as an extension to the individual home, giving the illusion that together they formed a continuous square. These principles were applied until the 19th century, when sequences of uniform buildings of a continuous height became the prevailing trend. This change was related to a change in the use of the road from an intimate space for the neighbourhood to an avenue for public parades. This trend represented a clear expression of interest in focussing on the social aspects of urban life, from looking at facades to observing the circulation of traffic in the road. This circulation and its location, the road network, are at the focus of contemporary studies of urban dynamics. Concern for transport and mobility within the urban system has surpassed concern for the study of social contexts among urban planners.

The square was initially the most important element in urban public life. The square is a well-defined place that can be considered the possible destination of every type of movement within the city, a place of calm within the circulation. Important buildings in the square physically represent the focus of urban life. The original focus on individual buildings has gradually been shifted from this single element to a dynamic structure. The focus has shifted from a system of built elements, representing destinations, to a system of open elements, representing flows. In this system, the buildings are no longer considered points of orientation, but instead serve to underline the flow, so that much importance is assigned to elements that are not "in line". This philosophical outlook produces roads with walls at a uniform height, without facades; these direct the view to a specific focal point. Orientation is linked to this specific focus and to identifying it. Without it, the whole frame of reference is destroyed, leaving the individual confused, especially at nodes requiring a choice of direction, such as at road crossings. The focus of planning has thus been shifted from the static element of the square to the dynamic system of the road.

Urban architectural studies no longer consider only the static built environment, but also focus on the physical reference system in urban dynamics. Among the discipline's goals is analysis of the city as a whole, which was traditionally a subject of other disciplines. Recently, architectural approaches to the urban environment have tended to initiate projects with a detailed interdisciplinary analysis of the project site called "environmental planning" [Cetica 1994], so that architectural spaces in the urban environment are defined on the basis of an analysis of the functional needs and formal requirements to be fulfilled through implementation of the project. These approaches are based on acknowledging the need for an integrated approach, but usually employ a traditional approach to urban planning decision-processes, which is now supported with an interdisciplinary basic information set, used in a nonstructured subjective evaluation process. Today urban architectural studies concerns itself with re-qualifying previously identified parts of the urban texture: this demonstrates the difficulty of formulating goals for the development of a continuous physical reference system that would guide the individual in urban flows.

During the 1960s, two distinct theories of urban planning emerged that are still characteristic of the overall view of town planning today:

1. the 'system view' of the town, which essentially derives from a theory that views the *object* of town planning as a system of interconnected parts;
2. the 'rational process'view, which analyses the *process* of planning as a rational process of decision-making.

Both theories share the same conception of planning and control: the 'cybernetic' model of planning and politics, which is directly linked with systems theory and rational decision-making through the so-called 'science of cybernetics' [Taylor 1998].

The development of a global rather than a national economy that has been taking place since the end of the seventies has caused governments and town-planning authorities to have less general control over the planning processes. Many theorists have therefore turned away from 'grand theorising' about planning to more problem-centred approaches that focus mainly on five areas:

1. the economic decline of some urban areas and the development of theories concerned with urban economic regeneration;
2. planning to give equal opportunities to disadvantaged groups;
3. planning for environmentally sustainable development;
4. revived concern for the aesthetic quality of urban environments;
5. participatory planning according to the concerns of local democratic control.

2.2.1.4 Classical urban ecology

"Classical" urban ecology studies the biological aspects of the quality of life in the city. Related analyses model the urban natural environment mainly in terms of air quality, water supply and quality, soil quality, noise and biotopes. In the city individuals require a certain minimum standard of environmental quality, but pollution is continuously produced there, so that it is difficult to maintain this standard. Usually the "natural" circulation of a single object of analysis is considered as the basis of the model of the biological circle in a rural environment. This is adapted for the urban environment by adding the polluting factors measured within the city or expected to be produced by known sources. The difference between the continuous rate of change of the rural environment and the complexity of that of the urban environment requires some additional adaptation.

Quality of life problems have existed in all major societies, but have been taken into account as a serious argument for changing the goals of urban management only in specific contexts. The values and norms that have evolved within the socio-cultural system form the basis of the economic structure, but they also determine society's vision of the environment [Douven 1996]. The willingness of decision-makers to act because of environmental problems depends on the public perception of the importance of the ecological system and the desire to preserve it and prevent its degradation. Ecological values and norms change over time and between cultures, giving them a dynamic character. This is shown by the increasing public environmental awareness in recent decades and by the fact that policy plans nowadays pay more attention to environmental issues than they did in the past.

The sub-discipline of urban ecology that analyses urban climate considers the city "a disturbance of the physical and chemical consistence of the atmospheric boundary interval" that "causes climactic change in comparison to its undeveloped surroundings". [Freyer 1996] In other words, the city is regarded in terms of its negative impact on nature.

2.2.2 Urban dynamics

Urban dynamics are the interactions between the structural elements of the urban system. Although different approaches to the description and analysis of these interactions exist, this thesis addresses exclusively those employed in the disciplinary fields that need to model the dynamics of the urban system most often: sociology and economic research. These contribute to the cultural background of the actors involved in the case studies developed in chapters 6 and 7.

2.2.2.1 Urban sociology

Urban systems are man-made structures that make up a human habitat according to the traditions of the society that inhabits them. In order to understand urban dynamics, sociological research analyses the expectations of individuals in relation to the urban structure, the way the individual inhabitants band together to form a social structure and how this social structure is related to the physical structure of the town.

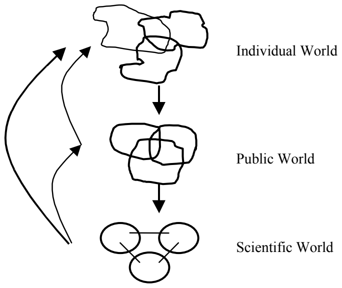


Figure 2.2: Process of defining complex concepts.

Human interaction is structured at three levels of generalisation: The "individual world", the "public world" and the "scientific world" [Norberg-Schulz 1982]. The "individual world" refers to individual experiences that follow similar patterns and that derive lessons as relatively fuzzy descriptions of concepts or "objects" perceived relatively indistinctly unless a specific object has previously been imagined in detail. Individual perception depends on the context in which a specific object is perceived (e.g. a tree will be perceived differently if looked at during fruit collection or while climbing it). In order for these personal patterns to be structured and communicated, they need to be related to a social context, i.e. a set of conventions permitting generalisation: this forms the "public world". The "public world" consists of different levels, each corresponding to a set of conventions. The larger the scope of the convention, the more general it is and the less interference from individuals is involved in its perception. The "scientific world" analyses objects detached from the specific context, thus eliminating subjective values.

The three levels of generalisation interact continuously. Individuals (and the individual world) are dominated by limited sets of experiences and impressions and are guided by complex sets of values. In relation (the public world) individuals can achieve a common basic set of values, supported by an integrated fund of information. The scientific world is used by the public world to structure and organise the perception of objects considered of common value. It is used by the individual as a source of information that helps the individual gain a more detailed perception of an object.

In this context, it becomes clear that the actors in a DSS development process need to understand the scientific rules developed by each other’s public world to understand the values involved in the project, and thus to reach a compromise in order to develop the application.

All human actions are linked to spatial experience [Satti 1991]. A space is organised by the continuous interaction of three elements: physical space (the subject of geography, urbanism and architecture), social space (the subject of sociology and anthropology) and mental space (analysed by philosophy, psychology and theology). But space is not the only factor that dictates the rules by which social systems change. It is in the synthesis of space and time that the symbolic forms and languages of social systems, along with the physical signs of a culture, are created. The dynamic aspect of socio-temporal action forces every actor in the social system to continuously take into account possible future developments, modifying the rules according to a continuously changing reality. The spatial shape is the result of the relationship between these three elements: space, time and human interaction.

Socialisation means the continuous extension of the individual's world. Rudolf Schwarz summarises the relationship between space and individual as: "The individual is born in the country that existed before him. But gradually the country becomes home-country, a place full of memories in which life is lived [...] Paths and places are transformed into memory, time and space become the history of his existence." This describes how the spatial and temporal environment of the individual impacts the individual world as a physical expression that has been assimilated from the public world.

The word city derives from *civitas*: a well-known and safe environment able to assist the human being (*cives*) in relating to unknown surroundings. Growing up, the individual discovers the city as a structured totality, which belongs to everyone, and which is able to convey a sense of identity. This is reflected, for example, in the Egyptian hieroglyph "city", which also means "mother". The city is thus imagined primarily as a detached and identifiable place. To satisfy this condition, the urban context must possess a concrete form, unlike the relatively formless surrounding landscape.

Human beings generally prefer relatively complex environments. Because human nature is explorative, a lack of stimuli is perceived as boring. On the other hand, every person prefers to encounter a limited amount of complexity and ambiguity: surroundings that are too complex surroundings seem confusing and induce a desire to escape. Individuals develop intellectual schemes for integrating into their specific environments. This integration is not complete or fixed. There will always be tension and fluctuation, e.g. there might not be identification with any specific place. These tensions provoke a desire within the individual to change the environment. This creates a continuous interaction between man and environment. The architectonic space is one physical result of this interaction: it is a means for the individual and public worlds to influence the physical environment.

The internal urban structure is a complex result of individual and social worlds which "take place" in time. The most basic elements of urban form are the "fence" and the "conglomeration", direct expression of social functions: another characteristic model is the continuity along a path. In major cities these structures create hierarchical systems with more or less geometrical tissues at all sub-levels of interaction. To form a reference system for the different individual and group identities the city has to offer images: neighbourhoods need to have particularities, directions of pathways have to be explicit and nodes have to be recognisable places.

The sociological description of the urban system thus considers the city as the most complex possible human habitat, filled with different groups representing different public worlds. All inhabitants use scientific explanations to construct a temporary reference system to identify themselves within the city, and all inhabitants have an impact on the physical environment of the city. Decision-processes regarding the urban community involve the development of a set of conventions that are understandable and acceptable to the main social groups within the city. These processes should begin with an analysis of the conflicts among the stakeholders' conventions. The physical space is the result of human interaction over time: the future urban shape results from current and future action on the physical environment.

2.2.2.2 Economic analysis of urban systems

The economist considers increasing urbanisation as a human migration over a long period of time and as a spatial concentration of economic investments in public areas [Allen 1997]. Places offering a workforce with appropriate skills and a market are expected to attract economic investment. People migrate to areas that offer job opportunities but competition for space limits urban density. Thus the economic model of the urban system is determined by the physical structure of the urban form and by the importance given to certain areas by the organisational level.

The most important economic approaches to urban systems modelling were introduced by the classical urban economics of the German school in the nineteenth century [Betuglia et al. 1987]. The relationship between location and transport is currently being researched, but was not specifically mentioned until the middle of the twentieth century. Since the 1960s, research has focused on integrating geographic theory with urban economics and on developing mathematical models for planning.

These models generally consider the price of urban land or the extent of transportation systems as the main indicators of urban dynamics. The analysis focuses on:

- the urban form as a whole as a function of socio-economic activities and of the given transport network;
- the location of residences and transport within the urban system;
- the location of services and travel to them;
- the location of economic activities or residences and the related flow of commodities;
- the location of residences and travel to work.

The economic model of the urban system represents the flow of goods or services as it changes over time, depending on demand for them. The demand is reflected in the price an individual is willing to pay for a specific good or service at a certain stage. The flows consist of a migration from one geographic area to another over certain periods. These might be as short as a daily rhythm or as long as a forecast of urban growth. Historic series and typical migration patterns are generally the basis of the simulation.

Betuglia et al. [1987] [1] distinguish three key points for understanding the static and dynamic behaviour of systems of location and transport:

- spatial choice behaviour models;
- mechanisms for the formation and spatial differentiation of prices;
- the technological structure of inter-sector transactions and of mechanisms of production and consumption.

The first models clearly describe the urban system as an open market. The application of the theory of the free market to the urban system does not consider the urban system as the expression of a community composed of different sub-communities. Decisions made by individuals do not impact only on themselves or on only other one party, but on the whole physical environment influencing other system dynamics and third parties. Attempts have been made to incorporate these effects into the modelling structure as so-called "externalities", i.e. "as costs produced by the free exchange, which impact on third parties, to collective goods, which the market cannot supply" [Stone 1988]. The introduction of externalities brings additional factors into the game, which cannot always be measured as economical cost. If these externalities are considered relevant, the efficiency level of the urban system cannot be objectively determined solely as a relation between costs and benefits.

The perception of the urban system as a market system is based on two important factors in society, which were introduced during the industrial revolution: employment and wealth in urban areas. The role of the city has changed dramatically and the main force influencing society has become economic growth. When economic stagnation occurs, other important factors are brought in to focus the organisation of the city. A new set of goals is under development, but not yet well settled. The limits of economic analysis in itself appear clearly now that the externalities created by the production process are no longer considered irrelevant.

Many approaches to modelling urban structures have borrowed from natural science the assumption that a static equilibrium characterises a crystalline urban form. In order to comprehend this model, one has to think of an aerial photograph of the city: in this model the time factor is excluded. The static theories have assumed that the disconnected actions of individuals, each pursuing his or her own goals, could drive the system to an equilibrium state characterised by some sort of global optimality. Thus the models "froze" the urban system for the purposes of analysis, ignoring its dynamic character.

Several recently developed models tend to introduce additional factors into their approaches, but achieve valid results only when integrated with theories that have been input from other disciplines.

---

[1] See Appendix I for a summary of his assumptions and short introduction to his different models.

2.2.3 Institutional aspects

2.2.3.1 Policy aspects of urban systems

Policy is an instrument that transforms moral values into a defined common reference set of guidelines for a specific public world. The organisational level of society uses the models defined by policy in order to direct and control urban dynamics.

A pluralistic society is composed of multiple circles of public worlds, each with its own reference set. Policy actions referring to a single public world have to consider the values held in common by the individual worlds composing it. Policy guidelines refer to a group of public worlds to analyse the reference sets representing each of them in order to extract a more generalised common set. Policy actions and decisions in the urban environment always impact on multiple public worlds, often with conflicting reference values. They therefore cannot aim at finding optimal solutions, but must instead find compromises that take into account the different goals of the stakeholders involved in the processes impacted by the policy action.

Policy measures within the urban system area are guidelines based on a perception of dysfunction within the urban system and on a specific set of reference values generally accepted by the public worlds. Policy impact assessment includes an analysis of the expected direct and indirect impact of the policy action, a consideration of the reference values of the stakeholder groups involved in these processes, and an evaluation of their relations. The preferences of the decision-maker(s) must also be examined in relation to their specific values and those of the stakeholders.

Urban policy measures are a means of guiding urban dynamics in order to achieve goals defined by the public world. The model of the city defined by policy analysis describes the organisational structure of the different public worlds and expresses their sets of reference values in terms of the formulation of goals, rights, duties and rules of interaction.

Discipline	*Model of Urban System*
Social Dynamics	Socio-cultural and physical reference system of the individual and public worlds deriving from an historic form and human action over time.
Economics	System defined by flows depending on demand for goods or services that change over time.
Geography	Surfaces, lines and points denote physical objects, organised by their location and described in relation to a geometric reference system.
Demography (Statistics)	Area with a certain population density or assigned the title "Municipality".
Architecture	Physical expression of value sets for the organisation of flows and the formation of future generations.
Ecology	The natural environment as changed by the physical impact of socio-economic processes.
Policy	Space shared by different public worlds that define periodical common sets of guidelines reflecting a general set of reference values

Table 2.2: Summary of disciplinary approaches describing the urban system.

2.3 INTEGRATED APPROACHES

The following paragraphs present a select set of approaches to integrated description and modelling of the urban environment and/or urban environmental problems. Unfortunately use of integrated models has not yet become routine in planning. These models, "developed in various fields, facilitating communication between different planning disciplines" are described by van Delft and Nijkamp [1977], after a relation of the historic emphasis on scientific and planning specialisation instead of integration. Indicators are very frequently made use of in urban management to limit specific actions within the urban environment including planning activities. Interdisciplinary models have been introduced into the control mechanisms but not into the planning mechanisms of the urban environment.

The controlling institutions, on the other hand, attempt to convince the planners to adopt a more integrated view of the city because they notice interaction between different sub-systems of the urban environment. This interaction is noted especially strongly when it leads to the environment's degradation. Planners are thus confronted with the necessity of taking into account factors typically analysed by other actors. The first direct response to this problem was the integration of information, no longer confined to its traditional disciplinary sources, into the planning process. These approaches refine the original disciplinary models, integrating input from interdisciplinary databases. A second step incorporates information derived from different disciplines into inter-disciplinary models.

The following paragraphs describe select approaches that attempt to cross borders between disciplines in order to produce a fuller simulation of urban dynamics. This selection is intended to demonstrate possibilities for future co-operation, as well as to offer an opportunity for viewing the system, the city and even a specific situation within the system from the different points of view that compose a multi-dimensional picture.

2.3.1 New urban ecology – man's ecosystem

This type of analysis is different from "classical" urban ecology[2]. Classical urban ecology sees the urban environment as a disturbance to the natural landscape, with a negative impact on the flora and fauna that is to be reduced as much as possible. Human-centred urban ecology sees the city, instead, as man's ecosystem. Classical urban ecology is interested in the protection of nature, while human-centred urban ecology is interested in methods for the ecologically sensitive planning of the human habitat.

Unexpected and uncontrolled changes in the natural environment have been detected during the last decades. In the developed world, these changes have begun to be considered to be among the parameters that define quality of life. Rising standards of living and awareness of the consumption of non-renewable resources have led to the creation of the expression "sustainability". This expression is often used, but lacks a precise definition. What is important in this context is that, for the first time in history, the notion of future generations' legacy in terms of the manmade environment is seen not as the preservation of a group of symbols and structures that memorialise historic

---

[2] Paragraph 2.1.2.4

eras, but as the preservation of the living environment for future generations. Western society has taken notice of the destruction of its own environment.

Out of this context new approaches to ecology have been born. The sub-discipline of biology researches animal species' ecosystems in an attempt to preserve their equilibrium. The disciplines within ecology are thus linked to geographic areas. Out of this context the discipline "(new) urban ecology" has been born. The discipline of ecology, by nature, makes use of multi-disciplinary tools for data acquisition and representation. It describes different aspects of the environment including its biological, geographical, sociological, meteorological and chemical aspects in order to create a problem space for their analysis. This new science looks beyond the approaches it used earlier, attempting instead to apply a combination of different methods and tools to describe the complex system it observes and represents.

Since ecology has increasingly become the theme of politics [Breuste 1996], the processes of ecological analysis have been developing quickly. Ecology has been asked to provide methods for evaluating many kinds of change within the physical urban environment. Planners and managers needed to include evaluation processes derived from a new discipline into their analyses. They were confronted with a new procedure: the environmental impact analysis.

The traditionalist planners and urban managers confronted with this new additional check to their activity have reacted with scepticism. They were required to present their plans to commissions using the method, but these commissions usually employed experts to apply it. Within several years, a list of indicators and planning rules had been derived from the continuous application of the method so that what is considered a minimum standard of sustainability has been introduced into the planning and management process.

The original goal of applying ecological rules to planning processes has been reached, but an important opportunity has been missed: an understanding of the interaction of different (eco)systems including the human ecosystem and the environment has not been incorporated into the planning process. Although inter-disciplinarity could have been accepted in the planning culture, this has not actually happened.

Instead urban ecology, which originally analysed animal biotopes within urban landscapes, began at the end of the eighties to analyse the city as a typical human ecosystem. Urban ecologists began working together with planners. Urban ecology now analyses the "complex effects of man on the environment, as well as how the environment itself effects human beings." [Breuste 1997]

Urban ecology is a new field of research that has been made mush use of in European cities. It could therefore be a useful discipline to contribute to an inter-disciplinary vision of and approach to management. This does not mean that ecological aspects are the most aspects of the European urban context, it just means that urban ecology has been the first discipline to begin thinking and working in a more integrated fashion in the past few decades. It provides a good example of how interdisciplinary management could be approached.

2.3.2 Indicators

As an initial approach to forming a synthesis of the perspectives of different disciplines so that the object of their analyses can be viewed as completely as possible, it is useful to list that the disciplines consider. In order to list the aspects of the urban environment, there must be agreement about which expression indicates which aspect or dynamism. In a geographic area like Europe, where the presence of different ethnic languages complicates the difficulties posed by the multitude of disciplinary languages, this requires very complex procedures. Once the aspects are defined, an understanding must be reached about which aspects are considered problematic. For this understanding to be reached, each aspect must be represented. Further, each aspect must be represented in a way that is measurable, i.e. through characteristics or indicators that are measurable.

These indicators have been used in ecological research right from the beginning and have been used in the formulation of environmental legislation at all geographic levels. A consistent set of indicators allows an understanding of all the elements composing a system. An understanding of the interdependency of the indicators and a description of the system environment and its dynamics are required in order to comprehend the system dynamics. Thus the indicators represent the set of aspects defining the status of the system. After they have been defined, a formula describing the system dynamics must be developed.

2.3.3 Integrated modelling

2.3.3.1 Environmental management approach

Due to the need to introduce ecological parameters into management processes, economic research has produced various approaches to what is called environmental management. One example is described below:

The urban economic system includes human activities like production and consumption. These activities take place in households, companies and institutions [Douven 1996]. To develop and to function, these activities require things like space, energy, food and natural resources. These needs will put various amounts of pressure on the ecological system. Whether or not this affects the environment depends on the environment's capacity to resist this pressure. Ecological knowledge about the environment's sensitivity to change and its stability is relevant to determining the maximum tolerable amount of pressure from economic activity. In this approach, the results determined from ecological research are required for economic modelling, so that the inter-disciplinary approach is sequentially linked.

2.3.3.2 Cities and regions as self-organising systems

The following model developed in the field of economic urban system modelling attempts to illustrate how the limits of disciplinary modelling are reached when it attempts to simulate the dynamics of the urban system.

Allen [1997] developed a model in several different steps:

First, the urbanisation of a region is considered to be due to the successive integration of economic functions introduced at random places and times into the system, together with the evolution of means of transport and communication as different centres grow and compete with each other. The population responds to the resulting spatially inhomogeneous employment opportunities.

At the second step, the interplay of positive and negative feedback between jobs and people is taken into consideration. Jobs attract jobs and people, and people attract some jobs to them. This second step takes the migration of people between zones into account, assuming that people and jobs want to be at the centre of town. Land prices then tend to increase there and, simultaneously, increasing levels of noise, congestion and pollution decrease the city's attractiveness to potential residents. This leads to suburban residential areas and, after a certain time, forces retail and service activities to migrate to the periphery of the town.

Allen applies his model to the development of an imagined region with different urban centres, thereby avoiding the need to define a static starting profile for an existing situation and also avoiding the need to consider the influence of disturbing factors that are not taken into account. The results are continuously compared to a convincing picture of urban growth observed in different schemes that analyse it. This analysis of an invented region shows that urban form depends on the 'scenario' of policies, technology changes and events that occur over time and that 'timing' itself is a critical issue in history. The nature and personality of a city and the quality of life of its inhabitants depend on a dialogue between the process captured in the model's equations and its scenarios. The dis-equilibrium trajectory of the system is important in determining its future. The model views the evolution of a system of urban centres as a dynamic interaction between supply and demand in two spatial dimensions (flat) of the chosen region.

Allen's analysis of the effects of intervention in the system above, described in terms of lifting trade barriers, illustrates some problems in economic theory and its application. The situation he observes is this: two previously stable urban hierarchies of centres are suddenly brought into contact with each other. The presence of long-range functions within both hierarchies ensures that the effects of lifting the frontier are felt not only at the border but also throughout the whole domain. The results of various simulations indicate that the urban structure observed in a region depends on an interplay between a sequence of internal historical accidents, on the relative timing of demographic changes, on the lifting or imposing of economic barriers and on the range of interaction of the centres, which itself depends on transportation technology at a given time.

In a complex system of interdependent entities, the decisions made by individuals, or by collective entities representing certain localities, lead to the emergence of a large-scale structure, which is not anticipated in their thinking, and which will later, in fact, determine the choices open to them. This is the "collective" aspect of individual actions that characterises society. The results of these actions appear in the development simulation as "historical accidents". This profoundly changes traditional economic theory, which explains or forecasts the effects of actions and policies as equilibrium. The structure is related to the values of the parameters of the environment but it also depends on the initial condition of the system, i.e. its detailed history. The structure of the system results from a mixture of historical necessity and historical accident, since non-linear interactions produce irreversible changes. This poses problems in the comparison of the results of different scenario applications. The problem is that of comparing dynamic evolutions, where symmetric intervals can be used as well as intervals that are defined by major stages of evolution. Comparing the life of twins, for instance, the behaviour analysts often start with a comparison of static "pictures" taken certain ages, but may then notice that for each individual may have needed a different amount of time to pass through specific stages of development because of differing goals or other factors influencing their evolution. A comparison may be made that takes into account important steps in their development such as receiving academic degrees, marriage etc.

Often political decisions are based on the assumption that "it is beneficial to establish free trade arrangements and to lift frontiers whenever possible". However there are no quantitative models supporting this assumption and it appears to be an economic "ideology" that produces the belief that the unfettered market is the "best" situation. This is a typical example of the use of pseudo-scientific arguments to mask conscious or unconscious goals. Allen's application tests this ideology with a mathematical model that simulates the path of socio-economic development resulting from the lifting of a trade barrier at different possible stages in the development of the urban hierarchies. He demonstrates that lifting frontiers changes the evolution of the system, but what is considered "better" or "worse" depends both on who and where one is in the system and what one's goals are.

This part of Allen's research clearly demonstrates the problem with a lack of pre-defined goals and values to define desirable scenarios and evaluate resulting structures. A decision process depends on setting these goals. In modern society economic theory has often been considered the main source of information for political decision processes. This does not depend on the evolution of the scientific research, but on the focus of industrialised society upon the production and distribution of wealth. As long as production was seen as continuously growing and thus seen as something that would in time resolve all problems, the expansion of the market was seen as a major good in itself. Now this growth has at least slowed down. The general "truth" of the market rule has come into discussion. It is crucial to understand which assumptions have been made out of "ideologies" and which are founded on quantitative information and analysis. This is one major role of the research that supports decision-makers in defining new goals. Other major objectives of this research include the analysis of current systems and expectations and the development of tools for a flexible and dynamic definition of how the decision-maker's perceives urban space. These tools should enhance his evaluation of impacts on the urban space by taking into account dynamics that can be simulated with quantitative and possibly also with qualitative methods. Allen mentions this second task, pointing out that "the exploration of the consequences of using different value sets to weigh choices is itself an important issue".

The limits of the mathematical models are represented by a description of the connected behaviour of its different components based on the supposition that the behaviour of each of the components taken alone has been successfully represented for all the situations that may be encountered during a simulation. This is due to the model's failure to incorporate the learning process into its application. The parameters are clearly fixed before the run and the decision-maker has no way of seeing the impact of his specific settings. Multi-criteria methods try to overcome this problem by presenting the decision-maker with an interactive module for defining his specific scenarios and preference settings within a loop, which permits the modification of these settings as soon as their intermediate results become apparent. This reveals another dynamic process: changes in the decision-maker's definition of his goals, or the basic parameters of his choice, depend on how much information he possesses.

Simple goals cannot be defined for the urban system because the sum total of human behaviour within it results from an intricate web of influence and effects that links many different scales of process and organisation. Behaviours and processes are interconnected and their effects interpenetrate them as well as their surroundings; these connections are bilateral.

For example, the experiences of people driving into the city affect their choice of route, and the effectiveness with which they are allocated to the available network results in greater or less satisfaction; this therefore affects their desire to re-locate. This, in turn, influences building and land-use prices, which impact on traffic flows and the demand on road networks. As a result, changes occur in the pattern of residential and business locations and the flows between them. The overall effectiveness of the system and quality of life offered by a city affect its competitiveness with other cities as a location for further investment and activity. The opportunities attract migrants with their own cultures and demographics: ultimately the city's population and age pyramid is impacted, changing the need for services and amenities and the character of the city. The nature of the typical inhabitant will also change, along with that of different neighbourhoods. A continuous co-evolutionary change takes place throughout the complex urban system. This linkage of spatial and temporal scales is the reason why understanding human systems requires a 'complex systems' [Nijkamp, Reggiani, 1998] approach.

In traditional modelling, parameters are typically changed as external inputs. But this is an over-simplification, because it leaves out the co-evolution of the environment that occurs with its population and the process of learning and adaptation that occurs in the micro-elements and individuals that make up the system. Changes at the macro-level influence changes at the meso and micro levels and vice-versa. What is considered a parameter on one level may be a variable on another level and may therefore evolve with changes in the system.

Other problems with traditional modelling have been detected. For example, seemingly minor decisions or differences in detail may potentially evolve into essentially different futures. Information concerning the conditions of a city will always be imperfect and incomplete: however good a model may be, it will still fail to predict some developments and must therefore be modifiable for the future.

Modelling is understood to support a learning process about the integration of demographic, economic, social and environmental aspects of the system as an approach to analysing and understanding the dynamics that lead to the current urban form. That understanding is not supposed to be complete, but the best possible approximation available. Models are not seen as tools for forecasting, since it has been demonstrated that small details have the potential for a strong impact and since every model is, by definition, an approximation. The model is considered an aid in better understanding the sensitivity of a system to the variation of specific factors. Without a model that reproduces our view of a system, we cannot understand whether our view of its dynamics corresponds to what has happened until now and we cannot detect what information we lack in defining the problem. Thus a model is both a stimulus to learning and the representation of present knowledge.

2.4 CONCLUSIONS

This chapter illustrates a select number of traditional disciplines' approaches, along with integrated approaches, to European urban environmental management. This is to introduce the technical actors in the DSS development process to the variety of points of view involved. This introduction prepares them for their role in developing a tool to support actors in the complex system described in chapter 5.

The following chapter presents some of the actors in European urban environmental management and analyses tasks they perform and their interactions with the other actors. This chapter attempts to show their patterns of interaction, which are usually not considered within the related problem-solving strategies.

Together, chapters 2 and 3 depict the complexity of decision-making in European urban environmental management based on the variety of actors and problem solving strategies involved. This introduces their cultural backgrounds and evaluation methodologies, which are required as a basis for the DSS development process proposed in chapter 5.

CHAPTER 3 Processes and tools used in urban environmental management

3.1 INTRODUCTION

In chapter 2, a select number of ways of describing and analysing the European urban environment have been described in order to illustrate the views of multiple disciplines within the related decision processes. Based on this overview of the actors' various backgrounds, chapter 3 introduces different aspects of the role of a decision-maker in European urban environmental management (3.2). Section 3.3 illustrates a set of external aspects influencing the decision process to indicate that not only the specific problem, but also factors like the sociological background of the decision-maker (3.3.1) or her/his position in the decision process (3.3.2 and 3.3.3) may impact the final decision and the way it is represented. Finally, a select set of urban issues to which DSS may be applied is given, not as an exhaustive overview, but to guide the reader to start asking questions about the detailed characteristics of the specific problem-solving process that is to be supported by the application under development. The representation of the problem space is described in more detail in chapter 5. It is important that these aspects of the European urban decision process be described as background for the appropriate application of the decision theory introduced in chapter 4. An understanding of how these aspects may be analysed is crucial to the development of an appropriate DSS, as introduced in chapter 5.

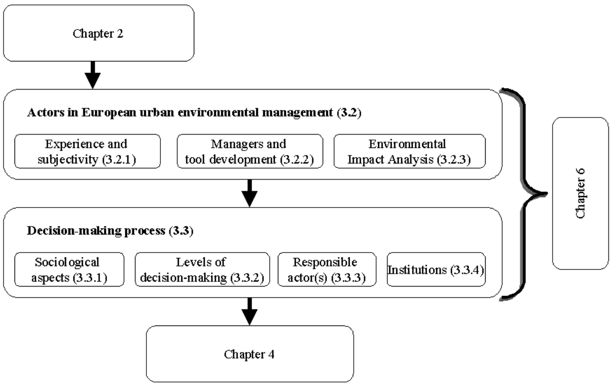


Figure 3.1: Chapter 3's logical structure

This chapter does not attempt to develop a complete glossary of processes and tools that have or might have been applied within the case studies reported in chapters 6 and 7, but instead attempts to introduce them. These processes and tools are at the basis of the DSS-maker's script approach to development.

In order to develop of tools for urban environmental management, it is important to understand the needs of the final user. Each user can be defined by her/his specific disciplinary and technical background, as well as by the traditional tools typically in use in his or her user-groups. These tools may be guidelines or reports, training courses or software, telephone hotlines or conferences. In order to reach a specific audience, it is important to observe their habits and the way tools have been developed within the market for their specific daily use. Keeping the end-user involved during the whole design process is the basis of a tailored solution that helps reduce the thresholds of supporting technologies such as digital tools and group support approaches.

The different classes of actors in urban environmental management include local administration, urban planners, architects, engineers, traffic and transport planners, and actors in tourism, industry and commerce, etc. who all use different methods of analysis. Although listing all possible methods exceeds the scope of this thesis, it is within its scope to define an approach to analysing relevant elements of the end-user profile in order to prepare a specifically suitable instrument. This task looks simple: just go and ask some representatives. Even though this is the most straightforward approach to the problem, it does not necessarily lead to a useful conclusion. The questions inherent in this type of analysis include: whom to ask exactly; how to contact the right persons in order to obtain useful answers; which methods to use in order to analyse acceptable tools; what would a specific user session look like; how to interpret results and how to foresee upcoming changes in end-user behaviour during the period required for the development of a tool, etc. Section 4.4 will introduce some significant techniques for user behaviour analysis, present a portfolio of techniques for possible application and illustrate the procedure for applying them by following two case studies.

3.2 ACTORS IN EUROPEAN URBAN ENVIRONMENTAL MANAGEMENT

3.2.1 Experience and subjectivity – selected actor profiles

To support a specific decision process, it is important to be aware of the different actors involved, their requirements, their interests and the tools they are accustomed to using. It is also important use this knowledge to generate the appropriate support for their decision-making.

The following table summarises some selected general profiles of possible groups of actors. It includes their major interests, the related traditional decision processes and the practical tools they employ. The scheme may be used within DSS application development to understand stakeholder interaction and to investigate DSS user requirements in the case of single or multiple user applications. The profiles provided include the actor descriptions required for the case studies described in chapters 6 and 7.

Policy maker (European level)		
	Profile:	- Decision-maker on policy framework - Client (through EC funding) - Compares different urban systems at low resolution level (indicators)
	Area(s) of interest:	Urban aspects in European context
	Influencing factors:	Member states
	Related actors:	Other policy fields at European, international and member state level

	Decision-process:	- Single decision process for role as client
		- Group decision on policy actions
		- Typical decision process is given through
		  - evaluation criteria for project evaluation and
		  - indicators for urban system evaluation;
		  - subjective sequence of decision steps to be assessed.

	Tools:	Currently, strong request for multi-criteria evaluation tools. Low resolution data see the city as an item with different characteristics.
Policy maker (urban level)		
	Profile:	- Defines strategic goals for urban development within the background policies defined at higher hierarchical levels; - Controls implementation.
	Area(s) of interest:	Overall urban development
	Influencing factors:	Electing majority, higher hierarchical government levels, economic/employment powers
	Related actors:	- Hierarchically higher levels for background conditions (scenario analysis); - Hierarchically lower levels for evaluation and implementation;

	Decision-process:	- Single evaluation of implementation;
		- Usually group decision on policy actions (council)
		- Typical decision process is given through
		  - indicators for urban system evaluation;
		  - subjective sequence of decision steps to be assessed.

	Tools:	Spreadsheet analysis mainly based on economic tools. Forecasting. Not well documented further (to be assessed). Medium resolution data see the city as a whole with different subsystems.

Urban Planner		
	Profile:	The urban planner is responsible for planning the physical patterns formed by the use of land within the urban borders. Responsibilities for this task vary within the European member states. [3]
	Area(s) of interest:	Land use of soil and its change
	Influencing factors:	Pressure from higher local administration, traditionally applied solutions,
	Related actors:	Technical infrastructure planner, transport planner, architect, landscape and urban green planner, environmental assessor, etc.
	Decision-process:	- Group decision process with other planning departments - Typical decision process is given through - evaluation criteria and weighing them - subjective sequence of decision steps to be assessed.
	Tools:	Land use mapping, GIS, 3D modelling, remotely sensed image processing, statistical modelling. Medium resolution data see the city as a whole, zooms on high resolution for detailed land-use planning.
Traffic Planner		
	Profile:	The traffic planner is responsible for planning the mobility of goods and persons within, out of and into the urban borders. The responsible departments for this task vary within the European member states.
	Area(s) of interest:	Traffic flow, Transport infrastructure
	Influencing factors:	Pressure from higher local administration
	Related actors:	Technical infrastructure planner, urban planner, landscape and urban green planner, environmental assessor, etc.

---

[3] For more information on these distinctions, please refer to paragraph 2.1.2.2.

	Decision-process:	- Group decision process with other planning departments for the overall planning process;
		- Single decision process for infrastructure implementation
		- Typical decision process is given through
		  - evaluation criteria and weighing them.
		  - subjective sequence of decision steps to be assessed.

	Tools:	Digital and manual land use mapping, GIS, 3D modelling, remotely sensed image processing, statistical modelling. Medium resolution data see the city transport network as a whole, zooms on high resolution for detailed traffic planning.

Table 3.1: Selected set of possible actor profiles.

This table may be used as a general framework for describing stakeholder profiles in an urban problem case. Nevertheless, it includes only basic information on the actors. This needs to be supplemented with information about the specific individual actors, who might differ essentially from these prototypes. The framework should serve as a "first guess" profile to be adapted to each case and integrated with more detailed information and as a template to be developed before the first interview. The detailed final profile descriptions are a first step in decision support, representing an overview of the points of view of the actors. They clearly describe general preferences within the evaluation process, interdependencies of actors and decisions and responsibilities at different stages in the decision process. They thus form the basis of the problem model and of the interaction of the actors within the DSS development process.

In this sense the detailed profile description is a decision support tool in itself, which helps to illuminate the different parts in the game and the requirements of the actors. It describes different points of view involved in the process and the methods of looking at and analysing the urban environment.

The tools usually support part of the decision process, not its whole. To describe and model the urban environment properly, all actors need to gather information. Most actors today use digital systems to store and process this information within more or less complex database management systems (DBMS). The aggregate information used at the management level is stored in simply structured DBMS with highly flexible processing capabilities, such as spreadsheets. The controlling and implementation levels of decision making sometimes require very large data sets with complex storage systems that use data for predefined processing steps and that thus have less flexible processing capabilities. These functionalities are often anticipated with a specifically adapted graphic user interface.

Information representing the urban environment is not only comprised of numeric or linguistic information, but also consists of geographic information, images, sound, smell, etc. Not all of this information can be represented by computers, but the modes of representation are continuously growing with the development of information technology. Systems that were originally developed to store and process geographic information (geographic information systems – GIS), for example, nowadays include complete alphanumeric databases and/or permit the use of external DBMS through their interfaces, handle data and image processing through internal and external model implementation, allow cartographic and 3D representation of landscapes and projects, handle multi-user sessions through a network and are able to support group decisions via video-conferencing. Often GIS applications have been called decision support systems in literature, but although they support decisions like any spreadsheet does, as long as representation of data and information is their basic rule, they do not actually support the user in the decision-making process.

If such a tool is used by the decision-maker(s) to be supported, it could serve as a very good starting point for DSS development. Part of data storage, processing, display and reporting could be covered by this system, which would help the user to accept and use the system through the familiarity of its interface. But it has to be clear that while the DSS user sometimes coincides with the GIS or other tool user, he sometimes does not. If the DSS user works on a higher managerial level than the GIS/tool user, the system must be tailored to resemble the tools employed by this user and not the most sophisticated tool available in house. This sounds fair, but many applications suffer from such mistakes.

In order for the evaluation process to be further supported, the decision-maker(s) need to be supported in describing the problem case. Similarly all stakeholders must understand that "their" system is incorporated within a more complex problem description and must discover the full framework of the evaluation process, consisting of the elements and dynamics of the urban sub-system, the alternative possible solutions to be considered, the actors and their preference systems, the responsibility systems involved and the complete workflow of the evaluation process.

3.2.2 The role of managers in decision tool development

Sprague and Watson [1989] separate the role of managers within DSS development into four parts:

- approver and administrator
- developer
- operator
- user of output.

Even though Sprague and Watson's study focuses on businesses in the United States at the end of the eighties and the number of case studies included does not permit proper statistical analysis, it remains the only study that answers questions about how DSS are developed on the basis of real and essentially successful implementation cases.

DSS policy issues with regard to the manager as *approver and administrator* are usually informal within an organisation. The DSS supports upper or middle management. The DSS is usually administered by specific individuals in a department. Evaluation of the DSS's performance is based on nothing more than intuition and DSS master plans do not exist. A data processing department or vendor usually provides hardware and software administration, including networking facilities. Data input and logic support is provided by the DSS user/manager.

A few observations have been made regarding the manager’s role as DSS *developer.* Even though managers participate continuously in the decision process and middle management provides a strong leadership role in development, none of the DSS examined attempted to formally model the manager’s decision-making process as a way of accommodating a personal approach to decision-making. Decision style was accommodated by building into the DSS the capability to interact with a variety of approaches or styles.

About the development of the DSS user interface, Sprague and Watson state that even though there is an intuitive appeal to designing the display component of a DSS to accommodate the user’s cognitive style, there are problems with this approach. These include: cognitive style measurement problems, variations in a person’s cognitive style about decision-making tasks, and the heterogeneity of cognitive style among multiple users. In their study, they suggest the use of display generators and note the usefulness of their capability for adaptation by the user on-the-flow. In 1989, software development had just started to produce adaptable interfaces and thus the relatively few transformable attributes of the display where manageable by a non-expert interface designer. Today there are innumerable options for interface design and interaction and multiple types of user interface that can be used for DSS display modes. A display mode should therefore be defined during design of the DSS and the user/intermediate technical support should be trained in ways it may be adapted to the user’s cognitive style.

When managers are considered as operators, they are found to be occasional DSS users who leave the DSS’s operation to an intermediary who adapts the DSS to the manager’s specific approach. This intermediary’s influence is not studied by Sprague and Watson, nor will it be an issue within this study, but it would be worthwhile to analyse the opportunities this role offers in more detail. Interviewing managers about their analytical use of decision support software and models of decision making shows that DSS is currently not much used in the decision processes that focus on the active phases of decision making, e.g. communicating, justifying and explaining a decision rather than choosing a specific solution. The active phases of decision-making depend on fuzzy inputs to the evaluation process and they consider intermediate steps in the evaluation process to support the proper choice rather than considering the choice as the final stage in the supported process.

DSS *output* is created almost exclusively for the management level. Most analysed DSS supported single decision-making or, at most, a multi-user approach with sequential decision steps. Group decision support was offered less frequently.

3.2.3 Environmental impact analysis and assessment (EIA)

EIA is “a statutory process of assessing the environmental impacts of a project.” [BEQUEST project glossary, on-line in 2000]

Since the 1950s the need to define more detailed requirements to project EIA has been felt, since environmental degradation has become increasingly problematic. At the end of the sixties the USA was the first country to introduce rules for EIA reporting. These rules have been formulated in the “National Environmental Policy Act” (NEPA) of 1970 which was re-formulated in 1975 [U.S. Department of Energy, 1975]. The law's objective is detailed in section 2: "To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality."

The two fundamental concepts of EIA named within the NEPA consists of:

1) defining the area of analysis to be considered within the EIA for the project, alternatives and their impacts;
2) encouraging each institution to co-ordinate their own EIAs in the most transparent manner possible.

The content of the EIA reports are given in section 102, point C:

1) the environmental impact of the proposed action,
2) any adverse environmental effects that cannot be avoided should the proposal be implemented,
3) alternatives to the proposed action,
4) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
5) any irreversible and commitments of irretrievable resources that would be involved in the proposed action should it be implemented.

The European Union introduced its first EIA Directive on Environmental Impact Assessment of Projects in 1985 [European Commission, 1985]. It was amended in 1997. The Member States had to accept the amended EIA Directive by March 14th 1999 at the latest [European Commission, on-line in 2000].

This European EIA procedure ensures that environmental consequences of projects are identified and assessed before the projects are. The public can give its opinion and all results are taken into account in the project's authorisation procedure. The public is informed of the decision afterwards.

The European EIA Directive outlines which project categories will be made subject to an EIA, which procedure will be followed and what the assessment will contain. Following the signature of the Aarhus Convention by the Community on 25 June 1998, the Commission adopted on 18 January 2001 a Proposal for a Directive COM(2000)839 [European Commission, 1997] amending, among others, the EIA Directive. This proposal is intended to bring the provisions on public participation into accordance with the Aarhus Convention on access to information, public participation in decision-making and access to justice in environmental matters. [4]

The phases of European EIA development are listed below: [Colombo 1996]

1) Project description
2) Description of the environment
3) Impact identification and evaluation
4) Presentation of the study
5) Public participation

---

[4] For more information on International Environmental Agreements, please refer to [26].

6) Consulting responsible authorities
7) Decision made by the central authority
8) Project realisation, maintenance and observation

The different approaches illustrate the difficulty of using a single model as a valid description of the urban environment. Because it was designed in order to support a single decision-maker, one model of the urban environment might be produced on the basis of her/his mental model of the city. Since the process of decision-making is usually a group process or one influenced by multiple stakeholders, a user-specific model of the urban environment could cause misunderstanding right from the beginning of the process. There are three possibilities for dealing with this problem while developing a tool for decision support:

1) The DSS designer could develop a model of the urban environment from the results of the user and stakeholder assessment sessions;
2) The decision-maker's model could be reproduced in the tool, keeping in mind that this is not a generally valid representation and informing the decision-maker about the implications of this (this is only possible for single decision-makers);
3) The decision-maker/group of decision-makers could be asked to define the model in detail and to reach a compromise for representing the problem environment as a first step in integrated co-operative decision-making.

EIA in urban planning treats the city as a background for the evaluation of specific projects and/or policies. Alberti et al. [1994] affirm that "EIA tries to evaluate the effects of a project, not its quality in terms of corresponding to specific goals." His negative formulation of this statement reflects a frequent misunderstanding that EIA is a tool from human-centred urban ecology instead of (as is actually the case) having its original routs in classical urban ecology. EIA is an instrument evaluating the impact of a project or policy on the natural environment. It attempts to introduce environmental risk factors into the decision-process when decisions must be made about the implementation of large-scale projects and policies. EIA is not a tool for human centred urban ecology, i.e. it is not a planning method, even though it has often been discussed in literature in the context of planning. Current planning processes are required to take EIA evaluation into account as one element within project evaluation, but not to support an integrated planning process.

3.3 THE PROCESS OF DECISION MAKING

3.3.1 Sociological aspects of decision-making in the urban-environment

Every era has a specific set of dominant ideas, represented in different ways in all social expressions such as literature, lifestyles, cultural forms and political or other ideologies. One of these ideas, which characterises all social forms, is morality, i.e. the set of generally accepted goals for the development of society. The new lifestyles have led to the demise of the notion of universal morality, but this does not mean that specific codes of values or behaviour no longer exist. Assigning importance to marginal elements within the context of the original moral consensus signals in fact the precarious moment between the demise of one world-view and the inception of another. It is up to the organisational level to formulate rules ensuring that generally held morals will be respected.

In order to make a choice, the individual must interpret the situation using a reference set of values. A decision in today's pluralistic society requires the choice of a reference set accepted by the related public worlds. As "pluralistic" means that several sets of values co-exist, before taking a decision it is necessary to familiarise oneself with different value sets and to be capable of changing position if this is required. Architecture is an expression of man's need to lend form to the environment, following his own value sets in order to convey it as a reference system to future generations. Architecture and urban planning therefore serve the public world in trying to link the individual to the public structure. Architectural structures represent a physical reflection of the different levels of subjective worlds, from the individual, through different groups defined by specific value sets, up to the most general levels of the human rights organisation. The boundaries of the developed environment coincide with the boundaries between the private and public worlds, as well as those that divide different public worlds.

Changes in space depend on the original form of the space, on the social reference system of the actor creating the change and on temporal variables [Satti 1991]. A decision-maker in urban planning, in order to make a conscious decision, must understand fully the physical structure of the urban system in question, as well as the social reference systems in question and the dynamics of all of these systems.

3.3.2 Levels of decision-making

Thierauf [1988] distinguishes four levels of managerial and operational activities:

- Strategic planning – the development of overarching goals and methods for achieving them;
- Management control – the process of assuring that the goals are accomplished effectively and efficiently;
- Operational control - the process of assuring that specific tasks are accomplished effectively and efficiently;
- The control of day-by-day operations, including providing feedback to the appropriate level of management.

Analysis of these activities shows that there are no strict boundaries between them but instead, a continuum within their applications.

What about public authorities who manage the urban environment? In these cases there is an overarching strategic level that decides upon the general policy of the city government: this is the political level or "policy makers". In local policy-making, the strategic level is divided between defining strategic goals and defining general methods. This strategic level may also be defined within regional, national or international bodies.

Example:
- Overall strategic planning: because human health is critical, the amount of exhaust needs to drop in the main shopping areas of the city centre by 15%;
- Strategic planning at the level of the urban planning office has to decide which method to use to reach this goal and has to check its feasibility with other departments and the policy makers. It must also check for

possible conflicts with other policies: a workplan is then developed and tasks are assigned;

- Operational planning departments/groups (urban planning, green management, traffic management, industry control, police, public transports etc.) take over responsibility for detailed task planning. The detailed final plan is composed on the methodological level of strategic planning;
- The workplan is implemented and handed over to day-by-day managers who collect feedback and report it to higher levels of decision-making.

Problems usually arise when the hierarchical structures in decision-making and implementation are not reflected in the hierarchical structures of the institution(s). Where decision processes have to be organised by different departments at the strategic planning and/or operational level, major problems often occur when the actor(s), who decide upon the strategic method and upon the tools for the application conflict with those who decide upon the overall management of the operational planning on the other hand.

In complex situations, resolution is usually reached through a "champion". This champion is an actor who facilitates the communication between and co-ordination of actors involved in the decision and implementation phases. This champion does not need to have a high stake in the decision itself himself, but does need to be accepted as moderator. Because he is in charge of communication during the choice of a method to reach predefined goals, the champion is in charge of selecting appropriate tools to establish this communication and of reporting (intermediate) results. The champion has to facilitate an agreement on the tools to be used in supporting the decision process. The actors involved in the decision process must also agree about how the final results should be represented to them before the champion can begin to manage the process itself. The more inter-disciplinary and fuzzy the problem description becomes, the more an appropriate tool is required to store and structure the information needed for the evaluation and to support a structured decision process step-by-step. In this case, the champion will develop or commission a specific decision tool and will translate user requirements to system requisites.

3.3.3 Single and group decisions

Urban management decisions are not made in a vacuum. Contextual factors affect the process of decision-making. In urban decision-making multi-disciplinary factors have to be taken into account within a nested hierarchic government structure. If the actors influencing the decision are no longer considered stakeholders, but instead shareholders in decision-making, the whole process becomes a group decision. Within this group decision several processes of individual decision-making are continuously followed. Group decision-making includes individual decision-making, possibly involving different actors at different times in the decision process.

Individual DSS are usually conceived as interactive tools that support the complete decision process. Group decision support systems were originally built on this premise, but the overlapping of individual and group decision making processes and the differences between individual disciplinary approaches soon required a more detailed analysis of the differences between individual and group behaviour. An examination of how a basis for mutual comprehension could be reached also became essential.

Comprehension is the assignment of a meaning to something. Communication is based on mutual comprehension. Two theoretical approaches describe the process of attributing meaning [Scheper 1991]:

1. The *dictionary approach* claims that the meaning of a code (linguistic expression, sign etc.) is constituted by and represented through its components. Each code refers to a definition consisting of primitive concepts.
2. The *encyclopædia approach* describes the code as a symbol indicating one or more elements at a level of signification, i.e. a concept. Any element of language refers to a conceptual sense outside the symbolic level. This offers a way to describe these concepts in different ways.

The process of communication can be described as follows:

1. In order to create a message (communicate) the sender translates a concept into a code;
2. This code is transmitted through a channel into a context;
3. The deriving signal is captured by an addressee and decoded via a proper meta-code.

In order for clear comprehension of the message to occur, the creator's and the addressee's meta-codes must coincide with the code transmitted within the specific context. Differing meta-codes and circumstances change the meaning of codes, so in order to guarantee clear comprehension the codes must be discussed so that a common meta-code can be defined for a certain context.

Group decision support is therefore required not only for the steps in evaluation, but also to guarantee a high level of mutual comprehension within tool development, and within the evaluation process. It is also necessary for the presentation of (intermediate) results.

3.3.4 Institutions involved in European urban local government

The paragraphs above include the observation that when DSS are used in business applications, they usually serve upper and middle management. This section analyses the identity of the actors in European urban management who would be able to profit from the development of similar applications. Who are the possible users?

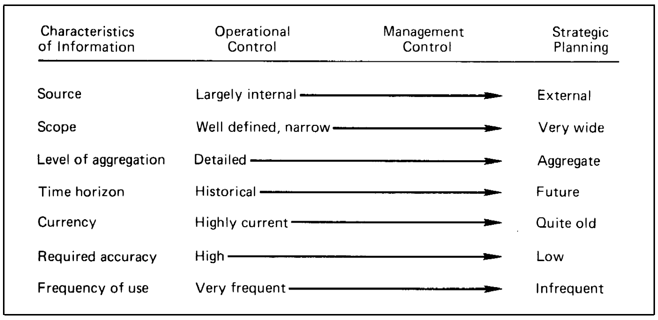
European city administration is responsible for the implementation of political decisions and the daily management of towns. Amongst other fields of responsibilities the following are related to the physical structure of the city:

- Infrastructure management:
  - traffic network
  - utilities and facilities
- Land ownership management:
  - cadastre (register and map)
  - taxes
- Town development and planning:
  - regional and local planning

  - permission for construction
  - planning large town development projects
  - supervising implementation in collaboration with other departments
- Environment:
  - environmental monitoring
  - management of green spaces in the town area
  - natural reserves management including habitat monitoring and biotope mapping
  - environmental impact assessment for construction projects
- Communication:
  - internal communication with other areas of administration and departments that do not specialise in the specific fields of environment, planning, etc.
  - external with citizens: informing the public to increase understanding of planning decisions.

All these responsibilities require continuous evaluation of the status quo. Problems within the urban environment must be monitored, and goals for future development must be defined. In addition, decisions aiming at reaching these goals must be implemented. In Europe, strategic goals are usually defined within public government bodies. The methods for achieving those goals and for achieving management planning tasks are run by public institutions, by private companies or by public private partnerships.

To support decisions about these activities, information from inside and outside the institution is required. Anthony [1988] describes the mix of internal and external information required in figure 3.2.



Characteristics of Information	Operational Control	Management Control	Strategic Planning
Source	Largely internal →		External
Scope	Well defined, narrow →		Very wide
Level of aggregation	Detailed →		Aggregate
Time horizon	Historical →		Future
Currency	Highly current →		Quite old
Required accuracy	High →		Low
Frequency of use	Very frequent →		Infrequent

Figure 3.2: Internal and external information [Anthony 1965].

Because of different types of actors, different tools are currently used for decision making in these fields. Some of these are listed in paragraph 3.1.2.

3.4 CONCLUSIONS

In chapter 2 a select number of ways of describing and analysing the European urban environment were pointed out in order to illustrate the multi-disciplinary views present within the related decision processes. Chapter 3 offered a glance at the multitude of methods applied in European urban environmental management and the different parts decision-makers must play within the process of problem solving. These two chapters introduced decision-makers and tool developers to the complexity of their roles in order to enable them to participate in the preparation of a tool able to support them properly during the evaluation process. This introduction forms a basis for the approach presented in chapter 5.

In economic research, a new line of analysis was born in the 1960s out of attempts to cope with the problem of changing value sets that depended on the responsible decision-maker's subjective point of view and on the interests of stakeholders. These systems try to support one or more decision-maker(s) in modelling her/his/their specific value set(s) in terms of preferences referring to multiple evaluation criteria, which are preferably inter-disciplinary and often conflicting. Different methods of decision support made possible by these so-called multi-criteria analyses (MCA) are described in detail in Chapter 4. This will prepare the reader for the decision support tool development process in co-production between user(s), stakeholders, client(s) and technical developers that is detailed in chapter 5.

CHAPTER 4 Decision support systems – a selective review

4.1 INTRODUCTION

Chapters 2 and 3 introduce the actors, disciplines and methods that have been or might be applied in the case studies reported in chapters 6 and 7 and that form the basis of the DSS-maker's script development.

This chapter introduces the theory and methods applied in specific tools for decision support: the decision support systems (DSS). Again, the methods named are not listed to complete a glossary, but as a theoretical introduction and toolbox to support the implementation of the approach described in chapter 5. This chapter also introduces users and clients to the cultural background of the experts in DSS technical development and assists them with the choice of an adequate method for each specific case.

Figure 4.1 this chapter's logical structure.

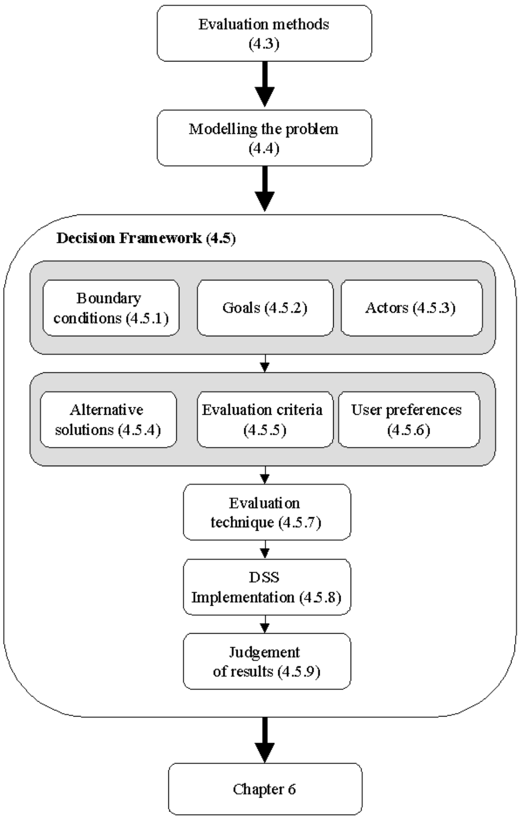


Figure 4.1: Chapter 4's logical structure.

4.2 INTRODUCTION TO DECISION SUPPORT SYSTEMS

When approaching a decision, one may blindly act at the prospect of a problem, or assume that a suitable solution may be found by reasoning the problem over. The first type of approach does not allow for any external support. The second searches for indications of the problem's solution within the problem's dynamics, evaluating the expected impact of any possible solution in relation to the desired type of change in the current situation.

"Decision Support is the activity of a person who relies on clearly explicit but more or less completely formalised models, in order to get answers to the questions posed to an actor in a decision making process. The answers should enable a prescription of the behaviour of the actor, increasing the consistency between the evolution of the decision process and the objectives of the actor". [Roy 1985]

While there are many definitions of Decision Support Systems (DSS) [Keenan 1997], there is general agreement that these systems:

- attempt to help one or more decision-makers to find concrete solutions for decision problems;
- focus on supporting rather than replacing the user's decision-making skills;
- need to support semi-structured and unstructured decisions;
- facilitate the use of data, models, and structured processes in decision making;

DSS have formed a well-established area of information systems application since the early seventies. The first DSS derived from management information systems developed in economic "Operations Research". Traditional applications range from operational control to management control and strategic planning.

Numerous disciplinary areas are relevant to DSS development. These include computer science, management science, operations research and some areas of social science. Computer science represents the systems' background in terms of technological concepts and Information and Communication Technology provides the hardware and software tools necessary to implement DSS design components. In particular, computer science provides database design models and programming support tools that are very important for the effective implementation of a decision support system. The fields of management science and operations research provide the theoretical framework in decision analysis that is necessary to design useful approaches to decision-making. The areas of organisational behaviour and behavioural and cognitive science provide information about how humans and organisations process information and make judgements in a descriptive fashion. The design of effective decision support systems requires background information from all these areas.

The structure and components of a DSS are linked to the specific problem it addresses and to the characteristics of the actor(s) involved in the process. The most important processes in planning, which could be supported by a DSS, can be classified as [Mandl 1994]:

1) storing, processing and presenting data required continuously, repeatedly or even once in relation with the specific problem;
2) representation and user-transparent description of simple and complex relations between data inputs relevant to the decision process;
3) generation of possible alternative solutions to the problem;
4) modelling and simulation of impacts deriving from desired, proposed and/or existing alternative solutions,
5) comparison of the performance of each alternative solution considered with a set of decision criteria and preferences formulated by the decision-maker;
6) analysis and evaluation of possible conflicts deriving from the different sets of preferences linked to different actors within the process of decision-making.

Fjermestad and Hiltz [1996] conclude, from analysing 122 applied experiments, that the higher the complexity of a problem and the larger the group of decision-makers involved, the more the DSS support is appraised during the decision-process.

This sounds logical if one considers the fact that a DSS offers a kind of description of the problem, which all possible users should be able to understand, and thus represents a common basis for discussion among all decision-makers and stakeholders. Information about and models of the dynamics of all the different aspects of the problem are available during the whole decision process. Also the effect of a structured approach becomes more evident with a larger number of participants within a group of decision-makers. The structured approach enables all actors to participate in the process without handicaps based on lacking information and helps them to communicate, defend or modify their personal points of view.

It is a particular challenge to develop tools that are intended to support decisions in environmental management. These tools must support stakeholders ranging from technical actors to public administrators by handling a common base of information from various disciplinary areas and applying rules for the evaluation of alternative solutions to the problem. The different views and preferences of all the actors at stake must be taken into account.

4.3 EVALUATION METHODS

The first models of decision-making processes described the processes as strict sequences of steps to be followed. Attempts to analyse decision processes on the flow showed that this was unrealistic. After this, the different phases of decision-making were considered as interchangeable pieces of a pattern within an iterative process [Scheper 1991]. Observation of several decision processes shows that the decision process starts with the definition of a goal and ends with the approval of its implementation. Intermediary decision steps may be reached and may result in additional changes in other steps that are to be looped back into.

In the past, cost-benefit analysis (the attempt to express all positive and negative impacts of an alternative by the use of one single criterion: the price) has been the most commonly used method for evaluating discrete alternatives [5]. This approach is most frequently applied to single-step evaluation problems. Many decisions in environmental management cannot, however, be handled exclusively in terms of price or another single evaluation criterion. Related methods, such as cost-effectiveness analysis [Seiler 1968], the planning-balance-sheet method [Lichfield et al. 1975], and the shadow project approach [Klaassen 1973], are significant improvements over traditional cost-benefit analysis for complex problem solving, but do not permit satisfactory evaluation of incommensurate and intangible outcomes.

The development of methods and procedures that take into account various evaluation criteria, is called Multicriteria Analysis (MCA). It has been defined by Roy [1985] as follows:

"Multicriteria analysis is a tool to aid decision and a mathematical tool to compare different alternatives or scenarios against several, often conflicting, criteria in order to guide the decision-maker(s) to a rational judgement."

To approach problems of decision-making by relying on multiple criteria, different evaluation methods have been developed over the years. There are two major schools of MCA [Labreque 1998]:

---

[5] Refer also to paragraph 2.2.2.2.

a) The American School is characterised by *complete* aggregation methods that eliminate the incomparability of the different criteria and that often search for one optimal solution (e.g. the *Multiple Attribute Utility Theory (MAUT)*[6] and the *Analytic Hierarchy Process (AHP)*[7]). The MAUT defines the complete aggregation as the process that structures distinct elements in order to obtain a homogeneous context leading to a result. This means a common unit or "currency" has to be defined, in which all criteria may be measured, in order that they can be compared within a common context. The area of research covered by the American School is called "Multiple Criteria Decision Making" (MCDM).

b) The European school, applying *partial* aggregation methods, which take into account incomparability and which try to find the best possible solution for satisfying the different actors (e.g. the *ELimination Et Choix Traduisant la Realité (ELECTRE)* [8], *PROMETHEE* [Vincke 1992], the *Reference Point Method* [9], the *Distance to the Ideal Point Method* [10]). The area of research covered by the European School is called "Multiple Criteria Decision Aid" (MCDA).

In order to choose a proper evaluation methodology and, possibly, a related tool, it is essential first to define the decision space. The decision space includes the goals of the decision process, the dynamics of the system impacted by the problem to be solved, the actors in the decision process, the set of possible alternative solutions to be evaluated and the set of the characteristics of these alternative options used as evaluation criteria.

MCA has developed different methodological approaches to comparing a continuous or discrete set of alternative solutions to a problem. The evaluation is based on the specification of particular goals, a structured description of the possible alternative solutions via cardinal characteristics, and the comparison of these alternatives. The logic of decision-making on which the theoretic approach of DSS is based lies in the comparison of each alternative solution's performance in relation with a consistent set of decision-criteria. The final result consists of a visualisation of the one optimal solution or a ranking of possible alternative solutions in relation to their fulfilment of the pre-set goals.

Discrete methods [Nijkamp, Voogd 1985], developed by the discipline of "Multi-Attribute Decision Making" (MADM) [Zimmermann 1987], are based on discrete decision spaces composed of a few known alternatives described by specific attributes

---

[6] Application of a simple linear function for each criterion.

[7] Hierarchical structuring of the decision space.

[8] Principle of majority: if an action A1 is at least as good as any other for the majority of the decision criteria and if there is no criterion for which the action A1 is much worse than another action, then action A1 is the best.

[9] Determine a specific reference value for each decision criterion (co-ordinates of the *Reference Point*) and calculate the distance from this value to the values obtained for each alternative option.

[10] Like in the *Reference Point Method*, the co-ordinates of the reference point are the optimum values for each criterion.

related to the decision-criteria. The goal of MADM is the preference ranking of the alternative solutions as the basis for a decision seeking the "best possible compromise" in relation to the decision-maker's goals as a solution. A major step in all these methods is to construct a matrix of alternative solutions against evaluation criteria, the so-called Impact Matrix. The usual methods applied for comparing the alternatives are a weighted linear comparison of criteria to scores or concordance-discordance analysis (outranking), which consists of pair-by-pair comparison of the performance of the alternatives in relation to one specific decision criterion.

There are many discrete multicriteria methods, for 'hard', 'soft' and mixed evaluation problems, with each method having its own particular advantages and disadvantages and making its own individual assumptions. Some of the most popular methods are the expected value method, the discrepancy method, the goals-achievement method, the concordance approach, the permutation method, the frequency approach and the geometric scaling approach.

Continuous methods are especially appropriate in planning processes that involve some kind of capacity determination. The related research is called "Multi-Objective Decision Making" (MODM). In application, for example, to siting problems, space is seen as a continuous resource, meaning that it cannot be represented as a limited set of alternative locations. Much attention has been given to the development of continuous methods for 'hard' evaluation problems relying on quantitative information. The results consist of different types of optimisation methods. Some of the most popular of these are utility methods, penalty models (such as goal programming models), min-max approaches, reference point models and hierarchical models.

In cases where the decision space is clearly defined, a specific evaluation method may be chosen from the range of existing methods[11] and directly applied. If the goals, alternatives, preferences and/or criteria are not directly defined, a one-step continuous evaluation is not possible. In these cases, the decision-makers have to be guided in defining the related elements of the decision-process via a trial-and-error interactive process starting from a preliminary definition and ideally resulting in an accepted profile. This requires interaction between analyst(s) and decision-maker(s) in order to guarantee the best possible translation of the decision-maker's conceptual model of the decision-space into a representation modelled within the DSS. In order to optimise the communication process, the approach developed in chapter 5 introduces the decision-maker(s) and other actors as parts of the DSS development process.

---

[11] For further reading, see [42] or [43].

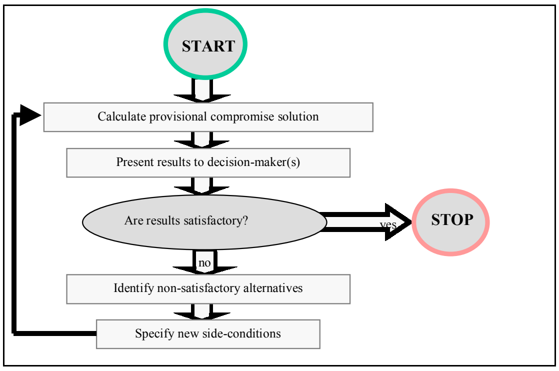


Figure 4.2: Interactive evaluation procedure

Interactive procedures of this kind are based on an information exchange between the analyst and participants in the decision-making process [Nijkamp, Voogd 1985]. The basic feature of such procedures is that the analyst suggests a certain provisional feasible profile of the element to be defined for the decision maker(s), for example, a compromise, to get feedback on unsatisfactory aspects of the provisional solution.

Instead of presenting a fixed solution, the analyst thus develops a learning procedure in order to reach a satisfactory final compromise in a limited number of steps. Consequently, the first proposed compromise is only a trial solution, which is presented to the decision maker(s) as a frame of reference for judging the efficiency of alternative solutions. The easiest way to carry out such an interactive procedure is to ask the decision-maker(s) which values of the policy objectives are satisfactory and which are unsatisfactory. This can easily be done by using a checklist that includes all values produced by the first solutions.

Now suppose that a number of criteria are judged to be unsatisfactory by the decision-maker(s). This implies that a new solution needs to be identified with better performance. Consequently, all solutions with worse performance may be discarded.

The new solution will be again judged by the decision-maker(s): this procedure will be repeated until its results converge with a satisfactory solution.

Interactive procedures have several benefits. They provide information to the decision-maker(s) step-by-step and they can be included in a dynamic decision environment. They also actively involve all participants in the process. One limitation of this approach is that the final solution can be influenced by the procedure followed or, especially, by the starting solution. In addition, for several continuous evaluation methods, there is no guarantee that the solution can be obtained within a finite number of interactive cycles unless it is assumed that the decision-maker(s) is/are acting in a consistent way. The approach also assumes that a group of decision-makers representing different interests can always arrive at general conclusions about the satisfactory and unsatisfactory aspects of preliminary solutions.

4.4 MODELLING THE PROBLEM SPACE

> "A system is a collection of people, resources, concepts, and procedures intended to perform an identifiable function or to serve a goal [...]. The notion of levels (or hierarchy) of systems reflects that all systems are actually subsystems, since all are contained within some larger system. [...]. The interconnections and interactions among the subsystems are interfaces.
>
> Systems are divided into three distinct parts: inputs, processes, and outputs. They are surrounded by an environment and frequently include a feedback mechanism" [Turban 1988].

In order to describe the problem as a system that afterwards can be processed by a digital tool, a structured projection of the real-world problem must first be produced. This projection is an abstraction, but it is also an image of the problem that will be processed by the DSS. This means that if the model is very complex the development of the DSS will require many resources and the tool will be more complex. They complexity of the tool increases in proportion to the number to details incorporated into the model. Aspects not included in the model will not be considered in supporting the decision so certain important factors might be omitted.

In addition, the more the problem space is isolated from its environment (closed system), the easier it is to understand the system processes and the neater the model outputs are. But if such a system is strongly influenced by its environment, these interactions might change the whole model, requiring complex interface modelling, perhaps through scenario definitions. Thus the problem-modelling phase forms a very delicate basis for the whole decision process.

To initiate the modelling process, the decision-maker/client and the analyst have to define a common descriptive structure for the model. To find a solution to any problem, the decision-maker forms a mental representation of the problem itself. This consists of a kind of running simulation of the situation, and is called by psychologists a mental model [Zwisler 1998]. Mental models are defined by D.A. Norman [1983] as: incomplete, limited in their possibilities for running, not resilient over time, not neatly distinguished from each other and unscientific. They do not necessarily reflect real mechanisms and they minimise the cognitive resources needed for the representation.

To minimise the use of these resources, problems that are perceived as similar are approached in a schematic way. Experts therefore usually solve even simple problems within their areas of expertise more quickly than novices do. When analysing basic data, they activate a known solution scheme and follow the steps automatically, whereas novices must first create a novel scheme on the basis of the specific problem indicators. The way the problem is represented depends on its individual mental model, which is itself dependent on the portfolio of problem-solving schemes and/or categories known to the decision-maker.

Several problem-solving techniques have been developed. Thierauf [1988] explores four of them in greater detail:

- *accurate problem definition:*

A problem-diagramming procedure isolates root causes. First, all the main problems, symptoms, and related problems are listed. Each is then numbered. These numbers are written at random on a piece of paper and each is circled. Arrows are then drawn to show what causes what. The real problems become clear at the end: arrows only lead away from them.

- *problem definition table*

A table is set up to answer questions about the nature of the problem with either a positive or a negative response (it is / it is not). This leads to a more concrete understanding of the problem.

- *reversal*

The reversal approach looks not at the problem itself, but at possibilities for changing its environment in order to eliminate it. This leads to new perspectives upon the problem.

- *redefinition*

Redefining a problem in a larger context may open up additional solutions. Not only should the problem itself be considered, but also the definition of user needs and habits as well as other environmental variables. As long as these are seen as the problem environment, they are regarded as "fixed" and the possible number of solutions is limited. When such variables are included within the definition of the decision space, the set of possible solutions may be enlarged.

These are just some examples of techniques that can be use to define a problem, but they can be used selectively or in combination for almost all problem-solving cases.

In DSS development, it is not the decision-maker him-/herself who finalises the tool. It is vital that the graphic user interface (GUI) be structured according to the decision-maker's individual way of representing the problem. The decision-maker needs to represent or communicate the proper mental model to the analyst and/or the DSS designer. This could possibly occur in a figurative way, which could later on be included in the GUI's method of representation. Often decision-makers are not accustomed to describing models, and would thus typically start by naming some elements within it.

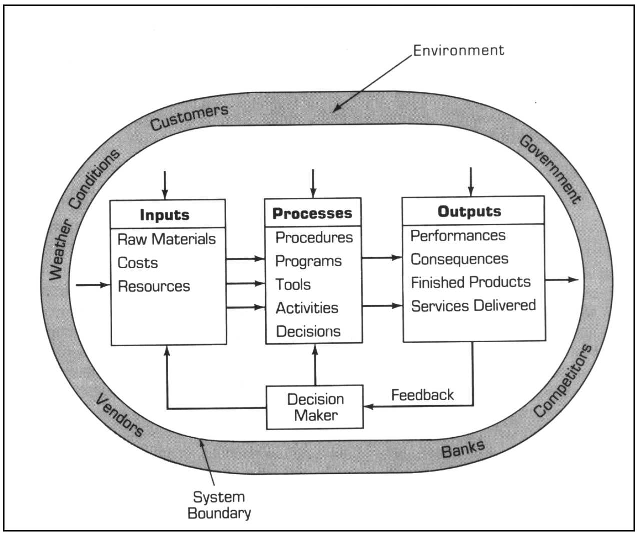


Figure 4.3: The system and its environment [Turban 1988].

Representing the description on a table-game-board (known situation) might help structure it. In this situation the representation is built through the continuous addition and alteration of elements. It may be helpful for the analyst to create an adaptation of the general problem layout represented in Figure 4.3.

Experience has shown that it is difficult to focus a discussion without such support. The following paragraphs analyse different aspects of problem modelling as a basis for the concrete problem modelling in the DSS design considered in chapter 5.

4.4.1 Analysis of the problem complexity

A problem's complexity is the perceived difficulty of describing the interaction between factors influencing changes in the state-of-the-art. This means that to describe the complexity of the problem, one must first describe the state-of-the-art. A description cannot include all aspects of the situation at the beginning of the evaluation process, but must include all aspects relevant to any possible change. Factors left out during this description may lead important side-effects to be ignored during the evaluation.

The state-of-the-art must be described in terms of current negatively perceived effects, their source(s), the reasons these sources are required and by whom. This way the first alternative solution is defined as "business as usual" and the first group(s) of stakeholders is identified.

To find other stakeholders, one has to understand what would happen if the sources were simply eliminated without being replaced. This could, in some cases, be another extreme alternative. If this option does not satisfy the decision-maker, alternatives must be found to solve the problem. The easiest way is to replace the source with alternative options.

A second possibility is to change background conditions, so that the source is no longer needed (e.g. move from a suburb to within walking distance of the workplace to eliminate the need for a car). These changes include changes in behaviour patterns and are much more difficult to analyse, since they include additional groups of stakeholders and fuzzier results dependent on the unknown side-effects created by a completely new background pattern (e.g. does the partner then need the car to get to work? Are more trips to the suburbs necessary to care for the elderly? Are more trips necessary for recreational purposes?).

Further, a decision produces its impact over time. Scenarios for the future (e.g. petrol prices will triple within the next three years, electric cars will be plugged into household electrical sockets) may be developed to take this dimension into account.

1) What is wrong? What is/are the source(s)?
2) Why and for whom does the source exist?
3) What would happen if the source were to be eliminated without replacement?
4) What new element could replace the source without re-creating the problem?
5) How could background patterns be changed to eliminate the need for the source?
6) What possible future scenarios can be expected?

These questions assist in the initial development of the decision space, but they have to be supplemented by the inclusion of the points of view of the actors involved, the client, the decision-maker and possibly the stakeholders. The results might surprise the decision-maker, and thus assist with the evaluation.

4.4.1.1 The problem as perceived by the client

The development of a tool for decision support is a resource-intensive process. This development process is linked a customer's request. This thesis calls the DSS developer's customer *client*. In DSS theory, the client is usually identified with the DSS final user. The practical cases observed by the author of this thesis showed that the client could not only be identified as the final user, but that the client might also be a stakeholder or even an actor interested not in the single decision process, but in a strategic goal.

The problem of the non-identity of the *client* with the decision-maker has not yet been discussed in the literature. This thesis attempts to include an analysis of the client to avoid classifying the success of a DSS only as it is linked with its end-user and to include all actors' goals into the DSS development process.

The client requests or funds a project for DSS development with a certain goal, so that the client is a stakeholder. The client's goal has to be determined in detail to guarantee the DSS's successful delivery. The clients' role within the decision process must also be defined in order to anticipate possible conflicts of interest between the client and the DSS end-user. The following examples illustrate possible conflicts.

Example 1: A car seller would like to convince his customer to buy a car. To gain his or her confidence, he would commission a tool to define the user's needs. The tool would select, on the basis of the client's criteria settings, the type of vehicle the user would prefer. As alternative options within the database, the set of vehicles within the car-seller's catalogue would be included. This would lead to a scenario in which the user would choose the best solution from the car-seller's range of products. The tool supports the user in defining his/her needs, but the client's requirements exclude all options in the database from the range of possible alternative solutions.

The database in *Example 1* is linked to the client. The set of evaluation criteria is most probably developed on the basis of typical questions asked during the sales process, so that they are linked to the decision-maker's needs. This creates an ambiguous situation: although the system attempts to choose the best solution out of the set of options, these options are not selected from all available options on the market (objective choice) but from the client's portfolio (limited choice). In this case, the client is a stakeholder involved in the evaluation process who limits the choices available.

Example 2: The EC has funded the development of several DSS for specific local applications. Most of these applications were intended to be applicable on a European scale. Local actors have, however, been involved with the projects, very often as representatives of the end-user group. Nevertheless, very few of these DSS are applied in the real world at the moment and it is becoming increasingly difficult to convince local actors of the utility of their investment in the development of these tools. Most of the time, this is because the projects have their own lives independent from the use of the tool. Resources are expended on deliverables produced during a specific time frame and on a final product, but they are not expended on increasing the project's applicability or on increasing the tool's acceptance among end-users. The EC tries to correct this problem by asking for more user-oriented development. But there is a common problem for all developers: it is difficult to define a tool that is both locally useful and has a demonstrated European dimension. The developer must find a level of detail useful for both the EC officer and the local user. This mostly leads to generalisation of specific elements. After this, the tool must again be adapted by the local user, who has to defend the effort spent to the local authority that funds the adaptation.

Example 2 illustrates how different requirements for a certain level of detail within the definition of the scenario, as well as inflexible time frames between the client and the DSS user may hinder the final tool application.

The two examples illustrate the two major roles of the client:

1) a direct interest in influencing the user's choice;

2) an interest in the decision to take place.

Client 1) influences the evaluation itself by manipulating the quality of the input to the decision space. Client 2) requires a generalisation of the evaluation process for strategic goals and thus eliminates levels of detail within the definition of the decision space and/or the description of the results. Both interfere in the process that supports o the evaluation process by influencing information quality and/or representation. In order to guarantee that the end-user receives the maximum amount of support possible, the client's requirements should be communicated to the end-user as background conditions at the beginning of the project's development. This usually does not happen, because client's influence on the project's outcome is not perceived.

4.4.1.2 The problem as perceived by the decision-maker

In order to support a decision-maker's evaluation process, the problem, as it is perceived by the decision-maker, must first be modelled. Most everyday evaluation processes are not consciously structured and rarely do decision-makers have to outline all the individual steps in these processes. This creates a situation where whenever an analyst tries to lay out the problem structure he/she is initially confronted with scepticism ("why do you want to know all this? Do you think I am no longer able to make decisions?"). After overcoming this barrier, he/she is then confronted with the problem of structuring and conveying a complex system of aspects, options and their weights within a conceptual model.

In many of the DSS development processes documented in literature, it is the analyst who finally sketches out the background conditions and the decision space as it is understood after an initial interview (or as it is described by the client, at the risk of mixing the points-of-view). This initial sketch should be developed in detail in consultation with the decision-maker in a second interview and, later on, possibly in consultation with other stakeholders regarding their fields of influence.

In most cases known to the author, questionnaires and/or protocol sequences of interviews and sometimes short telephone calls and cross-checks with partners of the DSS developing team have formed the basis for further development of the decision space. Whether or not to perform a final check that this phase of development produces an accurate outline of the model of the decision space has generally been up to the client.

4.4.1.3 The problem as perceived by the stakeholders

Within a complex evaluation process, the stakeholders represent groups with interests in the evaluation process that may possibly put pressure on the decision-maker. This pressure has different qualities and power indexes from one stakeholder to another and sometimes even differs over time, e.g. just before an election. To support the decision-maker with his/her evaluation, the stakeholder groups must be identified, and their view of the problem and possible alternative solutions and scenarios must be sketched out.

In most cases of single actor evaluation process known to the author, the descriptions of stakeholder profiles have been drawn from literature and sometimes have been adapted by the decision-maker and/or the client. The client's position is unique within the definition of the decision space as long as he/she is not identified with the decision-maker. The best practice for DSS development would be the verification of the stereotype profiles and weighting systems against actual local stakeholder representatives. This is usually skipped because of resource problems, or unwillingness on the part of the decision-maker or the client to make the tool development public before at least a prototype is ready for presentation.

This is different for group decision-support tools, which are designed to support groups who requested their development or who are obliged to use them. In this case, all participants can be regarded as decision-makers and are usually considered more carefully.

4.4.2 Analysis of the support required by decision-makers

Often the support required by the decision-maker and the decision-maker's profile are analysed in a single attempt. Within this thesis, these aspects are handled separately to underscore the importance of defining the various goals for the tool's development before classifying the end-user. Otherwise, one risks inserting the DSS developer's or the profile analyst's interpretation of the user needs (deriving from the interviews held for profile definition) into the place of the user's own interpretation of his/her needs. The user and the client should have the opportunity to define and to understand their own expectations for the process.

The amount of support required within the decision-making process is defined according to several factors: the evaluation step(s) supported, the level of detail analysed, and whether a decision must be made or whether the process analyses or confirms an existing decision or proposal. The profile defines the traditional evaluation process, the hierarchical structure in which the decision-maker is placed, the decision-maker's skills in using specific technical tools, etc. The required support defines the results expected by the user/client and their representational needs; it also describes the end-user's skills and requirements for physical interaction with the tool as well as his/her typical parameter settings within the decision-space. User acceptance is closely linked with the design of the interface of the supporting tool. The integration of representational schemes known to the user with traditional tools could increase the acceptance and use of such a tool. R. Zwisler [1998] found through testing the acceptance of different graphic user interfaces to simple mathematical solutions, that the user more easily accepted a known graphical scheme.

4.4.2.1 Questionnaires

Questionnaires are designed to serve a variety of purposes including screening individual respondents and obtaining data on populations of interest in applied theory-based research. The form and content of questionnaires vary with the purposes for which they were designed and with the methods by which they are administered. Like other pencil-and-paper psychometric instruments, questionnaires may be administered on an individual or group basis.

One-to-one administration involves a single administrator or questioner and a single subject or respondent. This is the method adopted for end-user profile assessments. There are different methods for collecting answers to a set of questions:

1) The questioner poses the questions orally or in printed form and requests either an oral or a printed reply. Typically, a face-to-face or at least a telephone interview follows this procedure.

2) The questionnaire is administered by a computer on an individual or group basis (e.g. through the Internet). The computer is programmed to pose questions, collect the answers, evaluate the answers and print the related results.

Group administration is required when prototype tools are designed for specific user groups (they are usually required for publicly funded research prototypes) and for stakeholder assessment. This approach typically involves two methods:

1) mail survey, which entails sending a questionnaire by mail to a large group of people;
2) a group survey of selected representatives of the group at a designated time and place.

For an overview of the pros and cons of specific methods, please refer to Aiken [1998].

The process of constructing a questionnaire begins with the definition of a purpose, which then leads to a plan. When the plan calls for the construction of a questionnaire that gathers information on a wide variety of matters, the plan becomes rather complex. In these cases, a table of specifications or a flowchart is useful for preparing the directions and questions. The format of the questions and the directions that introduce them vary according to the purpose of the questionnaire and the form of its administration. For example, long questions are less appropriate for oral administration than for mailed questionnaires.

The overall purpose of any questionnaire is to motivate a sample of people selected from the target population to give truthful and thoughtful answers to all relevant items on the questionnaire. Achieving this goal can be facilitated through:

1) making the questionnaire clear, attractive, brief, meaningful and interesting;
2) choosing a questionnaire designer who possesses the technical skills to construct such a questionnaire, and who clearly understands its purpose, topics, and conditions of administration and who also understands the characteristics of the people to whom it will be administered (the designer should have thorough knowledge of all actors and rules).

This short introduction to questionnaire techniques ought to show that a questionnaire should not be developed without the co-operation of someone skilled in developing them, or without at least specifically training another actor involved in the DSS development process. Otherwise there is an increased risk of misunderstanding the collected replies so that the results obtained may not enhance but may detract from the tool's development.

4.4.2.2 Observation and interview

The most widely employed method of personality assessment is some form of observation. Observation means taking note of events and keeping records of what is seen or heard. Because having previous knowledge about certain people and/or the purpose of the research may lead to bias, the observer should have access only to absolutely necessary information. This method may be applied during the user and stakeholder assessment sessions in combination with interview techniques and it may be applied to group decision-making to enhance understanding of the dynamics of the group and the interaction of its members.

The interview can be defined as a "face-to face verbal interchange in which one person, the interviewer, attempts to elicit information or expressions of opinion or belief from an other person(s)" [Maccobby, Maccobby 1954].

Interviewing collects the same information as observation (what a person does) since the technique includes controlled and uncontrolled observation, but it also obtains information about what a person says. The major emphasis in interviewing is, however, on the content of verbal statements made by the interviewee. Information typically gathered in interviews consists of details of the interviewee's background or life history, in addition to data on feelings, attitudes, perceptions and expectations that are usually not observable. An interview can be an end in itself, and as such is commonly used for user profile assessment, but it may also function as a way to get acquainted, or as a lead-in to other assessment procedures or to co-operation. Interviews may be used to start the co-operation process in DSS development.

Aiken [1999] gives the following recommendations for how interviewers should act:

1) friendly but neutral, interested but not prying, in their reactions to interviewees;
2) warm and open;
3) patient and comfortable, not hurrying the interviewee;
4) accepting of interviewees for what they are without showing approval or disapproval;
5) timing the questions and varying their content with the situation;
6) developing a conversation that flows from topic to topic;
7) paying attention to what is said and how it is said;
8) asking for clarification or repetition to confirm understanding.

The degree to which interviews should be structured depends on their goals and the interviewer's skills. Less experienced interviewers typically prefer structured interviews, as these results are more easily quantified for the purpose of analysis. Experienced interviewers generally prefer greater flexibility in the content and timing of interview questions, and thus less structured approaches.

In any case, a topical outline of the interview helps the interviewer to structure the information to be collected beforehand and may lead to a more- or less-structured interview permitting structured storage of the gathered information.

4.4.2.3 Checklists and rating scales

In order to evaluate the gathered information different results must be compared. Rules for this type of comparison are usually provided in checklists or rating scales.

Checklists require yes/no decisions about the presence or absence of particular characteristics. They can usually be constructed quite simply and are commercially available for multiple purposes. However, checklists do not permit sophisticated ranking and thus even the use of a large sample of participants may produce stable results.

Rating scales may consist of numerical designations, verbal descriptions or objective descriptions. A semantic differential is interpreted here as a special form of numerical scale. The errors that can occur when rankings are made include:

a) ambiguity errors;

b) constant errors (leniency, severity, central tendency);

c) contrast errors;

d) logical errors;

e) proximity errors.

Different error smoothing methods exist [Aiken 1999], but when a rating scale is constructed as carefully and objectively as possible and the raters are well trained, the reliability coefficients between 80 and 90% can be attained. This also demonstrates the importance of training the users of the evaluation methods applied within the DSS.

4.4.2.4 Role- plays

"Role play or simulation techniques are a way of deliberately constructing an approximation of aspects of a 'real life' episode or experience, but under 'controlled' conditions where much of the episode is initiated and/or defined by the experimenter"[Yardley-Matwiejczuk 1997]. A role-play may involve one or more actors, it may include imaginative activity on the part of subjects, or it may consist of a 'snapshot' of reality or a longitudinal experience of an 'as-if' event. Role-play allows the manipulation of time and space, restricted only by pragmatic considerations.

Children explore their worlds with play and posit 'as-if' conditions: they practice aspects of their identities in bizarre or banal make-believe settings. They discover each other's reactions, powers, knowledge and identities through this method.

For an in-depth analysis of theory and practice of role-plays, please refer to Yardley-Matwiejczuk [1997].

4.4.3 Analysis of the decision-maker and stakeholder profiles

The profile describes the actor's skills and his/her requirements for physical interaction with the tool as well as his/her typical parameter settings within the decision-space. The end-user's profile thus defines the nature of the tool. It answers questions like whether a crude DSS interface would be understood or if a sophisticated, adapted graphic user interface is required, or if a digital tool is completely unacceptable. It also shows which training steps would be required for the use of different types of tool, etc.

In addition, all profiles initially weight the different evaluation criteria according to stereotypes. An initial user-profile description must be input in order to define the tools to be used, and a second input to all profile descriptions is required for initial tuning of the evaluation itself.

Mostly this analysis is done in a single session, depending on the expense of multiple visits. The author of this thesis has observed that the actors often have difficulty when defining their expectations, their skills and their weights at the same time: they often become confused about weights, criteria and alternative options. This procedure may be done in a single step only if afterwards it is structured and represented to the actors clearly, in order to check for possible misunderstandings. In order to avoid tiring the actors, the following instruments could be used for different steps within the analysis and a check of the previous step could be combined with an introduction to the new type of analysis.

4.4.3.1 Questionnaire and statistical profile definition

The techniques are the same as those described in section 4.4.2.1. A statistical analysis of input from literature is often used in stakeholder profile descriptions. This input should be identified as such or should be checked with the real stakeholders. The questionnaires are usually used to provide a first impression of the end-user group and sometimes of significant stakeholders, especially if not enough information about them can be found in literature.

4.4.3.2 Interview

The technique for interviewing is described in section 4.4.2.3. The interview is usually conducted in order to define the skills and facilities of the end-user’s working venue and should be used to assess the client’s requirements. It can also be used to fill gaps or clear up misunderstandings that have occurred in questionnaire analysis. The basis of the discussion should be clear to the interviewee: it is very important at this stage not to loose the actor’s interest, so existing results should be described to the actor, and the reason the interview is needed should be explained. The interviewee should not be confused with unstructured questions. Time frames for further information-gathering should be clearly explained and the actors should be informed about the results of the interviews and their use within the tool’s development.

4.4.3.3 Role-plays

The technique is described in Chapter 4.4.2.4. The role-play method might be especially useful after the first sketch of the actor’s profiles, to enhance understanding of the different profiles within groups of decision-makers, and their strengths and preferred alliances, etc.

4.4.3.4 On-site analysis of current problem solving approach

This instrument is very useful for an understanding of the traditional evaluation process. It assists in explaining why different approaches might be required, or if specific political antagonisms or other pressures might have produced the demand for the tool, i.e. to individuate the stakeholders. In addition, typical tools can be analysed in terms of the possibility of their inclusion within the final DSS. This way, the user would be able to identify parts of the evaluation process that were previously supported, without needing training about this part of the tool.

4.5 THE DECISION FRAMEWORK

In general, an integrated approach to problem solving using MCDA methods follows a framework including:

1. definition of boundary conditions of the system on which the problem impacts;
2. definition of the goals for problem solving;
3. definition of actors involved in the decision-making process;
4. definition of a set of possible alternative solutions;
5. definition of evaluation criteria;
6. identification of the decision-maker's preferences;

7. selection and application of suitable evaluation techniques;
8. implementation of selected evaluation techniques;
9. judgement of results.

Depending on the type of evaluation pursued, these actions can be undertaken simultaneously or sequentially. An evaluation framework should give insight into conflicts within the decision process and should be adaptable to different demands. An evaluation process often has a learning character enabling it to adapt flexibly to changing circumstances. All possible users concerned must be able to understand the evaluation analysis.

4.5.1 Boundary conditions

In order to analyse a problem, boundary conditions, i.e. the environment on which the problem impacts, have to be defined.

A rational decision may encompass one of three different types of conditions [Paruccini 1992]:

a) conditions of certainty, assuming a decision-maker is selecting one best solution from a set of perfectly-documented alternatives,
b) conditions of uncertainty, where the results of the decision depend on circumstances which are not completely known,
c) multicriteria decisions, assuming the impossibility of taking a decision based on one single criterion of choice and assuming the uncertainty of some part of the basic information.

The description of real world decision problems occurs in decision theory via models, which have been classified by Raiffa [Bell et al. 1977] into three major categories:

- Descriptive models, defined by a set of mathematical relations, which simply predict how a physical, industrial or social system may behave.
- Normative models, constituting the basis for decision making by considering an entirely rational set of arguments. Hence quantitative decision problems and idealised decision-makers are postulated in order to define these models.
- Prescribed models involving systematic analysis of problems as carried out by normally intelligent persons who apply intuition and judgement.

4.5.2 Goals for problem solving

Any evaluation method should be appropriate to the problem it concerns. Each type of evaluation may require a specific method. Problems may be classified according to the characteristics of the decision process and according to the relevance of the available data. A very important subdivision of problem classification concerns the distinction between discrete and continuous evaluation problems. In the case of discrete problems, the alternatives are known a priori; in the case of continuous problems the alternatives cannot be distinguished beforehand, but are defined implicitly by equations simulating their characteristics.

In any discussion of providing computer support for decision making, many classifications of decision problems from different perspectives may be used. Some evaluation problems must be solved immediately (single step problem), whereas other problems may be treated in a process-like approach (multi-step problem). In the second case the 'learning function' of the evaluation is stressed more. Evaluation is seen as a process during which one may add successively more information so that the ultimate solution is identified in a series of sequential steps.

A generic decision process may aim at any of the following types of goal [Jaquet-Lagreze 1985]:

a) selecting the one and only action to solve the problem (the decision support should identify a set of incomparable and/or equivalent actions),

b) choosing all good actions,

c) choosing some of the best actions (offering total or partial ranking of the actions to facilitate the selection) or

d) describing possible alternative solutions and their impacts.

Another important distinction is that between soft and hard evaluation problems. Soft problems are mainly defined by qualitative or ordinal information about impacts or characteristics of alternatives and/or weights, whereas hard problems are based on quantitative information. Mixed evaluation problems include both qualitative and quantitative information.

4.5.3 Actors involved in the decision-making process

In order to choose the right evaluation methodology [Nijkamp, Voogd 1985] and possibly a related tool, it is essential first to determine the identity of the user of the tool itself and of the actors involved in the decision process. The user of the tool may be the one and only decision-maker, one or more members of a group of decision-makers, one or more consultants to a decision-maker or a specific consultant for the application of the tool. The tool may be used to support a group decision: it may need to be used by different actors at the same time, within one room or from different terminals. The tool may also be accessible to the public for a collective decision process. These multiple applications require multiple solutions. The methodologies used range from a vote by hand to a global information system. The more complex the problem, and the more complex the information to be considered, the more probable it is that a formal tool is required to support the decision-maker(s) in understanding the decision space and defining and evaluating alternative solutions to the specific problem.

Historically the analysis of decision-making has considered one single decision-maker responsible for choosing a solution to a problem. The problem and the decision space therefore had to be defined as a system entirely comprehensible by the decision-maker. No other actor was considered.

Even though many decisions have been and still are taken by single decision-makers, complex problems often require information deriving from different areas of interest. Therefore, even in the early days, decision-makers gathered an advisory group around them for several reasons. The advisory group fulfils a triple role:

a) supplying additional information on the specific circumstances of the problem;

b) giving insight into the different evaluation criteria and the specific preferences of each single member of the advisory group;

c) distributing responsibility.

Up to this point we have considered a single decision-maker. Within a social system, however, many problems are solved by groups of decision-makers. The simplest case is the one of an election of a representative within a group in which all members have the same right to vote and simple majority is applied as the evaluation rule. The group of decision-makers includes each person with a right to vote, i.e. all group members. The set of alternative solutions to the problem is given by a limited set of alternatives to vote for, the candidates. The methodology used considers one vote per group member at an equal level using a majority method. A final ranking is achieved by listing the possible options by number of votes. This simple example may illustrate the role of evaluation methods within all decision processes. The acceptance and applicability of the chosen method is at the basis of the acceptance of the final results obtained within the decision process. Evaluation rules are not necessarily complex, but they do depend on the characteristics of the boundary conditions of the related problem. In relation with the quoted example about elections, the existence of more complexly composed groups has required the development of more sophisticated rules like proportional or plurality methods.

The decision process described presumes that the importance of each actor in the decision process is balanced. However, often this balance does not occur. In this case there are several actors with different levels of relevance within the decision process. Sometimes these actors may not take part directly in the decision process itself, but represent groups of interest for the decision-maker (e.g. interest groups, administration, global public, etc.).

The larger the group of decision-makers become, the more the rules of decision-making change from those defined for group behaviour to those defined for the behaviour of the global public based on interaction between and overlapping of different interest groups.

Evaluation methods may be classified by the actors involved in the decision process, distinguishing between multi-person and single-person evaluation problems. In the case of multi-person problems, one has to take into account the impossibility of arriving at precise group trade-offs, because of the dynamics of preferences and the strong 'bargaining' characteristics inherent in such decision-making processes. A single-person problem offers more possibilities for a systematic trade-off analysis; however, also under these circumstances implicit political aims may dominate the evaluation.

Decision process may thus be faced by

a) one single decision-maker alone;
b) one single decision-maker using an advisory group for expert information;
c) one single decision-maker using an advisory group to include influence from other actors in his decision;
d) a "democratic" group of decision-makers;
e) a group of decision-makers with differentially weighted power;
f) the global public as decision maker.

as well as by combinations of these options.

Not all actors connected with the problem are decision-makers. Nevertheless these actors and their preferences impact on the decision-process as pressure factors to be considered by the decision-maker. In every case the set of evaluation criteria used has to take into account the characteristics of alternative solutions that are of interest to the different stakeholder groups involved. The aspects relevant to the stakeholder groups have to be assessed and included in the models, simulating the different evaluation criteria used by the analyst and developing the representation of the decision space.

One of the main problems a decision-maker is faced with is how to find the best possible solution that will be accepted by the stakeholder groups. Groups bargain until agreement on a specific compromise is reached. The final solution is pointed out when one coalition becomes strong enough to outweigh the others. A problem of this kind may be addressed via methods like equity analysis [Munda 1994] that apply similar multi-criteria evaluation methods to sets of alternatives represented by the preference rankings of each stakeholder or conflicting party. The stakeholder preferences would best be analysed directly using preference settings developed by the stakeholders themselves. Other useful overviews may be derived from settings representing the estimated inputs based on the stakeholder profile inserted by the decision-maker or a modeller expert in the specific area of decision-making.

4.5.4 Set of possible alternative solutions

Evaluation problems may need different kinds of outcomes: some problems require the identification of a number of acceptable alternative solutions, whereas other problems concern the selection of a single alternative.

The number of possible alternative solutions to the problem, called 'alternatives' in the following text, may vary between a discrete number and infinity [Nijkamp, Voogd 1985]. In cases where there is only one alternative, this alternative is compared with a pre-defined reference system and the alternative solution is either accepted or rejected as the solution to the problem.

The discrete evaluation problem with a distinct number of alternatives is very common. Both cost-benefit analysis and multi-criteria analysis deal with these kinds of discrete evaluation analyses. The complete evaluation method is applied in order to compare a set of non-dominated alternatives (Pareto set) via outranking methods.

The continuous evaluation problem is concerned with an infinite or very high number of alternatives. These sets of alternatives are represented by equations in relation with the set of evaluation criteria considered. Such a problem has to be approached step-by-step with approximating solutions via multi-objective programming models. The best possible compromise is calculated via optimisation of objective functions. Where possible, it is useful to reduce the number of alternatives to a discrete set.

4.5.5 Evaluation criteria

Decision-processes decide on alternative solutions to a problem [Gilpin 1996]. It is implied that continuing business as usual is also a possible choice. It is possible to discard all alternatives to the current situation or to implement one or another alternative. These actions are meant to have an impact on the current situation, producing certain developments. The goals of these actions may be profit-motivated, a matter of public policy, or nonprofit. The general effect may be an increase in per capita income with perhaps benefit or detriment to the quality of life locally, regionally, nationally, or globally. In choosing his/her goals, each actor in the game must, in any case, take into consideration the interests of other actors with a stake in the decision process.

Consider, for example, problems in urban land-use planning, like where to locate an incinerator. The decision may lie with public authorities, but they will have to take into account the probable reaction of various interest groups including environmentalists, the inhabitants of villages in neighbourhoods of possible locations, transport companies etc.

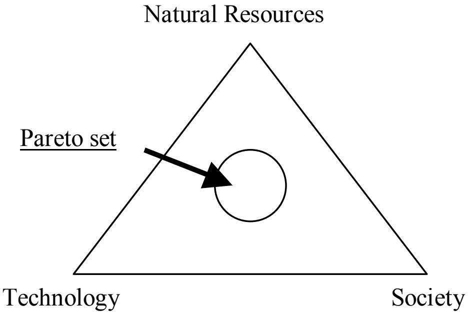


Figure 4.4: Set of alternatives defined by criteria.

This requires consideration of various characteristics of the possible alternative solutions as they are linked to the interests of the different stakeholders, i.e. a consistent set of evaluation criteria. The complexity of this kind of problem excludes the use of one single criterion as a representative for all criteria. How could one, for example, assign the same type of criterion to the value of a particular piece of land and the danger to health represented by the location of an incinerator to a grammar school?

The evaluation procedures treated in this chapter include only multi-criteria evaluation methods. These methods aim at describing a Pareto set representing a possible compromise choice of the different interests considered within the decision process.

During the definition of the relevant set of evaluation criteria, two tendencies must be balanced. To model the problem so that the model resembles as closely as possible the real world problem augmented by a number of decision criteria, the descriptive model must be complicated and its use restricted. In order to apply simpler and faster models the number of criteria is reduced, which leads to an approximation of the problem profile. The suitable number of criteria, or cardinal set of criteria, is reached if the introduction of additional criteria does not affect the solutions, which change because one of them is discarded [Bell et al. 1977].

Problems in the real world often do not permit the choice of a single decision criterion for the comparison of the alternative problem solutions. Therefore several, often conflicting, criteria must be defined. The definition of the set of decision criteria has to overcome certain difficulties:

- the danger of considering the same information as part of different key criteria. This may happen, for example, when environmental impact and human health are considered as different criteria. In this case air and water quality will be considered as indicators for aspects of both criteria. Even though air quality is seen from two different points of view, the original preference the decision-maker associates with this subject will count not only the specific point of view related with the criterion, but also the importance he assigns to the concept of air-quality in itself. This part of his point of view is counted twice in the evaluation process. This effect is called double-accounting;

- the danger of omitting some non-dominated alternative solution, criterion or cardinal aspect of criteria defining the decision space;
- the difficulty of finding data corresponding to the characteristics of all relevant alternatives as they relate to the decision criteria. In practice the relevant set of criteria often depends strongly on the availability of related data.

The selection of relevant evaluation criteria has a strong impact on the decision process and the related learning process for the end-user. In order to avoid the a priori exclusion of specific criteria or a rigid definition of criteria that may not suit the decision-maker, the evaluation procedure should permit dynamic substitution or addition of evaluation criteria.

4.5.6 Decision-maker preferences

The outcome of an evaluation process relies strongly on the point of view of the decision-maker. The characteristics of the possible alternative solutions relevant to the problem are represented by the decision criteria. The point of view of the decision-maker is represented by the definition of the goals of the decision process and the importance he assigns to each individual decision criterion. In some cases, after an initial evaluation the decision-maker may change his point of view according to the results of the evaluation process, thus following a learning process in terms of the impact of his preferences in relation with the outcomes of the evaluation process.

Whether the decision-maker's preferences are given directly or developed during an interactive process, an initial set of preferences is still required to start the evaluation process. To derive this initial set one or more of the following procedures may be applied:

- derivation of priorities on the basis of ex-post analysis of decisions taken in the past. This is not useful for unique decision problems.
- derivation of priorities on the basis of official documents and statements. This is useful for the definition of general issues and policy objectives.
- direct assessment of priorities on the basis of interviews or questionnaires distributed among the participants in the decision-making process. This is mainly useful for finding out about conflicting opinions. Results depend very much on the way questions are posed and on the experience of the decision-maker with evaluation methods and software.
- 'fictitious' assessment of priorities on the basis of consistent policy scenarios reflecting hypothetical but otherwise reasonable priorities for the policy criteria at hand. These scenarios may derive from official documents or experience.

The best way of accessing the user's definition of his decision space and his preference settings is a combination of the above approaches. An ex-post analysis and analysis of official documents may lead to an initial formulation of policy scenarios, rules for selecting alternative options and decision criteria. A direct assessment then may be very useful for fine-tuning the scenarios and detecting conflict situations.

The main approaches to modelling the decision-maker's preferences are to assign explicit weights to the evaluation criteria or to specify the preferences step-by-step on an interactive basis. This latter approach takes into account the fact that different sets of preferences linked to different actors within the process of decision-making lead to possible conflicts.

In most choice situations the information about preference settings is fairly weak [Nijkamp, Voogd 1985], so that usually only qualitative weighting schemes can be created. There are several ways to deal with qualitative weights in multi-criteria evaluation.

One approach is to calculate the extreme quantitative weights, in accordance with the postulated qualitative ordering. By applying a suitable multi-criteria technique for each extreme weight set, one can obtain an impression of the possible divergence in the final outcome of the evaluation.

The use of extreme weights may be very useful if priorities are expressed in detail. In this case it may be appropriate to select a large number of random quantitative weights that fulfil the ordinal priority ranking. For each random weight set a solution can be obtained, which can then be used to update a frequency table that expresses the probability that an alternative will have a first, second or other position. The information on this probability table can then be aggregated into a "most probable" final ranking or into alternatives for the given ordinal priority set.

A third approach is to calculate an approximate quantitative weight set directly, by assuming that the 'real' quantitative weights are uniformly distributed over the area delimited by the extreme weights. The expected metric weights can be modelled via analytic expressions.

4.5.7 Appropriate evaluation technique

In order to choose an appropriate evaluation method to be applied to the specific problem, one has to analyse the decision space. A checklist for the selection of an appropriate evaluation method may appear as follows:

1. *What are the goals of the decision process?*

If this answer is not well defined, an interactive approach may be useful in order to define the goals of the decision process, treating possible goals like alternative solutions to a problem consisting of choosing a specific goal.

Once the answer to this question is well defined, it leads to the selection of an approach that attempts to select a single optimum solution or a preference ranking and/or to employ a conflict analysis approach.

2. *Who is the decision-maker and who are the stakeholders and client(s)?*

Dependent on this answer is the choice of a single or multi-user approach and the definition of the evaluation criteria. The input of stakeholder profiles may be required if the stakeholders do not take part in the decision process.

3. *What are the possible alternative solutions?*

This answer identifies the usefulness of discrete or continuous methods. If no precise description in terms of a list of alternatives or a function describing the characteristics of these alternatives in terms of the whole set of evaluation criteria can be defined, an interactive approach to defining the set of alternative solutions to be evaluated may be useful.

4. *Which consistent set of evaluation criteria has been chosen?*

If the set of evaluation criteria is not clearly defined or is too large to be useful for a practical evaluation, an interactive approach to defining or selecting a cardinal set of evaluation criteria may be useful, That way all alternative solutions considered can be described consistently.

The type of evaluation criteria chosen determine whether a 'hard' evaluation method, based on quantitative data, a 'soft' method, based on qualitative methods, or a mixed evaluation method should be employed.

4.5.8 DSS implementation

Geoffrion [1994] defines Decision Support Systems as being characterised by six features:

- explicit design to solve ill-structured problems;
- powerful and easy-to-use user interface;
- ability to flexibly combine analytical models with data;
- ability to explore the solution space by building alternatives;
- capability to support a variety of decision-making styles;
- capability to allow interactive and recursive problem-solving.

Following the checklist in the last paragraph to identify an appropriate evaluation method that responds to the specific decision space, one notes that not every decision method has been implemented within a DSS. Often the development of a DSS includes the construction of completely new software created to support very specific decision processes. In order to prepare the required software implementation, the following checklist may be useful.

1. *Does a DSS implementation of the relevant evaluation method(s) already exist?*

In this case the relevant implementation should be cautiously examined to evaluate the possibility of adopting the pre-existing software version. One must consider how the pre-existing software defines the related alternatives, the evaluation criteria and the stakeholders to determine how they differ from what is needed. Usually they will not be identical and the software and its interface will have to be adapted.

2. *Who performs the functional roles within DSS development?*

The functional roles within DSS development are [Densham 1991]:

- the DSS toolsmith, who develops new tools for the DSS toolbox;
- the technical supporter, who adds components to the DSS generator;
- the DSS builder, who assembles modules into specific DSS;
- the intermediary, who sits at a console and interacts physically with the system;
- the decision-maker, who is responsible for developing, implementing and managing the adopted solution.

The answers to these questions determine the choice of possible technical tools, levels of communication between analysts and decision-makers and all other aspects of the technical implementation of the evaluation methods described in detail below. The roles are not necessarily assigned to different physical persons, but are essential for the development of the software implementation of a DSS. The typical software structure is described below.

4.5.8.1 Software users

DSS are always developed to support a specific approach to a problem. The following questions help to outline the framework of the DSS structure. Who are the potential DSS users? The decision makers? The intermediaries? Other actors and players? To enhance organisational efficiency and effectiveness, the workings of the group must be supported: discussion, negotiation and bargaining with colleagues are important dimensions of decision-making. While DSS users can be individual or group decision-makers, technical advisers, planners, interest groups or "the public" at large, many authors seem to consider the litmus test for such systems to be their ability to address the immediate needs of top decision makers. Gould [Enache 1994] wants to see DSS designed for users who are themselves decision-makers.

Winograd and Flores [Enache 1994] discuss some of the dangers that potentially threaten if the analyst who defines the decision space misunderstands the goals and profiles of decision-makers. These include:

- orientation to choosing;
- assumption of relevance, i.e. the assumption that the things the installed computer system does are the things most relevant to the decision-maker;
- unintended transfer of power to programmers, software designers and analysts;
- unanticipated effects, desirable and undesirable;
- obscuring responsibility by interpreting the machine as making commitments, and
- a false belief in objectivity.

A good DSS must deal with humans' capabilities as problem solvers, with their short term and long term limitations, associative memory structures, conservative biases, and decision-making illusions. And it must leave manoeuvring room to the user in order to have a chance of acceptance. Technically, this requires the incorporation of the user's judgements, values and knowledge into the decision support system.

4.5.8.2 Software structure

Usually the DSS structure is described as including four modules:

- a database management system (DBMS),
- a model base management system (MBMS),
- display and report generators, and
- a graphic user- interface (GUI).

The DBMS serves for data storage, input and handling. The MBMS serves the same purpose for models and sub-models. These data and models may then be weighed, compared or ranked in relation to a specific goal. The display and report generators should permit the structured representation of the process of decision-making followed during the DSS session. The GUI supports the user in handling the system without requiring any specific knowledge of the system architecture or the individual underlying models. Therefore it has to be as intuitively acceptable as possible and should possibly indicate approaches to and/or methods for problem-solving. The GUI mediates between the software system and end-user. Its clarity and adequacy for the user's needs predetermine the applicability of the whole system.

The revolution in ICT networking has changed the conceptual definition of these modules. The original concept of modules, all implemented within a single software system, on one computer, including all data and models, has changed into a virtual structure. DBMS, MBMS and GUIs using distributed systems make use of information, models and interfaces stored on different engines throughout the network. This way of implementing a DSS permits the use of information and models already installed and regularly updated on another site, avoiding the problems and expenses associated with data integration. Drawbacks consist mainly of data access security issues and difficulties deriving from the division of responsibilities for information and system maintenance.

4.5.8.2.1 Database management system

A Database Management System is a system that provides the functionality to support the creation, access, maintenance and control of databases and that facilitates the execution of application programs using data from these databases.

Within the DSS the Database Management System (DBMS) is the component responsible for retrieving, updating and visualising all types of information required. Desirable characteristics of a data base management system are the ability to manage a variety of data structures, and the ability to inform the system user of the types of data that are available and of how to gain access to them. These functionalities may be available within one software system and one complete database or on the basis of rules for accessing distributed databases through a common Application Programme Interface (API) module. In the case of distributed systems, the responsibilities for updating information and for system maintenance may be split between different actors.

The data stored within the DBMS typically belong to five major classes: input to the model for the definition of the user’s goals, disciplinary models, input to evaluation models, on-line-help and other documentation. All these data classes may consist of large datasets or single inputs. The on-line-help and additional documentation may not even be reported within the system, but are required for its use. The goals of the decision-maker and results of disciplinary modelling might also be assessed earlier, regarded as fixed, and incorporated into the system as input to the evaluation system. But all these elements are needed to form the final DSS, even though the digital system may include only an input and output facility to the evaluation model.

4.5.8.2.2 Model management system

Models are instruments that transform data into useful information. A model is an object or a concept used to represent a real situation or actual (physical) machinery, or a system, etc. It is presented in a form that is scaled down (physical model) or in an abstract framework that is well understood. A model is a plan for information processing and provides specifications for transforming information. Thus a model may be specified in mathematical expressions, in natural language statements or in computer programs. A mathematical model is an abstract (symbolic/algebraic) representation, which is made up of mathematical concepts involving constants, variables, functions, relationships, and restrictions.

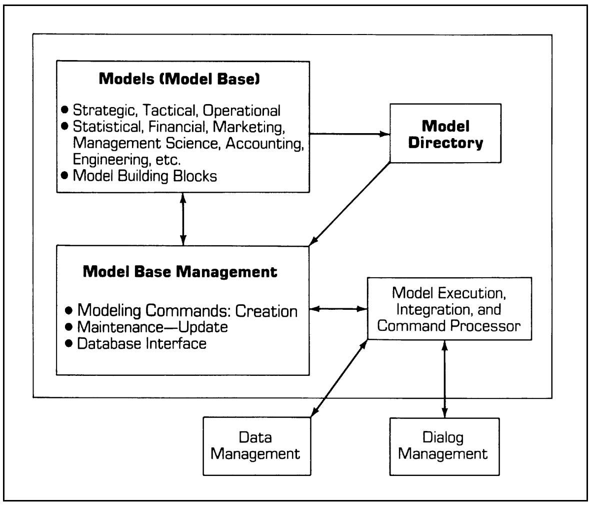
Models manipulate input and stored data to yield results or output. Such models update files, provide responses to user queries, and serve as "black boxes" for performing recurring analytical operations such as description, explanation, prediction, and resource allocation. Models are linked to families of methodologies and range from the very simple to the especially complex. Their applications run the gamut from operations research and decision analysis to artificial intelligence and other sets of tool-boxes.

During the past three decades, there has been an evolution of the type of information sources used in DSS from an emphasis on stored data and data analysis to an increased reliance on decision models. This has led the growth of the discipline of model management, as well as the creation of an increasing number of experimental and commercially implemented model management systems. Model management is concerned with the representation and manipulation of models and a model management system attempts to provide (automated) support for various phases of the decision modelling life cycle. Model management is a software component of a decision support system.

This evolution began in 1975 with the suggestion that decision models, like stored data, are an important information organisational resource that should be managed effectively and that specialised information systems --- that is, model management systems --- should be developed for this purpose. The purpose of a model management system is to insulate the users of a DSS from the physical aspects of model base storage and processing, just as the purpose of a data management system is to insulate users from the physical aspects of database storage and processing. This suggests a similarity between stored data and decisions models. The purpose of model management research is to extend existing knowledge of data management by investigating the properties of systems in which the information objects of interest are not files but rather are algorithms used to support decision processes. These algorithms and their integration rules may be stored on different servers across the information network and handled through appropriate APIs, which are elements of the MBMS.

The major functions of the Model Management System are:

- creates models easily and quickly, either from scratch or from existing models or from building blocks
- allows users to manipulate the models so that they can conduct experiments and sensitivity analyses ranging from "what-if" to "goal seeking"
- stores and manages a wide variety of different types of models in a logical and integrated manner
- accesses and integrates the model building blocks
- catalogues and displays the directory of models for use by several individuals in the organisation
- tracks model, data, and application usage
- interrelates models and appropriate linkages through the database.
- manages and maintains the model base with management functions analogous to database management: store, access, run, update, link, catalogue, and query.



The purpose of model management systems is to insulate the users of a DSS from the physical aspects of model base storage and processing, just as the purpose of a database management system is to insulate users from the physical aspects of database storage and processing.

Figure 4.5: Model Management System scheme by Turban [1988].

The MMS is typically divided into a maximum of five parts: the first supports the definition of the decision goal, one supports scenario modelling, one contains the disciplinary models that represent sub-characteristics of alternative actions or the evaluation criteria, one contains evaluation rules and models and the last one provides a conflict analysis module [Munda 1994]. The Model Management system also contains, in addition to these modules, the rules and routines for communication between the different software modules within the whole DSS, i.e. the related Application Programme Interfaces (API).

The relevant software choices depend on the DSS user's hardware and software choices and on the nature of the input models. Data can usually be transformed, even though this sometimes requires effort, which has to be taken into account. To transfer models, however, is a much more complex task.

Goal model base

What would the DSS user like to find out? Some DSS are designed only for a single application and thus might incorporate this question as fixed input so that this would remain unchangeable. In these systems the problem is posed in only one manner and thus the input is fixed. The goal model base, in these cases, consists of a fixed representation of the problem environment, which in the digital translation consists of a single input sequence (table, spreadsheet, digital sequence or other).

Because of the resource-consuming nature of DSS development most systems are instead designed to be applied in several different similar situations, i.e. they are able to deal with different problems, one at a time. If one intends to develop a DSS for such a family of problems, one must first represent this family set conceptually. The simplest possible question or expression that describes this family of problems must be found, e.g. "What is the best solution for a specific vehicle mission?" In this example the family of goals aims at finding the solution closest to the requirements of a specific goal, i.e. the "vehicle mission". In this question two important inputs are given:

1. the type of comparison of the possible alternative solutions: closest to a certain set of criteria;

2. the family of problems to be analysed with this system: vehicle missions.

These two parts of the question are linked with two different steps within the evaluation [12]. The family of problems is what the Goal Model stands for. The goal model permits the DSS user to specify which specific case out of the family of problem cases is going to be evaluated, i.e. it defines the content of the variable "specific vehicle mission". The definition is inserted at a conceptual level through a related GUI module. What this module looks like depends on which types of inputs are required and also on the DSS user's requirements and on which tools he/she is acquainted with. The most common method of input is in digital forms permitting selections or manually predefined inputs. It is also possible to use graphics and/or entire Geographic Information Systems as modules, if the user is familiar with this type of system. Expert system types of interfaces may be useful for the same reason. It is also possible to create interfaces other than graphic user interfaces as input to the Goal Model. This is possible if the specific problem type does not depend on the DSS user, but on some other actor or on the situation, or only includes a choice that could be made by pressing a button or inserting information through an audio interface.

Example: A car-sharing corporation offers the opportunity to apply for a car share over the Internet. In this case a client is asking for a solution to a specific application. The client enters the specific goal. The decision about which car to assign is made by the car-sharing officer. Since the client is only one of the stakeholders, the DSS user only selects the goal defined by the client and evaluates this request, searching the database for the best vehicle in the best location for the requested time-period. In this example the DSS's complete goal is not inserted by the client. The complete goal is: how can the client's request be best fulfilled given the current car park situation? This shows that the DSS user may not always be the one who inserts the inputs to the goal model and that the complete goal is not always modelled conceptually by the actor who inserts inputs into the goal model. It is important that the full goal is modelled inside the goal model and transmitted to the other DSS modules so that it may be considered in its entirety for the evaluation.

Inside the goal model the input from the user interaction is structured and transformed into a format that the digital interface can read to the other DSS modules, especially the MMS and the evaluation module. The problem itself is translated to the model through the interface, and the model of the problem is then translated into the digital model that is the basis for the evaluation. Each complete input through the goal model base generates a complete DSS adapted to this specific problem model.

The complexity of the goal model and its interface depends on the complexity of the problem itself, the diversity of the single cases composing the family of problems and the level of detail required by the DSS user. The MATADOR [13] project shows an example of a relatively simple form-type input through a Web-type GUI. The UTOPIA [14]application shows a much more complex system of interfaces permitting different levels of detail in the selection of the appropriate goal definition. This case

---

[12] For the type of comparison, please refer to paragraph 4.5.8.2.2.4 - Evaluation Model Base

[13] Chapter 6.

[14] Chapter 7.

demonstrates the possibility of using the goal definition module or GUI to access the goal model base, as an introduction to the problem type. The goal definition module or GUI could function as a support system in itself, training the DSS user to define the problem in detail and to understand the relation between each aspect of the problem and the quality of each possible solution.

The second step for the goal model definition, after it has defined the family of problems to be solved with the system, is to answer another question: "How can this family of problems be represented?" or: "What are the common qualities of the problems in the family?" The representation of the answer to these questions has to be translatable into a digital code that can be input to a model (digit, choice, number, geographic area, image, etc.). The most common way to pose these questions is through form input, where questions are asked in order to identify exactly the specific problem case to be analysed. The easiest way to find these questions is to describe two or three extremely different individual cases, structure these descriptions, determine the differences between them and formulate questions for determining the nature of those differences. After this, it is useful to confirm the results by comparing them with other cases. If the results do not coincide with those described in any other case, the set of parameters defining the alternative option must be enlarged.

During the UTOPIA project development a problem was encountered in the description of specific spatial patterns via simple choice inputs. To correct this, spatial modules had to be inserted. Other parts of the problem were linked to technical information, e.g. the road surface and the density of the distribution of filling stations. The DSS user was often not provided with this information and input was usually stored in specific modules of GIS or DBMS outside the system, so that other input interfaces had to be considered for this input instead of the GUI. Not all of these ideas have been implemented, but for a specific application pertaining to a city this could be added to guarantee more reality-driven DSS user support.

During the phase of goal definition for the specific application, the DSS user is often also asked to describe the problem's boundary conditions. This is not part of the definition of the goal, but is input to other modules of the MMS and is therefore described within those modules. The reason why this is asked for in parallel is to reduce the initial input of information so that it can be contained within a single session. In the author's opinion, it is important to distinguish between describing "what the DSS user wants to evaluate" and "what are the boundary conditions" and "how may boundary conditions change from within". The DSS user should not only be provided with a solution, but should also be provided with support in following the problem-solving approach. First the goals are defined, next the scene in which a change is supposed to happen is drawn, and then this scene is animated and/or projected for the future. After this, possible solutions are identified and/or selected and criteria for the comparison of these options are identified and/or selected. Before the evaluation, each evaluation criterion (preference setting) is assigned a particular importance. After this an initial attempt to perform the evaluation is executed to see what this specific definition of the decision space would lead to.

Scenario modelling module

An evaluation may include the state-of-the-art among the options it considers. A decision always attempts to implement the chosen alternative option most appealing to the decision-maker. One of the qualities of the problem environment is the time frame available for the evaluation, and thus the temporal perspective regarded within the decision process. The time frame considered depends on the phenomenon considered. If the problem is linked with emergency care for a highway accident, the time frame will start with the moment of the accident and end at most a few hours later. If the problem is one of sustainability, the next generation must be taken into account. For the first case, the background conditions impacted by the decision probably will not change considerably during the decision process. In the second case, the political and social background conditions might change completely, so it might be useful to consider different background conditions during the evaluation, or different scenarios. These scenarios might also help in other decisions about political actions that support the decision itself.

The different scenarios correspond to different settings of the problem environment. Within the paragraphs above, it has been pointed out that the degree of detail to which the problem environment is described and the quality of these background pictures modelled depend on the aspects of this background that impact the decision-space. It is like a set of filters with specific patterns that can support or hinder special options.

Technically speaking, the scenario definition splits the evaluation process into the same number of processes as introduced scenarios, running the processes in parallel until the final ranking/choice. After this the results achieved within the different scenarios can be compared. This does not enable the choice of a policy for a future scenario, but enhances understanding of which environmental factors impact – positively or negatively –the success of one or another of the options. This helps to distinguish between highly ranking options in different scenarios, but it also helps to individuate stakeholder behaviour that might favour one future scenario or another.

The definition of scenarios begins with the definition of the aspects to be modelled, i.e. which aspects of the environment influence the decision and which might change over time. These aspects are usually not modelled in a continuous way, but instead as a set of parameters to be incorporated into the environment at the end of the time frame observed. The scenario doesn't describes what happens during the passage of time, but represents a projection of what the decision environment will be at the end of the time frame, according to specific presumptions.

Example: which type of propulsion system should be used when setting up a new fleet? One major aspect to be considered will be vehicle life-cycle costs. This factor depends mainly on infrastructure costs, taxes and energy prices. Taxes may vary over time, depending on environmental and safety policies. Therefore a propulsion system with less environmental impact may be politically supported through lower taxes on these types of vehicles and their energy supply.

The second step is to forecast the "business as usual" scenario, i.e. how the environment will look if no current rules change. This scenario definition may be derived from different types of forecasting models. The scenario description is again limited by the factors influencing the problem and does not reflect the whole of the "real world" projection.

After this scenario is produced, other projections are made, assuming changes in the specific rules of the problem environment, such as policies. These rules may consist of the "vision" specific to stakeholders or of extreme positions with regard to the problem. This depends on the scope of the scenario definition.

After the scenario definition phase, different projections of the future environment are made.

1. Direct optical comparison of the results of the independent modelling and evaluation processes for each scenario. This is similar to observing different slides projected contemporaneously as tiles on the wall. Changing the resulting rankings/patterns/proposed solutions in relation to the specific scenarios can be analysed. This may help to illuminate relations between the performance of linked options and to show possible arguments against specific solutions.
2. The performance of a single alternative option within the different scenarios may be mapped, perhaps in a number of columns corresponding to the scenarios in which the performance of the specific option is ranked. The way the option's performance changes in relation to the "vision" represented by the scenario definitions may be observed. "Strong" and "week" options may be distinguished according to their performance in specific scenarios. A final ranking of the "overall performance" of the options may be reached by setting up a proper multi-criteria decision space that regards the scenarios as evaluation criteria in the evaluation modelling, described later on in this chapter. In a more superficial approach to comparison a weighted sum of the single performances might be analysed, taking into account the probability of the realisation of specific scenarios.

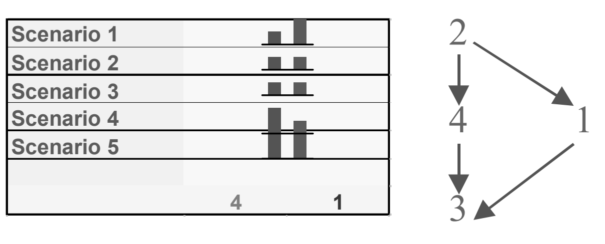


Figure 4.6: Pairwise comparison of the performance of two options and overall ranking of four options.

The scenario-modelling module contains all models needed for projecting the problem into the future moment that is to be evaluated. It thus models the different future states-of-the art against which the alternative solutions have to be evaluated. These models also require digital interfaces to the evaluation module and to digital models contained in the disciplinary model base. These interfaces collect the output generated by the scenario model(s) and route them to the models accepting those data as input to transform the decision space appropriately.

The DSS developer decides which aspects of the scenario are important to which parts of the decision space and develops the rules the data processing has to follow. An input and output scheme is produced. The toolsmith elaborates a translation of this scheme into digital code.

Disciplinary model base

As its name indicates, the disciplinary model base contains models representing single aspects of the decision space (specific evaluation criteria), the behaviour of single aspects of alternative options or the impact of specific aspects of the problem environment on stakeholder preferences.

As described in chapter 2, experts from different disciplines may assist in describing the decision space or alternative solutions and stakeholder profiles. Not only do these models often derive from different scientific background information, but they also have different technical requisites such as the programming environment and the linked graphic and technical interfaces.

Once the decision space has been defined, along with its requirements for data and information, a distinction must be formulated between the fixed data input and the change-related data input. The fixed data may be collected and/or generated and inserted into the DBMS. Aspects that change in accordance with circumstances or user preferences have to be generated on-the-flow by digital models. After the required functionality has been defined, the available models that fulfil these requirements are analysed in terms of the effort involved in input data collection. The level of detail and accuracy of model output is also considered, along with its adequacy within the complete modelling environment. Analysis is also performed on the accuracy of data processing, the quality of the interfaces to other models employed and the effort involved in adapting them, their running time and the effort involved in using the model and creating an adequate graphic user interface.

After the models have been chosen, they are to be incorporated into the DSS. A scheme must be prepared that represents the models as black boxes and reports only the required input data and the output produced. After this, all inputs and outputs are indexed. The indexes of the model inputs are represented in a table paired with the index of the output of another model that also produces them. In another table, the indexes of the model outputs are paired with indexes of the inputs to the model/models they correspond to. In this way, inputs that do not corresponding to any outputs are detected: these represent data not produced by modelling. These inputs have to be collected and inserted into the DBMS and retrieved through an appropriate interface developed by the toolsmith. The outputs not corresponding to any model inputs within the disciplinary models are compared with an indexed list of the required inputs to the goal, evaluation and scenario modules. If an output does not have any relevance, one should consider whether ceasing to produce this output could reduce the amount of data that must be collected, simplify the generating model and/or reduce the model's complexity and running time.

The tables of indexes that are generated represent data flow schemes for the models included in the disciplinary model base. They form the basis of the toolsmith's development of data exchange devices between the different models within and outside of the disciplinary model base. They can also be used in the software development handbook, simplifying the identification of variables that must be adapted in an eventual modification of the DSS application.

Evaluation model base

The evaluation model base contains all the rules and methods for the representation of the decision space, the setting of preferences and the process of comparing the alternative solutions for background to the given problem model. The choice of the evaluation method on the conceptual level represents the basis for the composition of the evaluation model module on the software development side. Each evaluation method might exist in a more-or-less adequate software implementation. The DSS developer must decide whether to use an existing evaluation software module and incorporate it into the DSS evaluation module or to develop a completely new module. To develop a completely new module corresponds to a very large project approach in which the evaluation process itself becomes a case study for testing the evaluation module. In order to support the decision itself without using it for DSS module testing purposes, it is more useful to apply either a complete pre-existing module or a DSS generator [Turban 1988].

The choice of the right application software to use depends especially on:

1. the evaluation approach chosen (single criteria, multi-criteria, group decision etc.);
2. the functionality required (end-user requirements, conceptual interfaces with other models and GUI etc.);
3. the software's adaptability to the application's needs (the accessibility to the implementation's source code, technical interfaces to other models and GUI, etc.)
4. other systems in use at the decision-maker's institution;.
5. the price.

The author of this thesis is not currently aware of any existing overview of available DSS applications and/or codes apart from DSS generators, which are the lowest level of aggregation within module development. Case study descriptions of specific applications often occur in the literature [15], but there seem to be no indications of available sources. The only methods for deciding on applications seem to be analysing documented cases in terms of their usefulness and making contact with the relevant institutions owning the systems to determine whether it is possible to use specific code. All indications regarding code have to be viewed within the time in which they were written. DSS and evaluation tools are rapidly evolving. The rise of the personal computer, along with improvements in available memory and in networking facilities, changes the possible implementation structures of these tools continuously. The core evaluation models do, however, reflect the conceptual evaluation process, a structure, that does not change much over time. Even though the face of the DSS applications changes, the core evaluation modules might become more sophisticated with faster data processing, but they might remain the same in terms of their basic components.

Conflict analysis module

Conflict analysis procedures permit the comparison of alternative rankings achieved on different levels. Some simply consist of the visual comparison of preference rankings in order to permit changes within the preference settings so as to approach a compromise. Other systems offer the possibility of analysing whether it is possible to build a coalition based on the preference settings that correspond to specific stakeholder profiles. These profiles may be represented within the GUI to show instances where the stakeholders may share interests with other stakeholders. This type of representation is possible within the JRC NAIADE tool, but a method for its direct implementation within the MIG has not yet been created, because resolving conflicts between different stakeholders' views has not been interpreted as being among the major tasks within the typical decision process.

4.5.8.2.3 Display and report generator

Display and report generators are not included in all DSS. Their goal is to allow the decision-maker to document the specifics of the decision process. This documentation may be used to justify a specific decision, or simply to record the steps in evaluating potential solutions and in setting variables in the decision-process in order to better

---

[15] e.g. [19], [20], [31]

understand the learning process connected with the repeated interactive use of the system.

Report generators may also serve to display and/or report preliminary results or the results generated by models linked to specific criteria. They also make it possible to preserve a printout of parts of the database relevant to specific situations. They may also help in the comparison of results obtained by different decision-makers, especially within a conflict analysis.

Report and display generators are thus functionalities which permit the consultation of intermediate or final results for further use in the decision-process or for the implementation of results obtained during the process of decision-making.

4.5.8.2.4 Graphic user interface (GUI)

The GUI consists of the signals the computer transmits to the user. A DSS may have different levels of GUI for the different users of the system and the different modules. An interface may consist of a static representation on the screen, a "moving" image or a different type of output such as printed reports. It may also consist of vocal output or signals transferred to other devices such as alarm systems or other output screens.

There is an interface for each system-user, including the system developer, model developers and also the decision-maker(s). Different parts of the GUI may have a different importance to specific users. It may be interesting to obtain a general overview of the decision-process initially and then to gain deeper insight upon considering it a second time. Therefore it is useful if the GUI of complex systems offers the possibility of considering the decision-process at different levels of detail permitting the initial use of aggregated settings.

Different interfaces will exist for access to the DBMS module and one interface will exist for access to the MBMS module for data and model input and processing. In order to guide the decision-maker in a consistent way, it should be possible to change the GUI during the guided tour through the decision process. If this is not the case, a common GUI should be developed for the different modules to assist in shifting between the specific DSS interface and the module interfaces.

In the case of DSS based on distributed systems, the GUI may be composed of panels stored on different servers on the information network. In this case it is particularly important to achieve a common layout and a vocabulary to be used through all the elements composing the GUI and logical structure. In order to be useful, the DSS should appear to the user as a uniform support to his decision, not as a melange of confusing information that has been cut-and-pasted together.

4.5.8.2.5 Data flow

The interaction of the DSS modules is controlled through the GUI. There are interactions between the GUI and each of the modules directly and interactions between the other modules according to different requirements.

Interaction between modules usually takes place using specific programmes that translate the output from one module into input to the other module. These mediators are called Application Programme Interfaces (API) and are represented by arrows in the figure.

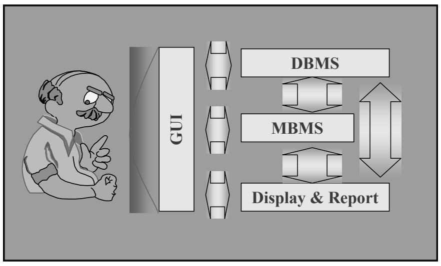


Figure 4.7: Interaction of DSS modules.

The user defines the decision-space through the GUI. After the decision space has been identified, the DSS transforms the conceptual settings into computational representations. Predefined settings are transformed into a DBMS request for the selection of fixed records, while other inputs are transformed into MBMS requests, transferred to the relevant models of criteria and alternatives and processed using DBMS inputs called by the MBMS. The result of this process is visible to the user as the representation of the complete decision space within the GUI. In MCA this representation usually consists of a graphical representation of the impact matrix. The result within the system is a mapping of the alternatives and criteria in terms of the rules relevant to modelling the alternatives via the criteria within the MBMS and in terms of links between MBMS models and DBMS records.

After the decision space has been defined and the evaluation method has been applied, user inputs in terms of preference settings are requested by the GUI. These settings are again transformed into MBMS input and are communicated directly to the MCA evaluation model, which calculates a preference ranking. The resulting ranking is represented within the GUI so that it can be considered and judged by the user(s). In cases where the user is not satisfied, the procedure may be repeated with changed preference settings or even additions to the set of alternatives considered.

Conflict analysis procedures permit the comparison of alternative rankings achieved on different levels. Some simply simultaneously display the preference rankings in order to allow changes in the preference settings to approach a compromise. Other systems offer the possibility of analysing possible coalition-building based on the preference settings that result from specific stakeholder profiles, which may be represented within the GUI, showing the ways in which different stakeholders might agree to compromise with other stakeholders.

At several steps the user may display or print screen shots, DBMS or MBMS reports, and preliminary or final results.

4.5.9 Judgement of results

Judgement of the results obtained from the decision-making process may be undertaken by the single decision-maker in order for him to evaluate the quality of his decision on the basis of his expectations. This may lead him to a re-evaluation of his original preference settings or the adequacy of the available information. This leads to a learning process, which might involve repeated application of the evaluation method.

In the case of group decision-making, judgement of the results includes the procedure mentioned above. It also usually includes an evaluation of the results obtained from different types of preference settings, depending on the profiles of different group members. In order to solve conflicts between the decision-makers or groups of decision-makers deriving from these different results, attempts are made to compromise to find the best possible solution. A problem of this kind may be addressed by methods like equity analysis or by applying similar systems to the above systems for conflict analysis related to the preference settings. The alternatives evaluated in this case would be the rankings produced by each party involved in the conflict.

In recent years data accuracy and reliability has become a very important task within the classification and application of data. Because DSS are based on the use of data, this subject cannot be ignored. The real goal of an evaluation of data accuracy is to determine the reliability and level of fuzziness that the DSS outputs are based on, or to find the complete set of variables influencing the level of uncertainty the system output copes with.

During any decision-making process there are multiple sources of uncertainty. The main sources to consider are:

1) the original data sources (measurements, input phase, data sets, user input);
2) the evaluation method;
3) the models;
4) misunderstandings deriving from man-machine interaction.

Defining the level of fuzziness in 1) and 2) is relatively easy and can be accomplished using an objective scale.

There is always some uncertainty about the applicability of an evaluation method (3), due to its implicit and explicit assumptions. Not all methods yield the same results, though this can be overcome in practice by performing some kind of sensitivity analysis on the methodological assumptions of the evaluation methods.

The class of errors deriving from 4) have to be taken into account during the development phase of the specific system application. They need to be reduced as much as possible via detailed assessment of the end-user's requirements and profile and via continuously checking that the system and the GUI are being used properly by representatives of the end-user groups.

4.6 CONCLUSIONS

To develop an appropriate Decision Support System to approach a specific multi-criteria problem, one must analyse the system influenced by the problem in terms of the actors in the decision process and the actions to be evaluated as possible alternative solutions to the problem. After this, the decision space must be defined in terms of participating actors, boundary conditions, possible alternative conditions and their characteristics. The relevant cardinal set of evaluation criteria has to be established by defining the type of data to be used in the evaluation process.

This definition of the decision space is the basis for each evaluation. An adequate evaluation procedure must be chosen from a wide range of methods. The use of a DSS that incorporates multi-criteria evaluation methods permits a structured approach to the problem definition, the handling and integration of multi-source information and the use of complex evaluation procedures for a non-expert user or user group. A decision-maker or a group of decision-makers may use a DSS to define boundary conditions and thus better understand the decision space, or to analyse the current aspects of the game and the influence of their individual preferences on the results of a structured process of decision-making.

European urban environmental management includes various areas for decision making, ranging from how to use agricultural land to how to manage coastal zones and how to engage in urban planning. The stakeholders have very diverse interests to defend. Often the major problem lies not in choosing a solution, but in demonstrating the adequacy of that solution to other actors or to the public. DSS help to document the decision process and assist decision-makers in comparing different possible courses of action on the basis of well-defined disciplinary models and data specific to the application case. This enables actors to better understand the variables at stake. It also permits conflicts among actors to be approached using a tool that includes the cardinal evaluation criteria used by each group. In this way, discussion can begin on an equal basis and the process of decision-making can be documented.

The insights offered in this chapter allows actors involved in the DSS development process to comprehend the cultural background of DSS experts and IT developers. At the same time, it provides a brief overview of the possibilities offered by DSS. This introduces the co-operative DSS development approach presented in chapter 5.

CHAPTER 5 A novel approach to introducing the decision-makers to the DSS development process

5.1 INTRODUCTION

Chapters 2 and 3 introduce the reader to the complexity of European urban environmental management, the different methods used to describe it and the difficulties inherent in decision-making in this field. Chapter 4 introduces the reader to the theoretical field of decision-support and to methods and instruments for its implementation in more or less complex environments. These elements are now used to present a novel approach for the development of DSS with high user acceptance tested on two applications, developed in parallel and described in chapters 6 and 7.

5.2 DSS USERS AND CLIENTS DEFINING THE DSS DEVELOPMENT PROCESS

Much has been written about new approaches to problem solving and how to support a decision-maker with a DSS. But "It appears that few DSS are actual models of decision processes" [Sprague, Watson 1989]. Why? User profiles and descriptions of the decision-process are taken into account by DSS developers, along with different stakeholder profiles and multi-disciplinary aspects of the decision space. The complex systems are described as closely as possible, but this knowledge has not always been applied.

One important step for solving the problem was taken when the man-machine interface of DSS was analysed as other digital interfaces are, and when the user-friendliness of the tools became a crucial component of the analysis [16]. The applications became more user-friendly, but most of these tools are still not put into practical use on a day-to-day basis.

This thesis looks at this situation from a completely new point of view: What about the problem definition and the tool requirements? Are they tailored exclusively to the requirements of the final user, or are her/his needs only part of what is considered in their design? In many cases the requirements that determine the final form of the system are composed of more objectives than that of the end-user(s) alone. Other actors and goals have to be considered in the development process, such as the actor providing the funding for the DSS development. This actor may not be the end-user, but this actor does have a high impact on the input to the system's development and thus on the final DSS tool. This might interfere with the fulfilment of the user's needs and thus with the usefulness of the product.

This new approach thus attempts to make DSS more useful in a specific complex environment, European urban environmental management, by analysing the role of all actors not involved in decision-making, but during the DSS development process. On this basis their roles and expectations can be known to the other actors involved in the process, so that the complete set of system specifications is known to all users. The parts played by the other actors should also be familiar to all users.

Through this understanding of all the parts in the process, the actors are introduced to the logic of DSS development and their role in and possible impact on this process.

---

[16] Refer to [19] or [49] for examples.

The role of the technical DSS designer is outlined since it is crucial for the translation of the decision-maker's and client's requirements, so that the technical designer can act as the "champion" of the DSS experts. The DSS designer directs the DSS development process as an improvisational drama, where each actor is assigned a role that must be performed using the appropriate skills and knowledge to produce a common play/output. This approach has been called the "DSS–maker's script".

First, this approach introduces the DSS end-user to the complex requirements to be fulfilled by the technical tool developers. Secondly, it raises the client's consciousness of how her/his requests impact on the final outcome and the user acceptance of the tool that is to be developed. Thirdly, it creates a common understanding of the system inputs, specifications and methods to use, which forms a complete basis for useful discussions about modifications during the tool development phases, based on the mutual understanding of roles, methods and possibilities.

The DSS development process is described through project management, i.e. it is developed through the definition of project goals (section 5.3), the project plan (5.3.4), a development phase (5.4 & 5.5.) and testing and implementation phases. The script is developed as a sequence of practical rules for all phases of DSS prototype development. Final testing and implementation is described in chapters 6 and 7. The testing process may require a loop back to some phases of development.

Up to now only experience during interaction with the system allowed the user to define additional system requirements in detail, and thus to formulate requests for DSS modification, producing a loop back to the development. In this new approach, because the user understands the original system specifications and the development process, the time between the definition of specifications and the performance of modifications requested by the user is reduced. Changes may be made before the tool is finalised and thus have a much higher probability of being implemented. The final tool presented to the user should be closer to what he/she requires, or, at least, even if there is a discrepancy between the required support and the final tool, the tool is still understood to be based on the client's requirements.

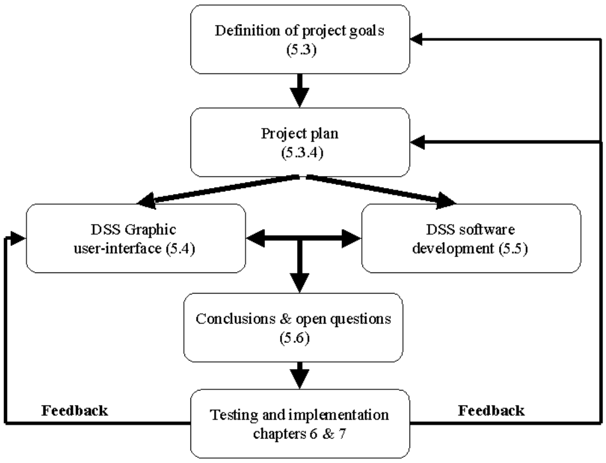


Figure 5.1: Structure of chapter 5.

The theoretical aspect of this approach has been tested during the development of the two applications illustrated in chapters 6 and 7. These demonstrate that the client has a very strong impact on the process.

5.2.1 Why focus on European urban environmental decision-making?

Economic operational research has produced instruments which permit the interactive digital processing of complex problem models through the representation and comparison of alternative solutions, possibly ranking the solutions in relation to the system user's individual preferences: these are called Decision Support Systems (DSS). These systems initially conquered the market for economic applications. Because the urban environment is an extraordinarily complex multi-disciplinary field, urban planning process would seem to be a field with a major need for these kinds of tools. In the U.S., they are already utilised in a wide variety of types of planning. In Europe, they are starting to be employed in economic and business applications, but are still not diffused within the discipline of planning as a whole.

An initial supposition about why this is so would be to assume that digital applications are not yet as familiar to European decision-makers and administrators as they are to Americans. This depends on their diffusion and on differences in confidence in technology between the U.S. and Europe.

A second look shows that there are different approaches to what planning is meant to produce and who the planning managers are. In the U.S., planning is usually performed in a private investment case or a Public/Private Partnership. In Europe, most planning activities are managed by public institutions whose embers are not easily convinced to use tools developed originally for economically oriented problem solving.

European decision-makers require tools for multi-disciplinary evaluation processes, but they fear that in DSS economic factors will be given too much weight. This has been the focus of several European developers in the field of Multi-Criteria Analysis (MCA) and Multi-Criteria Decision Aid (MCDA).

Even though many prototype applications have been developed in Europe and many resources have been invested in the process, these DSS did not become widely used immediately following the development. Most of the prototypes were instead discarded as soon as the application development was finished. Why?

Posing this question to the user usually provokes a simple response: the tool did not correspond to the user's needs, sometimes in terms of the overall approach to the problem, but much more frequently in terms of the user-machine interface, so that the user was unable to use the system. In the cases described in literature [17] and in applications studied directly by the author, a fear of being replaced by the system was expressed few times, but problems with understanding the tool itself were always present. Support is required, but only support that can be understood. While an expert might personally convince the decision-maker of his effectiveness, the tool can convince the decision-maker only by providing a clear understanding of the process and by producing practical results within applications.

A short literature analysis shows that a typical problem encountered with today's information technology appears to be one of the next milestones in increasing DSS diffusion: improvements must be made in the relationship between user and system, i.e. between user needs and man-machine interaction design. The DSS-maker's script aims to support the DSS designer in clearly defining each actor's role in every phase

---

[17] For more information, refer to [19].

of the DSS development process. This would make the actors participate in the development process, so that they could understand their role within the system right from the start of the design phase, or, in other words, so that they would know the product from its birth.

Scepticism also exists about the possibility of losing control over the decision process. This problem cannot be approached simply by changing the system, but must be addressed by developing appropriate tools for specific individual user needs. Usually DSS have been developed by experts external to the decision-maker's institution. Often these experts were programmers or economists familiar with the system, but not with the user's requirements. Increasing numbers of databases and specific interfaces to digital tools are developed nowadays in-house or by a specific computer subcontractor chosen by the institutions. This increases awareness of continuous changes in the software applications, as well as of maintenance problems linked with their use.

"No substitute exists for firsthand observation" [The Worldbank 1998]. Many attempts to get detailed information from this kind of observation have failed. The DSS–maker's script developed within this thesis attempts to support all the actors in DSS-development, including in-house technicians and/or the technical assistants to the decision-maker, in distinguishing the specific concept for their DSS. It does not, however, attempt to support the toolsmith in programming the individual digital modules behind the interface. Instead it increases understanding of the common project plan of DSS design and development, the roles within this plan and how a certain type of structure is developed. It also clarifies how requirements are translated into DSS characteristics. This process enables actors to formulate their requirements for modifications during and after the DSS development phase. This script can be read on a conceptual basis so that the DSS user can formulate a required change, and a technician familiar with the programming language can then follow the script to the module to be changed. This approach considers the DSS design as an incomplete tool, which is designed to conform as closely as possible to the user's requirements, but which can be continuously adapted during the implementation phase, according to changes in user skills and requirements.

The decision-maker's script approach is not useful solely for European urban environmental management and planning. Other DSS designers and users may also find the approach useful. It is impossible to support a user in practice without real-life examples from the application's field. Thus a single field had to be selected for the more detailed description in chapters 2 and 3. The author has a background in European urban planning and is therefore familiar with the field's requirements and is convinced that this approach to DSS development is the most useful one for this application area.

5.2.2 How to use the DSS–maker's script

The DSS –maker's script has two different interfaces:

- the paper version within this chapter;
- the interactive digital version on the CD.

Even though their textual content is the same, each of these versions will play a different role in supporting the tool designers. The paper version offers the actors in

DSS development an idea of the different steps to follow. It also presents their roles in each of these steps.

The interactive digital version is meant to provide continuous support during DSS development. This version uses information from all chapters in the thesis to provide an interactive on-line help system that includes links to Internet sources [18]. This version makes additional use of the interactive design features and the implementation of the application cases.

Sections 5.3 to 5.5 guide the reader through the major steps in DSS development, leading up to a structured definition of the DSS's layout. Section 5.6 presents the questions that remain unanswered.

5.3 DSS REQUIREMENTS

The DSS–maker's script is meant to guide the user and the designer through the DSS development process. This development process starts by defining what the DSS is intended to support. This chapter is dedicated to defining the goals of the DSS as a tool to support decisions in detail. It also lays out the roles of the actors in DSS development. In order to define the DSS's goal, the problem it addresses must first be described in a comprehensible way. A conceptual model of the complete problem and its environment needs to be developed (5.3.1). After this, the specific approach to decision-making envisioned for implementation in the DSS has to be outlined step-by-step according to a method agreed upon by both the DSS user/decision-maker and the DSS designer (5.3.2.). During different phases of the decision process other actors and stakeholders may also be involved. Section 5.3.2 attempts to determine who these stakeholders are and how they should be taken into account within the modelling of the decision process. For this, they must agree upon the role of the DSS within the decision process (5.3.4).

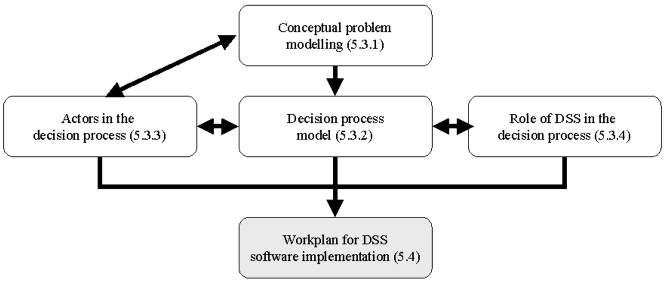


Figure 5.2: The structure of section 5.3 – DSS requirements.

After following all the development steps listed in this chapter have been followed, all DSS inputs will have been defined conceptually, and the list of ingredients for the system's development will be complete.

5.3.1 Conceptual problem modelling

The way each observer perceives the real world varies according to his/her individual mental schemes. These schemes depend on rules developed according to theoretical knowledge and former experiences. As described above [19], these rules are adapted to

---

[18] These sources are partly copied to the CD-ROM support to guarantee their timely availability.

[19] Section 4.4.4 and [45].

each new problem case. They are then compared with the decision-maker's experiences, with his theoretical knowledge and with external knowledge bases, for which he might need to search. The more familiar the decision-maker is with the type of problem, the easier it is for him to develop an approach to it. A decision-maker expert in one discipline would try to use problem-solving rules from this discipline, even in problem cases that do not belong to it, before trying to develop a new solution scheme.

These mental schemes may provide a key to how to structure the problem model, which must contain all the characteristics of the problem and its environment. In order to ensure that the mental scheme contains all characteristic aspects of the problem and its environment, the problem must first be analysed in terms of all of its relevant aspects. After this, relations between these aspects are represented within a conceptual model scheme. To get an overview of the elements composing the problem and its environment, certain questions should be asked, including:

1. What is perceived as disturbing now or is expected to disturb the harmony of the situation according to the decision-maker? What would he/she like to be different?
2. What would have to be done to change the situation, i.e. which factor creates the disturbance?
3. What would happen if the disturbing element were eliminated without substituting anything in its place? Which sub-systems would be influenced? Who would react?
4. Are there possible "substitutes" for the disturbing factor, or are there alternative solutions to the problem? How would they work and how would they impact other sub-systems? Who would gain or lose in this case?
5. Which background factors are not influenced by the disturbing factor, but influence the factor itself and/or the usefulness of substitutes? Are there "visions" for the future that could change the behaviour of the problem space? Does the decision-maker want to take their possible changes over time into account?

Performing this analysis produces a list of factors and actor viewpoints that would change with the substitution or elimination of the disturbing factor. These are to be considered within the evaluation, so that these actors, elements and their relations represent the problem model. This analysis also produces a list of the elements that are not altered by changes in the problem space, but that would impact on factors related to the problem if changed. These factors comprise the elements of the problem environment and must include the client's requirements.

After the elements of the problem and the problem environment are listed, the conceptual model is laid out. The model's representation must be as understandable as possible for the DSS user. In order to reach this goal, the conceptual modelling skills of the DSS user must be analysed. In an initial approach, the professional background of the DSS user is analysed along with related modelling schemes, as recorded in chapters 2 and 3. This serves as a set of examples for the actors involved in the case studies described in chapters 6 and 7. Related questions would be:

1. What is the DSS user's educational background? Are their modelling schemes linked to this?
2. Have they previously participated in similar projects? Have schemes been worked out for these projects?

Once the initial scheme has been built, the decision space is represented using the scheme and omitted aspects are indicated in an additional scheme or tentative model add-ons. The scheme is analysed to determine if certain aspects cannot be integrated into it. If aspects cannot be integrated, attempts are made to determine how and why this is so. This is the initial approach to creating the model, and should be presented to the DSS user. The user must then decide whether to use this representation and, if so, whether to omit certain aspects of it or whether to generate a more complex, less familiar scheme by incorporating other aspects of the problem model. In every case user and designer must remain aware of the impossibility of representing the whole of the real world problem. They must find a compromise between abstraction and detail that is enhances the representation, the completeness of the model at a certain level of detail and the method of information processing.

Different tools are available for the visual representation of the conceptual problem model [20]. The way the model development is represented to the DSS user should be based on typical problem-solving schemes with which he/she is familiar. If this should distort the problem's representation, a common sense model may be developed out of representational elements typical to the user's environment e.g. using graphics, physical modelling or simulations.

Example: In city-modelling interactive planning simulation tools, such as the Simcity [Simcity website, on-line in 2000] game, might be helpful for model definition. These systems are like jigsaw puzzles built out of 2 ½ dimensional graphical representations of the developed environment. Originally they are conceived of as games. But they teach their users to have a feeling for the interactions between the parts of an urban context, including technical networks. This type of game allows the physical urban context to be represented in a comprehensive way allows within a relatively short time frame. Social aspects of the urban context need to be described in a different form.

This example show that in order for the modelling "language" to remain comprehensible to the user, there may be limits on the representation of some aspects. Complex problem descriptions may require different models in order to represent different parts of the problem. In order to form an overview of these models, they must be linked together to represent the complete problem description.

The resulting model, or system of models, is presented to the decision-maker to be checked for completeness in terms of factors influencing the problem and in terms of comprehensibility and complexity. The more complex the model, the more difficult it is to create a structured overview that will allow the decision-maker to feel in control of the decision process. The final description of the problem that will be incorporated into the DSS has to be a compromise between a complete description of the real world problem and a simple schematic approach to it. The effectiveness of this compromise, along with the degree to which it corresponds to the real-world problem and its environment, determines the effectiveness of the complete DSS application. The

---

[20] For differences in the perception and representation of the problem space, please refer to section 4.4.1.

conceptual model contains all the aspects and rules of interaction that will afterwards be transformed into the digital decision space in the DSS software. Thus the problem faced in the DSS implementation phase is equivalent to the digital translation of the problem model, and not to solving the real world problem. Once the conceptual model has been defined, the real world is no longer considered, either for the DSS implementation or for the decision process to be supported.

After the problem space has been described in a conceptual model, the approach the decision-maker will take in considering it must be designed.

5.3.2 Decision process model

The purpose of this section is to enable the development of a framework for the evaluation process that is to be supported by the DSS. This conceptual decision process model describes the decision process as a sequence of acts including information gathering, comparing possible options and influencing factors, and making intermediary sketches of possible solutions until a final decision has been made. This kind of scheme may be represented as a box diagram, where a state that can be described as an unstable equilibrium corresponds to a box and the way to arrive at this state is represented by an arrow. Examples of these box diagrams are included in sections 6.3.2 and 7.3.2.

During the user assessment phase[21], the user is asked to elaborate on methods and schemes that are usually applied within her/his professional and personal environment. The responses received may support the DSS designer by increasing his/her understanding of the field, but the designer has to remain aware that the decision space is usually not consciously structured in detail during traditional evaluation procedures. An analysis of expert systems and DSS developed for application in the same field, explained in literature and/or created to support experts with a similar professional background may be useful for better understanding the process. An initial prototype of the decision process model may be developed on the basis of these techniques. This dummy has to be further refined through an adaptation process to be performed by decision-maker(s)/user(s) and DSS designer using one or more of the known types of interactive elaboration, such as brainstorming or role-play modelling [22].

If no general information about approaches to problem solving that are known to the user is available, a very general decision process model can be initially be used to structure the approach, such as: first define the problem space, then define the decision space [23], then formulate preferences, then evaluate each solution against the preferences, then evaluate results against each other, and finally, choose. This simple sequence could be used to structure rule the evaluation of every problem, but it might be necessary to illustrate these phases to the user by introducing application examples [24]. Additional guidelines may be derived from the experiences undergone during formulation of the conceptual problem model that was developed through application of the procedure described in section 5.3.1.

---

[21] Refer to section 4.3.6.

[22] For more information on these techniques, refer to section 4.4 or to [60].

[23] For information about the decision space, please refer to chapter 4.

[24] Introduced in chapters 7 and 8.

As the decision-maker is often unaware of which mental structures he uses to define the decision space, its exact composition may be difficult to determine solely from a list of the sequential steps followed in the process. It may be more useful to ask for a description of a decision process completed in the past, structure this description and illustrate this structure using a familiar example. This makes it easier for the user to identify the developed structure. The user might also identify problems encountered during this process and suggest modifications to the structure. This approach sounds more practical than literature analysis, but even when it is applied, the analysis of a report on a former decision process may be very helpful, since parts of the process tend to be omitted from oral description. Representation also tends to be distorted: undue importance may be attributed to steps that possess special interest for the teller at the moment of the narration. Additionally, oral narration often jumps from one point to another, so that the structure of the process may be very difficult to determine.

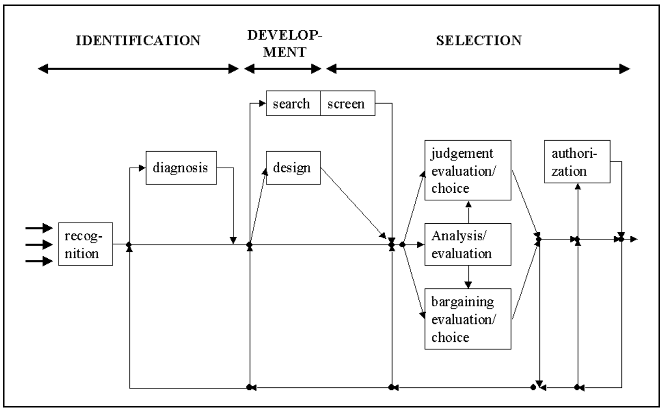


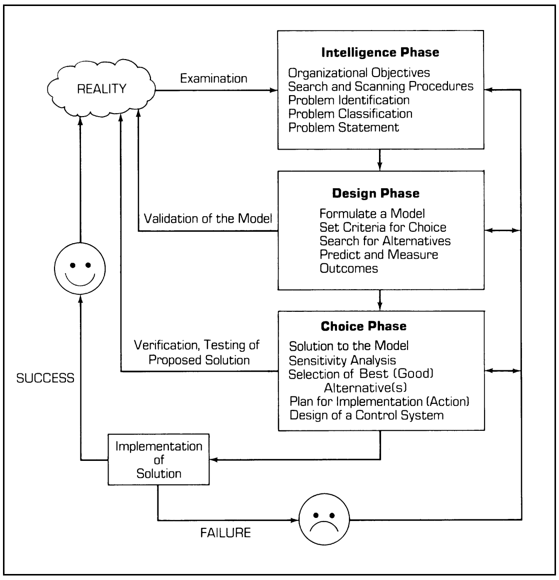
Figure 5.3: Steps describing the decision process [Van den Bergh 1996].

This is why it is listed last among the methods for modelling the process. If this procedure must be applied, additional structure may be provided by asking the decision-maker for a written abstract of the decision process before the interview. This way the decision-maker is forced to structure the process description and this initial model sketch can then be verified by comparing it to the narration.

The conceptual decision process model explicates the sequential steps in the decision-maker's mental evaluation process. The DSS is developed to provide support to this process or to a part of it. There are two ways of modelling the steps within this process:

1. the steps can correspond to reportable situations within the decision process, i.e. the representation is result-oriented;
2. the steps can correspond to the phases between intermediate results, i.e. the representation is action-oriented.

A flow-chart that shows the sequence of results and actions is used to represent the model. Which steps are represented as boxes, and which are represented as lines



connecting the boxes depends on the point of view from which the chart has been created. In a common sense approach, the results would probably be represented as boxes. For the DSS designer, however, actions occur within interface panels and intermediate results are generated within the digital system and reported in new panels. In this scheme, the results are defined through a combination of DSS user action and system action and are reported in an interface-reporting module.

Figure 5.4: Turban's scheme for modelling the decision process [1988]

The problem model is an input to this sequential decision process model. The output is the decision. After the problem and the process of approaching a solution have been modelled, it is important to consider which other actors may influence the process. This topic is treated in the following section.

5.3.3 Actors in the decision process

Chapter 2 introduces a selection of actors in European urban environmental management, their sometimes conflicting positions and some integrated multi-disciplinary approaches to modelling the urban system. This introduction enables its reader to understand which actors impact the decision or are active participants in the decision process. It also considers how these actors might be represented. Two types of actors are usually distinguished in literature: the actively-deciding actor(s), or decision-maker(s), and the actors who might influence the viewpoint of the decision-maker(s) [25].

In order to finalise the problem description, the actors must be inserted into the problem model. Each actor's ability to impact the process must be translated into variable impact factors and included with the profile of the decision-maker(s) in charge of each individual step in the decision process. Therefore additional distinctions must be made:

1. Some decision-makers are responsible for the whole evaluation process, but in other situations, partial decisions are made by multiple decision-makers;

Decision theory generally assumes that a single actor or group will use the DSS throughout the complete process. Because specific user preferences form the basis of the entire evaluation process, a DSS is not meant to be used by different users at different stages in the decision support process. In real life, most decisions must be approved at various levels of hierarchy before their implementation, and parts of the

---

[25] On decision-makers and stakeholders, please consult section 4.3.3.

decision may need to be made by different actors. In terms of DSS design, this means that the DSS designer and the user are responsible for defining the user's role within the decision process that the system is designed to support. They must also define how the results from the DSS may help sustain the user's role in the system. Questions to be asked include:

Is the decision process based on input resulting from other decision processes?

Does the decision lead directly to implementation or does it need further approval? If so, by whom? How should the results be represented to gain this approval?

Is only a part of the decision process relevant to the decision-maker or is a general overview of the whole process relevant? Does this lead to changes in detail representation for specific parts of the DSS?

2. To represent the problem space independently from its environment in order to determine whether scenario modelling might be required, it is necessary to divide the stakeholders into two groups:
   - actors impacting the problem environment, i.e. who may change the boundary conditions, such as the client;
   - actors impacting the problem space, i.e. the specific decision process.

Based on the conceptual problem model an initial distinction can be made: both the DSS designer and the DSS should answer the following questions for each element of the problem space:

Who assigns a value to this element?

Who has a positive or negative interest in this element?

Who may change the value associated with this element?

Does changing this element impact sub-systems of the urban system other than the one currently considered the problem space?

Is there a hierarchical connection between decision-maker(s) and stakeholder?

These questions enable us to understand how the stakeholders and their roles relate to the elements of the problem space. These can be listed to form a consistent basis for the problem model. Some stakeholders will probably be related to multiple aspects of the decision and/or its environment. To define the stakeholder roles in the decision-process, a list of related aspects and roles is produced. The decision-maker assigns each actor an importance in relation to each individual aspect. Each actor's role in the decision process is defined by where they appear within it and by the importance they are assigned by the decision-maker.

Different possibilities exist for defining the actors' roles and for modelling their reactions. Most often, literature analysis is used, or common sense descriptions produced by the DSS designer, an analyst and/or the decision-maker(s) are employed. The most detailed picture of the stakeholders possible could be given through a procedure similar to the user assessment, but this is very time-consuming and therefore not easy to implement in practice. But what if a major interest of the decision-maker is how to reach the best compromise among a certain group of stakeholders? In this case, each of these stakeholders must be described in an individual profile that relates to the problem space. The obtained profiles would then have to be organised within a system capable of processing these profiles and projecting a set of possible solutions according to the different viewpoints. Today only a few systems have been designed that permit analysis of the readiness of different stakeholders to build alliances [Munda 1994], but these systems provide very useful support to political and group decision processes. In cases where groups are in charge of decision-making in a stable constellation over time, the profiles can be refined continuously.

> "Stakeholders are those affected by the outcome – negatively or positively – or those who can affect the outcome of a proposed intervention." [The Worldbank 1998]

The detailed analysis of stakeholder requirements to be included in the DSS should include only those stakeholders who are relevant to the decision-maker(s), i.e. stakeholders with decision power, or with direct or indirect influence on the decision-maker. Stakeholders with no influence on the decision-maker are of no interest in the evaluation process, because the decision-maker does not assign weights to their opinions.

In order to define the group of stakeholders as a whole, an initial problem must be defined. After this, a list of stakeholders can be set up so that the following questions can be considered:

1. Who takes the final decision/choice?
2. Who asks for the change?
3. Who represents the groups affected?
4. Who pays for alternative solutions?
5. How does the decision-maker get her/his role?
6. Who might mobilise for or against the decision?
7. Who can make the process more effective by participating, or less effective by not participating or presenting outright opposition?
8. Who has to be convinced?
9. Where do the resources for making the change come from?
10. Who proposes/supports alternative solutions?

This list is not to be considered exhaustive, but provides an example that can be used when building a list specific to the application case.

For further details on approaches to analysing stakeholders, please refer to Section 4.4.

5.3.4 The role of DSS within the decision process

The analysis of the description of the actors in section 2.3 directly feeds into the definition of the role of the DSS within the decision process. This role is defined by:

- the role of the DSS user(s) within the process of decision-making;
- the steps within the process the DSS user asks to be supported in;
- the effect the use of the system has on other participants n the process.

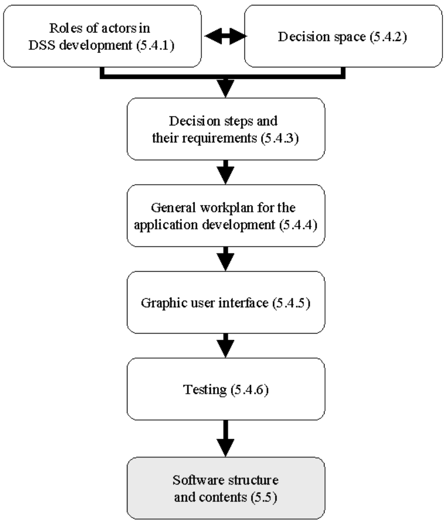
The role of the DSS user may be analysed by applying the procedure described in section 5.3.3. DSS are intended to support the full cycle of decision making from the problem definition to the final choice. This cycle has afterwards been analysed in more detail, distinguishing partial evaluations. DSS or DSS modules have been developed for those specific evaluation steps, such as scenarios for evaluating the time-factor or conflict analysis for stakeholder impacts. Before DSS development can begin, it has to be clear which part of the decision will be supported by the system. It is important to avoid the expectation that the system can be substituted for the user and can answer every possible question the user might have within the decision context. Only questions that have been considered in the system's design can be reproduced by the system. The DSS allows the contextual combination of elements usually analysed and described separately. It assists in dealing with complexity, but is not able to generate additional decision modes or aspects.

To derive which steps require DSS support within the application to be developed the problem model, the decision process model and the roles of the stakeholders are analysed for their conflict potential and the user is confronted with this overview of partial evaluation steps. The user chooses which part(s) are what she/he considers as the core DSS and may express the wish for other modules to be developed together or which may be added in future.

5.4 WORKPLAN FOR DSS SOFTWARE IMPLEMENTATION

Section 5.4 helps the actors translate the models developed within the processes described in section 5.3 into a general DSS software structure. It also assists them in developing a workplan for implementing the DSS, based on the ingredients and structures developed up to this point. This workplan includes the time frame, the actors and a step-by step description of the development and implementation phases.

In order to define the project plan, an assessment must be made of the expectations of the users, the decision-makers and the clients (if the client is not the decision-maker). The user's preferences and skills in terms of system interaction have to be assessed as well (5.4.1). These must then be represented and agreement must be reached about this representation. The steps in the decision-making process are illustrated in section 5.4.2, where they are described in terms of time and input requirements and in terms of the system's expected output.



Responsibility for different tasks within the modelling and integration of the decision process and the DSS modules may be assigned to different actors in the DSS development. Different actors may also perform different roles during the testing phases. Section 5.4.3 offers insight into the major roles within DSS application development. These roles do not coincide with the parts of the actors within the evaluation process, which is why they are outlined separately. After defining the individual inputs, section 5.3.4 provides strategies to be used in composing the DSS implementation workplan.

Figure 5.5: Structure of section 5.3– workplan for DSS software implementation.

5.4.1 Roles in DSS development

DSS systems are not tools developed by a single software programmer. The development of these complex systems is based on co-operation and incorporates different parts. Some roles may be performed by a single actor, but the development team always consists of at least two actors: the DSS user and the DSS designer (5.4.3.4). Within this chapter all the roles in the DSS development process are described in order to assist the DSS designer in dividing the work and the DSS user in understanding his own role in the DSS development process. In literature the DSS user is often described only in the role of the user of the final application or as the data source for some input requirements, but to encourage broader acceptance and use of the system, the DSS user's co-operation within the development process is essential.

The DSS designer is in charge of the DSS design and the transformation of conceptual models into software structure and design. Other parts, such as data retrieval, user assessment (5.4.1.3) and software programming (5.4.1.5), may be filled by different actors. Other distinctions between the roles may need to be made if the resources for DSS development are not made available by the end-user but by another actor (5.4.1.1) and/or if the DSS user is part of the supporting staff to the decision-maker (5.4.1.2).

5.4.1.1 The client [26]

The client commissions the DSS development. In decision theory this commissioner is usually supposed to coincide with the decision-maker, but in European urban environmental applications DSS are still experimental applications and specific

---

[26] For more information, see section 4.4.2.5.

techniques being are tested. For this reason, the tool is often developed within scientific case studies initiated and/or financed by an institution from a higher level of the hierarchy or by a scientific funding institution, such as the European Commission. These clients have interests that may differ from the decision-maker's intentions. These requirements form the basis of the whole tool development process and should therefore be considered framework conditions right from the beginning. They should be presented to the decision-maker to avoid misunderstandings and erroneous expectations.

In some cases, the problem environment might be tailored to the client's requirements. In other cases, the client's expectations might change the precision and the content of the DSS or fix some rules for selecting alternatives or evaluation criteria. The definition of the client's requirements might be the basic reason the decision-maker initiates the tool's development. For example, if the client requires that a generally applicable system be developed, the system would therefore not be tailored to the decision-maker's specific case, and this might cause the decision-maker to believe that he/she does not require such a tool. The assessment methods described in section 4.4.may be utilised to analyse the client's requirements.

An *important question* to ask is [27]:

Does the client have specific preferences in terms of reporting and/or display?

5.4.1.2 The decision-maker/DSS user

The DSS user may not be the real decision-maker him-/herself, but instead may support the decision-maker directly. In this case, the DSS user must specify the decision-maker's requirements and will summarise and interpret the results to the actual decision-maker. On the basis of output generated by the DSS, the actual decision-maker might evaluate the problem again. In this case, the DSS user needs the DSS to generate a report that meets the decision-maker's needs, so that the DSS user forms a living interface between the system and the decision-maker. To analyse the implications of this case is beyond the scope of this thesis, but for completeness this case has to be considered a possibility for the DSS developing group.

The role of the DSS user includes co-operating within the building of the conceptual models treated in section 5.3, formulating appropriate system requirements and co-operating in graphic user interface concept development and implementation testing. The ultimate role of the DSS user is the one for which the DSS is designed: making use of the application within real world evaluations. Within this section an approach to representing the user's system requirements is described.

Questions to be answered in this context deal with aspects of technical system functionalities, with user interface design and man-machine interaction modes as well as with the detail of the processed information and the use of applications familiar to the user. One of the most important questions in this context is whether the system would need to be used with networking applications. The system, for instance, might be intended for use through wireless communication devices in the future. It would then need to be adapted to certain graphic layouts and programming interfaces. In this case, the display generator software requisites would be restricted, but graphic user

---

[27] This list is not complete, but is meant to show that many factors have to be thought of when decisions about the system's display are made.

requirements still should not be neglected and should be carefully weighted against freedom of user location. Which display and reporting devices are used depends on what the user expects the system to do and what he/she is prepared to work with.

The second group of questions concerns the role of the interface as a means for running the DSS digital components, and for interacting with them in a structured way, possibly using different models or reports.

Important questions to ask may be [28]:

1. Is there more than one user and, if so, how are they connected?
2. What types of display is the user(s) familiar with?
3. What digital means are at the user(s) disposal?
4. Does the user have specific preferences for reporting and/or display?

5.4.1.3 The DSS designer

The DSS user is the key actor in DSS interaction, the DSS designer the key actor in DSS design and implementation. The DSS designer controls the end-user oriented technical DSS design and implementation. She/he formulates the DSS concept and directs the development process. This includes:

- DSS development project management,
- the interface between the other actors, i.e. translating user requirements into a software structure,
- the representation of all intermediate results within the design process,
- verification that the DSS's results are adequate for the user's expectations.

The DSS designer uses her/his skills to decide whether to employ other actors to perform the different parts within DSS development, and if so, which ones.

5.4.1.4 The specialist in user/stakeholder assessment

A sociological analysis may be made of the actors with a stake in the decision process and of how they view the decision-space. This type of analysis is based on methodologies developed in sociology and psychology. These sciences analyse symbolic systems used to represent the real world, investigate group behaviour, and research methods of asking questions that produce certain types of answers. Some of the techniques mentioned in earlier chapters derive from these disciplines[29].

When choosing to introduce a specific actor for this role, one must consider the benefits of the gain in expertise against the risks of distorting the model of the user/stakeholder: the description made to the specialist may not be identical to the DSS designer's interpretation of the results reported by the specialist. One must also reflect on whether the specialist will hinder the relationship to be built between the DSS user and the designer, which might begin with a common mental model development process. A good approach to this problem might be to employ the expert in user assessment to moderate between the two actors.

---

[28] This list is not complete, but is meant to show that many factors have to be thought of when deciding about the system's display.

[29] For more information, please refer to chapter 4.4 or [45].

5.4.1.5 The toolsmith

The toolsmith translates the conceptual model developed by the DSS designer into software code. She/he might use modules of different origin and incorporate them into the final DSS software. The toolsmith and the DSS designer co-operate most closely during two phases of the development process: defining the modules to be used and developing the Graphic User Interface (GUI). The DSS designer mediates between the user and the toolsmith by translating each of their requirements into the language of the other.

The following sections describe how the DSS structure is derived from the conceptual model. Major attention has been paid to the interactions between the DSS designer and the toolsmith.

5.4.2 The decision space

The decision space is defined by the possible solutions to the problem, the criteria the evaluation is based upon and the user preferences regarding those criteria. In addition future developments or stakeholders may be inserted to enable additional types of evaluation to be made. All these elements have been described for the conceptual problem model, but how are they translated into the impact matrix?

The first step would be for the DSS designer to draw up an initial framework for the matrix and compare it to the conceptual problem model developed in the process described in section 5.3.1. Conceptual descriptions of the elements would then be inserted.

After this, these descriptions have to be translated to a form that can be processed by a digital system. This requires that the characteristics of each element of the decision space be defined through a set of logical relations. The characteristics must be represented by a set of questions whose answers can be translated into a numeric code: a binary choice, a number or a yes/no relation. Through this process, the toolsmith represents the modelled elements within a system of mathematical relations, to be translated again into digital code.

After these abstraction and translation processes, the DSS designer and the toolsmith should verify that the mathematical relations correctly correspond with the initial conceptual model.

5.4.3 Decision steps and their requirements

The sequence of steps required in the decision-making process elaborated with the method described in paragraph 5.4.2 represents a general layout structure. In order to identify the resources necessary to translate these steps into DSS interaction modules, the specific user requirements are analysed along with the user preferences for digital system interaction. The requirements for modelling the individual evaluation steps are analysed as well.

In this analysis, the modelling and input data requirements of each step modelled conceptually according to the process described in section 3.2 are determined. The most common way to do this is to represent each step as an empty box with its conceptual model input (I) written to its left, and its conceptual model output (O) written to its right. This way the role of the system module supporting this step is clearly defined: it is module that transforms I into O [30].

How is the required transformation module developed? At this (still conceptual) stage of DSS development, the different tasks to be performed by the GUI are defined, so that the GUI is divided into its logical functions. These logical functions are analysed in terms of their representability by data values and/or models, to determine which resources might be required for their implementation.

This description yields a scheme that shows the digital models required for each decision step.

5.4.4 General workplan for application development

For a controlled project management process to occur, a workplan has to be agreed upon by the team of actors within the DSS design and implementation process. This workplan lays out a framework of conditions regarding the economic, time and personnel resources available and the responsibilities assigned to each actor in the process. Using the outcomes of the processes described in sections 5.4.1 to 5.4.3, the project workplan is designed. This plan consists of four schemes:

1. a flowchart showing each workpackage of DSS implementation and its relation with the other workpackages; for each package a responsible task leader is appointed;
2. a time plan showing the anticipated starting time, duration and ending time of each workpackage in relation to the whole implementation process and to the testing phases;
3. a list of milestones, the actor(s) responsible for each of these, and their deadline;
4. a list of the economic and institutional resources available to each participating actor and divided by the workpackage contribution.

These elements provide the general rule that guides DSS project management. Responsibility for the project management might be assigned to another actor. Even though this does not really impact the software development process, it takes some responsibility away from the DSS designer, who may have difficulties defending his/her role in decision-making. This happened at the beginning of both the MATADOR [31] project and the UTOPIA [32] project.

5.4.5 Graphic user interface (GUI)

On the basis of the workplan described in section 5.4.4, the process of DSS software implementation is described in sections 5.4.5 and 5.4.6. The process has been split into two sections, taking account of the roles of the actors in DSS development involved in each.

"In DSS the focus of the decision maker is on the decision being made. The output from the DSS is of interest only to the extent that it facilitates decision making. The DSS user wants to make use of the DSS to explore aspects of the decision. In order to

---

[30] See examples in section 6.4.3 and 7.4.3.

[31] See paragraph 6.3.2.3.

[32] See paragraph 7.3.2.3.

do this it should not be necessary for the user to go through long sequences of commands, to enable data moves between different modules of the system. It is central to the design of DSS that the modelling routines can automatically extract the relevant data from the database component of the system. In a DSS the user should only need to intervene in the system to control the modelling process, not to conduct the basic operations needed for modelling." [Keenan 1997] The software should allows the user to understand what is happening within the system at any given moment (if this is desired) and thus to stay in control of the modelling and evaluation processes, but it should not force the user to manually execute any modelling step that follows automatically from a conceptual input. Developing such a system is the main task of the DSS designer. The DSS designer defines the steps in the interaction between man and machine, the types of input, the opportunities to access the modelling process, etc. End-user acceptance depends on the user feeling in control of the process and feeling supported, not disturbed.

The interaction between the DSS user and the system can be described as follows: submitting the input produces a dynamic response, where the input inserted into the DSS models generates a reply that the user must understand and elaborate upon. The user reaches an intermediate state of equilibrium at different stages in the process and then communicates this to the system. The most stable state of equilibrium is reached when the user accepts the system's output without reacting any longer. This could occur when the decision has been taken or when the user is no longer interacting with the system.

The GUI receives the user inputs in conceptually structured input schemes. This input is transformed into model variable input and is directed to the underlying models and databases through the GUI. Some inputs are transformed into Database Management System (DBMS [33]) requests to select data records; other inputs are transformed into Model Management System (MMS [34]) requests and are then transferred to the relevant models of criteria and alternatives.

The GUI consists of display and report modules. Outputs supporting the communication between user and machine create an interface, which communicates a request for input or the status of computer modelling. It represents the "thought" of the computer and asks for verification from the user: this process is called "display". A display is meant to guide the user through a process supported by a digital system. This includes facilities for interaction, schematic representations of the process being supported, descriptions of the elements involved in the process, representations of the output from the process modelled by the computer, and additional information (such as on-line-help and database catalogues).

Outputs which do not allow further interaction with the user and which may be used as stand alone information sources outside the user-system interaction are called *reports*. Reports are snapshots of displays that are meaningful in and of themselves. They are saved to an output device. This device may be hard- or soft, i.e. it may be on paper or it may be a digital device within the DBMS or outside of it. The quality of these reports is important, since they present the *results* – intermediate or final - of DSS-user interaction.

---

[33] See section 4.3.8.2.1.

[34] See section 4.3.8.2.2.

The display and report generator module includes the methods and tools in the DSS user-system interaction, called the user interface. This paper offers an approach to GUI design that is intended to produce close co-operation between the DSS user and the DSS designer. It translates the decision process into sequences of interaction-steps between the user and the system, and defines the role of these steps in the evaluation process and in the interface design process.

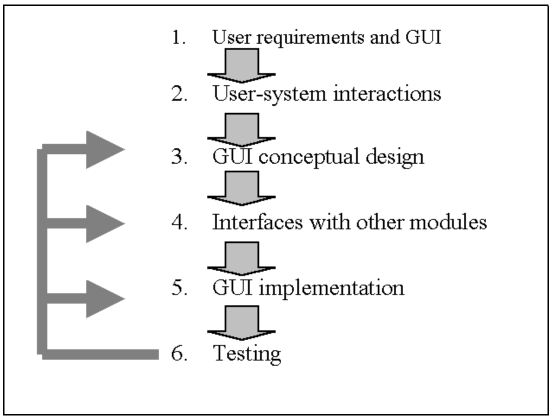


Figure 5.6: The steps in the GUI development sequence.

The designer of the GUI must first have access to an the assessment of user's skills and expectations regarding the system and his/her typical mental schemes (5.4.5.1).

Based on this analysis and the description of the decision process developed in chapter 3, the designer attempts to set up a scheme for the required user-system interactions (5.4.5.2). After this, the design concept of the GUI is developed: this again occurs in close co-operation with the end user (5.4.5.3). In order to guarantee that the GUI corresponds correctly to the DSS's internal module functionalities, the input/output scheme is translated into input/output specifications for the system (5.4.5.4). The final GUI implementation may look slightly different from the first design dummy for reasons of software implementation and due to modifications required by the user(s) or client. Choices have to be made by the DSS designer in co-operation with the user (5.4.5.5). A testing phase (5.4.5.6) occurs at the end of this development process to check whether the developed system corresponds to the expectations and requirements of DSS user and client. This testing phase may initiate a loop to some earlier phase of the project development, if user or client has expectations that are not being met.

Section 5.5 introduces a method for developing an internal system structure from the scheme of required user-system interactions.

5.4.5.1 User requirements and GUI

Who is the user and how is she/he able to interact with the digital system? Again, the approach to defining the GUI includes asking a number of questions. In literature, this problem has been approached mainly from the system development point of view: how can the required user inputs be gathered through the GUI? The answer to this question may vary and is usually derived from what the DSS designer expects of the user.

This paper develops an alternative approach, enhancing the GUI design process by incorporating co-operation between the DSS user and the DSS designer. On the basis of the conceptual problem model (developed in section 2.2) and the user's skills in interacting with digital interfaces (assessed in section 2.1), different methods may be employed, such as "trial and error", role-plays, or imitating interfaces already known to the user.

These techniques allow the following questions to be answered:

1. What do digital interfaces that are familiar to the user(s) look like?
2. What options do these interfaces offer?
3. How do they permit man-machine interaction?
4. Would those interaction modes be useful for interacting with the DSS?
5. Are additional interaction modes required? What types?
6. Are there existing software applications that could be used to train the user in the new interaction modes? Would the user accept this training?
7. How many users need to use the DSS? Where?
8. Does the user understand the current interface to the models to be included in the DSS?
9. How are decisions represented and to whom? How are decisions traditionally defended?

These questions also suggest that different GUI modules might need to be created for different parts of the DSS, perhaps for access to different disciplinary models, for access by different DSS users or for access from different locations.

First, the user's skills are listed, as are the system interfaces employed within the user's work environment. A second column is then added to the list, giving each item's characteristics in terms of user-system interaction and GUI functionalities. These characteristics are then grouped. After the user-system interactions have been defined according to the process explained in section 4.2, a list of the GUI characteristics familiar to the user is compared with the interaction requirements. The GUI design characteristics of the DSS are defined so as to be as similar to those familiar to the user as possible. The less familiar the user is with interacting with a digital interface, the more important this analysis becomes to the user's acceptance of the DSS.

5.4.5.2 User-system interactions

The decision process model described in sections 5.3.2. and 5.4.3 represents the general structure of the user-system interaction. In order to develop the GUI software implementation, this structure must be translated into a detailed input/ output scheme taking into account each relevant information-flow. The process introduced in this paragraph results in a conceptual scheme prepared by the DSS designer to serve as the developing scheme for the software programming by the toolsmith.

Based on the model explained in section 5.3.2, a scheme is laid out containing three columns: one represents the user, one the GUI, and one the DSS's internal structures. Section 5.3.2 explains how the major conceptual steps in the decision process can be categorised. On this basis, rows are assigned to each of these steps. A sequence of logical interactions was associated with each step in section 5.4.3, before the models to be implemented within the DSS internal software structure were selected. After the data and model system is set up, these logical steps are adapted for the relevant model input and output, i.e. the interface between GUI and the models/databases is defined.

This kind of digital interface between software modules is called Application Programme Interface (API).

	User	API	GUI	API	DSS internal
Step A					
interactions	**input A**	⇒	**transform & transfer**	⇒	**model**
	output A_1	⇐	**generate display/report**	⇐	**result for reply**
	input A_2	⇒	**transform & transfer**	⇒	**model**
	output A_3	⇐	**generate display/report**	⇐	**result for reply**
	…				
Step B					
interactions	**input B**	⇒	**transform & transfer**	⇒	**model**
	output B_1	⇐	**generate display/report**	⇐	**result for reply**
…					

Figure 5.7: Scheme for describing user/system interaction.

Defining the API between the GUI and the internal models poses some crucial questions for each step in the implementation process. These include:

- "Which DSS module delivers which part of the answer to the current input question?"
- "How do the partial answers have to be transformed in order to deliver a result corresponding to the user's expectations?"

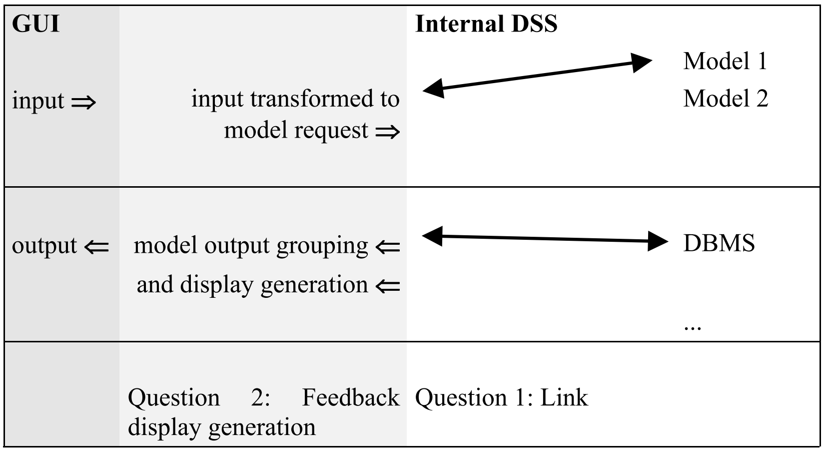


Figure 5.8: Flow chart for GUI-DSS API and GUI functionalities.

The answer to the first question defines the link between the GUI request and the model/database. The second question should result in the grouping of the model outputs within the GUI and their transformation into the output required by the sequence of the decision process. A related scheme is shown in the figure below. For other example schemes, please refer to chapters 6 and 7 [35].

Once the complete scheme has been built, it can be used to represent the framework structure for the toolsmith's API design and for the GUI's interaction with the internal DSS structure.

5.4.5.3 GUI conceptual design

The interface configuration (section 5.4.5.1) and the user-system interaction scheme (section 5.4.5.2) form the basis for the layout of a conceptual GUI design. In this conceptual design, a display configuration is laid out for each individual interaction between the user and the system. After this, the individual layouts are assembled into the sequence listed in section 5.2. The display steps are linked in this sequence, taking possible loops within the decision process into account. Reporting modules are conceived of based on the requirements of the user, decision-maker and client. Additional documentation and on-line-help modules are laid out and connected to the relevant panels. This GUI layout is then translated into a graphic digital prototype representation, consisting of dummy panels with interactive features according to sequential interaction planned for the final implementation.

This first dummy presentation may be developed with the help of interactive graphic demonstration software[36] and run as a video demonstration or via interactive panel sequences [37]. The more the user interacts directly with the dummy, the more likely he/she is to consider the GUI to be feasible. The presentation aims to test the user's ability to understand the panels and to interact with the system. In a second step, the sequence of user-DSS interaction may be tested to see if additional panels are required to increase the user's understanding of the support. This testing can also be used to determine whether the level of detail corresponds to requirements of the user and the client.

Steps of GUI design concept development:

1. Design one interaction panel for each interaction.
2. Compose the sequence of panels.
3. Define the relation between the panels (sequence including possible loops).
4. Develop modules or a form for on-line help and documentation.
5. Build the graphic interactive display dummy.
6. Test dummy through user interaction (its design and functionality).
7. Adapt dummy and test it again.
8. Agree upon the DSS layout design.

In this case it might be impossible to satisfy the requirements of both the DSS user and the client, particularly if they do not coincide or if they are placed at the same level in the decision process. If the client is also supposed to interact with the system,

---

[35] See the examples in sections 6.3.4 and 7.3.4.

[36] Such as Demoshield or Microsoft PowerPoint.

[37] Example descriptions are given in sections 7.4 and 8.4, and on the CD-ROM.

two different GUI sequences may be required. If the client does not interact directly with the system, but is interested only in some aspects of the evaluation, sub-modules of the report-generating part of the GUI may be added in order to generate the intermediate reports needed by the client or other stakeholders.

The dummy version is the first DSS "prototype" the user is confronted with. At this time, the user is able to compare the actual system with what he/she had expected. As most of the process, up until this point, asked the user to invest time and resources without a real visible result, this is a crucial point in the DSS's development. The user often has to be convinced that the DSS under development actually does provide support for the problem case. But this is also a point of no return. If the user accepts the solution, he/she will usually not accept fewer functionalities in the final verision than are presented in the dummy. The fact that it is a dummy often provokes the user to have even higher expectations of the final version. The DSS designer has to explain continuously that the dummy is merely an experimental version, and that the final result may look different. To avoid the risk of disappointment, the software planned for use in the final GUI development should be simulated as closely as possible in the dummy. If Internet techniques are supposed to be included, the dummy might include browsers configured as display panels, etc. Within the MATADOR and UTOPIA projects, the final GUI environment was not clear in the beginning and was decided upon only after the dummy testing. Even though the functional interface devices were the same in both the dummy and the final version, the absence of the recognition effect [Zwisler 1998] had strong negative effects on final user acceptance of the tools.

In order to assist the user in keeping track of the decision process, a detailed documentation and on-line-help system should be envisioned for each step supported. This documentation should include information on:

- the project/problem case the DSS was developed for;
- the specific application case analysed;
- the DSS and its methods, structure and functionalities;
- the actors at stake;
- the elements of the decision space;
- and possibly, as well, consequences of the final implementation of alternative solutions.

5.4.5.4 GUI implementation

The GUI-user interaction dummy (section 5.4.5.3) and the GUI-DSS model API scheme (section 5.4.5.2) are the two facets of the GUI layout that are ready, at this point, to be translated into digital code. To finalise this script for the toolsmith, the correspondence between the internal and external schemes has to be checked and the languages and tools for programming selected.

For this check the dummy interface is again analysed in terms of its input/output scheme, which may have changed following user instructions. This scheme is compared with the API structure described in section 5.2, and the API scheme is adapted if necessary. This adaptation process may have to be repeated several times if required by the user, as indicated in responses to the testing described in section 5.5.

After this programming tools must be chosen. There is a variety of commercially available display-generating software. To select an appropriate set of tools, the following aspects must be considered:

- the GUI interface is not static: individual displays are generated following defined schemes and integrating flexible system input and output;
- for the GUI-user interface, the final result has to resemble as closely as possible the dummy interface agreed upon with the user and be portable onto the display devices available to the user;
- the APIs have to communicate with models, database(s) and the GUI; they must have digital interfacing modes or tools at their disposal;
- finally the toolsmith's skill in operating one or another tool is important, if she/he is appointed before the programming tools have been chosen.

5.4.6 Testing

After the programming implementation tools have been chosen, a second dummy version should be developed, using the programming tools chosen for the final implementation to check if the user accepts the differences in graphic display between the dummy and final interfaces. Graphic demonstration software should again be used to avoid having to completely reconstruct the API. This might be needed if changes are made in the GUI after the DSS has been finalised.

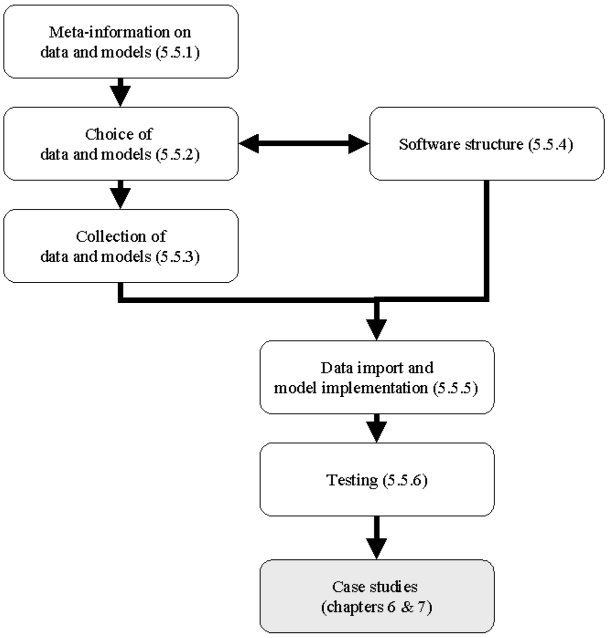
This testing requires an interactive session at which the DSS user and designer are present, and, if possible, also the toolsmith. To best record the changes required by the user, a panel-by-panel printout and a sequential graphic representation of the digital interface panels can be used. With these tools, changes can be recorded on-the-flow and communicated to technical staff.

It is very useful to incorporate the changes quickly so that the adapted version can be discussed as early as possible. Very good opportunities for this are provided by meetings lasting several days, like workshops and conferences, where the user is encountered outside his/her daily routine and is able to discuss several GUI versions within a multi-session approach. Minor modifications may be inserted directly, and larger changes represented at least on paper. This way the user feels part of the design process and, as a result, may become more open to co-operation. In the case of user groups, one report of the modifications suggestions by each individual group member should be produced from interviews or brainstorming sessions. The user group then finds a compromise among these solutions. A multi-session testing approach is the fastest way of reaching agreement on the final form. Again, a minimum of two days of meetings is required. The results may be recorded digitally or via hardcopy sketches.

Once the second dummy GUI has been accepted by the user, it can be implemented as the "face" of the complete DSS, i.e. connected to the DSS internal modules described in section 5.5.

The time sequence of the development steps described in two paragraphs above is overlapping.

5.5 INTERNAL SOFTWARE STRUCTURE AND CONTENTS



This chapter introduces a method for developing the DSS system structure and software specifications on the basis of the sequences of interaction steps between user and system defined in section 5.3.2.

Sections 5.5.1 to 5.5.3 describe methods for defining requirements and choosing and collecting data and models corresponding to the requisites defined in chapters 3 and 4.

Figure 5.9: Structure of section 5.5

Section 5.5.4 explains the software structure set-up, section 5.5.5 is dedicated to the implementation of data and models into the software structure and section 5.5.6 elaborates the interfacing of the different software modules described in section 4.2 as application programme interfaces (API). The final section is dedicated to DSS testing.

The choice of basic hardware and software and the final digital or hardcopy support to the DSS depends on the DSS user's specific requirements. A user not equipped with a computer, or unfamiliar with its use, will have to be trained or supported via paper manuals or through an operator providing an additional interface to the computer screen. The less familiar the DSS user is with the tools the DSS designer intends to apply, the more difficult it is for the user to accept the DSS. The first dummy development and its testing function as additional training for the user. The more the user interface differs from the dummy, the higher the risk that the user will imagine the final DSS to be exactly like an intermediate testing sample.

5.5.1 Meta-information on data and models

In section 5.2 the interactive scheme was defined in terms of required answers to the user questions communicated to the system via the GUI. In this context, black boxes were defined as generating the input to the information displayed by the GUI. These black boxes correspond to database inputs and modelling modules. The use of database inputs is more immediate and requires less processing time during the DSS session. Technically, it is preferable to the use of models. On the other hand, if only database inputs are used, and no data-generating models, in every case where a value is attributed to a question or an element of a question introduced to the GUI, it would have to be represented through a database input. For a discrete number of possible values this is possible, but for a continuous problem, it is not. A model has to be used in order to represent the problem correctly. In addition, a database list, once completed, permits fewer modifications in DSS functionalities than a model able to generate values on the flow. A choice must be made between the use of time-consuming but more flexible models and the use of faster database input.

In most applications a mix of data and models is used for the decision space. Models are used in every instance of evaluation handling in scenario and multicriteria modelling. Goal modelling, however, might result in a discrete set of possible goals and thus could make use of an underlying database.

	Database & Model functions	
input A ⇒	required functionality $_1$	⇒ output A$_1$
input A$_2$ ⇒	required functionality $_2$	⇒ output A$_3$
...	...	...

Figure 5.10: Database/Model input and output scheme.

The GUI-API calls that transfer the user's request and require a system-generated answer (described with the schemes in section 5.4) represent the input and outputs required by models and databases. Figure 5.10 is a diagram that defines these input and output requests. This scheme can be enlarged to represent the data generation required by other APIs , such as the reporting and evaluation systems.

These required functionalities have to be produced by data and models. Since model outputs consist of generated data, the output that is to be directed to the GUI must first be physically defined. This output definition should then be inserted into a meta-data scheme. A meta-information scheme for the data produced by the database/model system should include the following indications [38]:

1. Name of the output
2. Concept behind the output
3. Data source (data collection, user-input, etc.)
4. Time reference (date of measurement, revelation, and/or collection)
5. Data type (float, integer, fuzzy, linguistic, etc.)
6. Data accuracy (%, fuzzy tolerance ...)
7. Unit
8. Area of origin (specific thematic keyword)
9. One example set

Based on this description of which data are needed, the data source can be chosen from database management system inputs and/or generated by a model, as illustrated in the following paragraph.

---

[38] Example from the MATADOR project: 1. "Break time", 2. "Time interval covered during periodic breaks", 3. "User-input", 4."sec.", 5. "Integer", 6. "20 %", 7. "Minutes", 8. "Mission", 9. "30"

For more information, please refer to chapter 7.

5.5.2 Choice of data and models

The set of data and data generation tools must be able to handle all required direct and indirect outputs.

Other questions influencing the choice are[39]:

1. What functionalities are to be used for the representation? (networking, multi-media, etc.) Does this favour specific models/DBMS inputs?

2. How much detail is required for the related evaluation phase?

3. How are the elements of the decision space currently modelled by the decision-maker? What are the shortcomings and strengths of this mode of representation? Are models employed which may be implemented within the DSS?
4. How much effort is required for data collection/model implementation?

5. Do the actors in the DSS development process have skills in using specific data/models?

The different possibilities for collecting/generating each individual output are represented in a table, indicating their pros and cons. Elements that appear repeatedly are grouped together, and, finally, a list is composed that guarantees the required output set will be generated with a minimum of effort, taking the skills and physical resources available into account. The meta-information schemes for each element of the set are gathered together and the scheme is then enlarged by indicating each element's data/model source and structure.

If the application project does not foresee the implementation of a specific evaluation tool or method, please refer to the selection of approaches described in chapter 4, where the different conceptual models at the basis of each approach are described. If no corresponding approach is referred to in these chapters, please consult the related references, as it is outside the scope of this thesis to develop a complete listing of all approaches, which would anyway be outdated before this paper comes to publication.

5.5.3 Data and model collection

After the set of data and information generation models required for the DSS application has been defined (section 5.3) the data and models are collected. Although listed in the approach description, this tends to be the longest and most resource consuming phase of DSS development. To obtain data and models from the relevant sources is often requires an unexpected degree of diplomacy and luck. Therefore after the set of desired data and models has been defined, it is useful to contact their owners and to imagine possible substitutes because of copyright and availability problems. Problems of database completeness or data/model digital format might also require substitution to resolve. It has also to be taken into account that the user and client might have special wishes for the use of particular data sets[40].

---

[39] This list is not complete, but is meant to show that many factors have to be thought of when deciding about the system's display.

[40] See the case study described in chapter 6 for an example.

5.5.4 Software structure

While data and models are being collected in accordance with the provisions of section 5.4, the meta-information on data and models, the GUI design and the evaluation methods are brought together in the overall software structure design.

As described in detail in chapter 4, DSS are composed of three modules:

- a Database Management system (DBMS),
- a Model Management System (MMS),
- and a Graphic User-Interface (GUI), including display and report generators.

The GUI design is described in detail in section 5.4, along with the linked display and report generator requirements. The structural development process here relates to DBMS and MMS and to the implementation of the complete structure.

The definition of data and models to be incorporated into the DSS determines the software requirements of the structures hosting these elements. Data inputs may be accessed from simple input streams included within appropriate files. But the more complex the data structure grows, the greater its requirements in terms of comfortable input interfaces and API functionalities in the programming languages and display/report generators. These requirements are fulfilled by DBMS, which, nowadays, are incorporated in standard desktop configurations. This provides a comfortable and low-effort system for data storage and access. For very large amounts of data use or very sophisticated configurations, more data-specific DBMS (such as Geographic Information Systems) may have to be used. The database management system is selected in accordance with the quality and the quantity of the data to be stored and with software licensing resource requirements.

The concept of the MMS is less structured than the DBMS. It consists of a part of the computer's memory structure that is assigned to the DSS models. Each model has its own input GUI, which usually differs from those of the other models. If the DSS is supposed to be later used for different applications without support from external technical staff, some effort has to be put into documenting these interfaces. It may also be necessary to consider adapting the model GUIs to the DSS's GUI layout in order to unify the system.

Usually the models do not come with ready-made APIs. The next large task for the toolsmith, apart from translating the GUI design to GUI source code, is generating the APIs between the models in order to build the MMS. The model input and output scheme (section 5.4.5.2) forms as basis for this programming effort, along with the model specifications described within the meta-information (section 5.5.2).

All the DSS modules are developed at this time. To complete the structure, the APIs between the modules have to be defined. This is done by:

- first, describing the GUI-API-DSS internal system scheme (developed in greater detail in section 5.4.5), then adding the digital meta-information (the exchanged data) and finally referring the appropriate requests to the display and report generator(s);
- second, describing the DBMS requirements for specific models, i.e. the API between DBMS and MMS;
- and, finally, translating into structured digital code.

This process description shows that ultimately an additional DSS application-related module is produced: the source codes of the API, which are stored in an additional DSS module and which "glue" the other parts of the system together. This thesis calls this module, which has not yet been described adequately in literature, the DSS generator module. The complete DSS software structure consists of four modules:

- a Database Management system (DBMS),
- a Model Management System (MMS),
- a Graphic User-Interface (GUI), including display and report generators,
- and a DSS generator module (DGM).

Rudimentary toolboxes for practical API software implementation are currently incorporated in many types of general-purpose software such as spreadsheets or DBMS packages. "In modern DBMS and spreadsheet software, the use of macro and programming languages facilitates the creation of specific applications. Various generators have strengths and weaknesses in terms of their provision of the key components of a DSS, an interface, a database, and models. [...] However there is a very real sense in which the types of DSS design considered for a given class of problem are a function of the available DSS generators for that class of problem. In practice a small DSS project could be built, using an off-the-shelf spreadsheet or DBMS package, in less time than it would take to fully evaluate the full range of alternative methods of constructing the DSS. Therefore the DSS solutions actually constructed are strongly influenced by the perceived availability of suitable generators." [Keenan 1997]

Keenan summarises these strengths and weaknesses in the following table.

DSS Module	***Spreadsheet***	***DBMS***
GUI	tables, forms, charts	tables, forms, reports
DBMS	independent cell entries	linked database tables
Database functionality	rudimentary sort and selection	comprehensive queries
Models	built in mathematical functions, statistical and management science tools	basic mathematical functions
Model building tools	recorded or programmed macros	macro and database query languages

Table 5.1: Strengths and weaknesses of spreadsheets and DBMS.

To get an overview of the current conceptual types of DSS and to understand which of these could support a specific problem, please refer to chapter 4. If one of these tools corresponds to the problem case on which the application is to be based, the easiest way to develop the software is to look for existing application cases and try to acquire and adapt their source code. Often this will be difficult unless the application is a scientific study case, but by analysing their structure and possibly the pros and cons reported by their users, it is rather easy to derive a conceptual model and, after this, to develop a source application.

5.5.5 Data import and model implementation

Data import and model implementation techniques are very strongly linked to specific objects. This paragraph attempts to show some of the typical problems encountered during these procedures, so that the DSS designer and toolsmith may be prepared for the implementation phase and the user, decision-maker(s) and client may get an idea of why this phase usually consumes so many of the project resources.

Even though the DBMS may have been chosen because it had the largest data input compatibility, the collected data are never structured as expected, in the format expected, or as complete as expected. Primer meta-information helps to limit these problems, but cannot eliminate them. The meta-information described in section 5.5.1 is essential for software development. Additional information is required for proper data import and model implementation. This includes:

- the format the data is delivered in (Internet and floppy disk are simple, but large-frame databases may output onto tapes not supported by any available readers);
- the digital format and the version of the software it is produced by (more recent versions may not be readable by the available software, older ones may be distorted);
- the structure of the report contained in the file (header and footer indications may have to be defined for reading the information, simple text reports may not contain meta-information on comma-separated input, etc.);
- the name of the person responsible for the file generation (always the shortest way to a solution if something does not work).

After the data has been read into the digital system, a list is generated that shows each input value's position within the read-in file collection and where it is going to be placed within the DBMS. After a complete list has been made, importing procedures are performed, as required by the different external files and the DBMS.

The models are usually read into the system as a complete unit or are linked through a networking API from an existing implementation. In very few cases is a model adapted for a different software system, which usually requires a contribution from the model's developer. Today's opportunities for networking reduce the number of cases in which this is necessary to a minimum.

In sections 5.4.5.2 and 5.4.5.3, the required model inputs and outputs are described. The output generated through the model reporting system may not be limited to the pure text output required for the DSS. It usually contains, in addition, header and footer information and other calculation outputs. This additional information is useless for the DSS application, but has to be taken into account during the design of the output-capturing DGM, which afterwards selects the desired output for the DSS. The same problem occurs with model input: the model may require additional information to be delivered through a DSS or through static values assigned by the DGM model input facility.

Adapting the DGM from the structure required for the DSS to the final version adapted to the input information requires additional resources and attention. The DSS designer and the toolsmith should be prepared for this right from the beginning of the application development process, to guarantee precision in time and resource planning.

5.5.6 Testing

As in all software development processes, the individual modules and parts of the source code are tested continuously for functionality and failure-free interaction. The testing treated by this paragraph is, instead, the sequence of user-interactive testing sessions that may lead back to the DSS design phases, or that may put the stamp of final approval on the tested DSS version.

Essentially this testing session is very similar to the dummy testing in section 5.4.6. The only difference between them is that after the final approval, changing the prototype to its final form will require some software adaptation. No prototype is ever independent of the specific settings and applications used in the development process. For software to be portable onto different systems, it must be substantially tested. If, for example, the final version will be a CD-ROM that can be run from different platforms, the testing has to include these platforms, their individual software settings and more. Thus portability is a time and resource factor in software development.

5.6 CONCLUSIONS

This chapter represents the core of the thesis' work. It is a novel approach to improving the utility of DSS by introducing all actors in the development process to their roles in and influences on the development process. They are also given rules of interaction and are taught how these may impact on the resulting tool. The approach tries to match the input specifications made by all the actors with realistic user expectations for the final DSS. This adds a completely new aspect to decision theory and to the evaluation of DSS. The specifications for the final tool are not defined exclusively by its users and do not depend exclusively on data accuracy. Other actors also have much influence on these specifications, as well as on what is expected of the tool. This must be taken into account: multiple aspects and actors influence the outcome of the evaluation process supported by the DSS. In order for the DSS to support the user and the client, both must be aware of the client's expectations. The end-user must also evaluate whether his/her expectations conflict with those of the client. Taking the complete set of system requirements into account simultaneously allows developers to see if the system offers a complete solution to all the problems for which it is required. If this appears impossible, other way of reaching this goal must be found to avoid producing a useless DSS.

In chapters 2 to 4, the actors are introduced to a select set of disciplinary methodologies. This enables them to understand the backgrounds of the different players involved. A complete overview of all actors' backgrounds or of decision theory exceeds the scope of this thesis. Those of the actors encountered during the application developments described in chapters 6 and 7 are included, as are those of the stakeholders considered within those studies. These two specific applications serve as examples demonstrating which information is required to understanding the mentality and requirements of the actors a DSS supports.

For a summary overview of the major findings of this research, a description of the place of this thesis within DSS literature and a consideration of the new research questions it opens, please refer to chapter 8.

CHAPTER 6 Test 1 of the DSS-maker's script - MATADOR

6.1 INTRODUCTION

The methodology presented in chapter 5 was developed on the basis of the construction of two DSS applications intended to support fleet managers (MATADOR - MAnagement Tool for Alternative Driveline and Operational Research) and local administrators (chapter 7: UTOPIA - Urban Transport Options for Propulsion Systems and Instruments for Analysis) with the implementation of advanced propulsion systems in urban transports. The case studies served to test the theoretical framework of the methodology by creating sample implementations. The applications have been used to investigate difficulties in the implementation of each step, as determined in the methodological approach to DSS development described in chapter 5.

The case study descriptions function in two ways: the text version illustrates how the DSS maker's script approach changes the traditional approach to DSS design and implementation, whereas the CD-ROM version uses the single step descriptions as pop-up illustrations of the methodological steps described in chapter 5. They guide DSS developers in following the methodological approach in two application cases to demonstrate how to put theory into practice. This way the CD is a training programme for the implementation of the methodology. The CD-ROM version includes, in addition, an option for accessing the interactive interface dummies developed for the projects.

To better understand the structure of this chapter, please refer to the following figure.

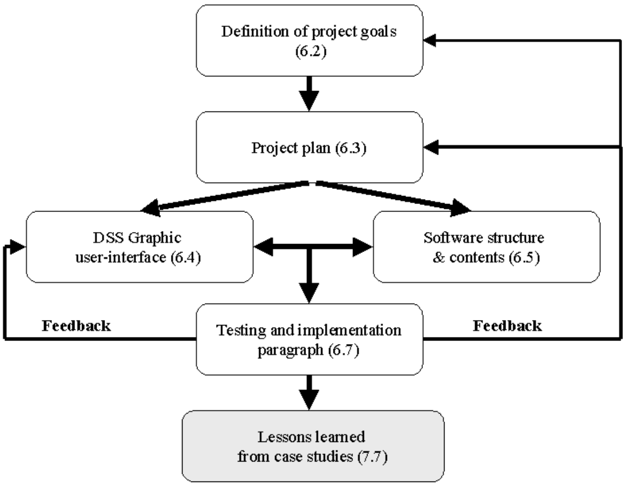


Figure 6.1: Chapter 6's structure.

6.1.1 The author's role within the project

The author of this thesis played the part of the project's DSS designer. This role did not coincide with that of the MATADOR project manager, since the DSS was not planned as the only result of the project. As the DSS designer, the author personally developed the initial DSS dummy prototype and was responsible for the prototype software programming. The other project partners performed the data collection and the end-user assessment. Before the testing phase ocurred, the suthor changed her place of work, and thus she did not conclude the work personally. Frequent changes in the composition of research and development groups often strongly influences the continuity of the implementation process, but in this specific case the process was not strongly impacted, since the resulting DSS version is a proof of concept, not a practical implementation in the client's office.

6.1.2 The MATADOR project

The Programme for Collaboration between CEU and National Programmes on Electric Vehicles (JOU2-CT94-0291) ended in June 1997. The main objective of this programme was to bring together the experiences of European electric vehicle test and demonstration fleets. The data from these tests and demonstrations have been stored in a database. The main objective of the MATADOR project was to enable managers and operators of European urban test and demonstration fleets with electric and hybrid vehicles to access the technical aspects and implications of conventional and non-conventional drivelines in order to:

- keep themselves informed on the state-of-the-art of conventional, electric and hybrid drivelines for road vehicles as well as on developments in vehicle design and construction aimed at reducing energy consumption and emissions;
- identify promising technologies for specific applications;
- assess the readiness of technologies for short term market introduction;
- better choose vehicles and drivelines to test or to demonstrate.

In this context, a DSS to provide managers and operators of test and demonstration fleets with a tool for the structured assessment of information about the technical aspects and the implications of conventional and non-conventional drivelines under operating conditions has been developed.

This was a case of DSS development commissioned by a client operating at a strategic level, the European Commission, requesting a support for actors at different locations acting within a very local urban environment, fleet managers.

The timeframe for the MATADOR project development was 30 months from February 1998 to July 2000. Seven partners were involved in the project as a whole, fulfilling tasks from project management, data retrieval and database development, to user assessment, DSS development, and testing.

The following sections describe the MATADOR DSS's development through the DSS maker's script and comment at each step upon how the application has influenced the script.

6.1.3 The project in the analysis of the DSS –maker's script

The initial project proposal included a traditional development framework consisting of a project management plan. During the start-up phase of the project, it became clear that the proposal had been prepared by a group of researchers and institutions supporting the designated user-group without having consulted them. But what do these users require? To find out, the DSS experts had to determine the users' cultural backgrounds and the evaluation methods at the basis of the fleet manager’s decision processes.

During the contracting phase, additional requirements to the system were defined by the funding institution. If the requirements defined by the project team reflected their image of what the end-user needed, these new requirements derived from a completely different source. Thus the definition of the system requirements, their final functionalities and the system layout had to be adapted for the possible final users and the financing institution. The importance of the part of the client had been identified for the first time and became original input to the DSS maker’s script approach.

This more complex situation in which the client is an additional “user”, in terms of defining requirements, lead the DSS maker to ask if there were other usually ignored aspects that strongly impact the DSS specifications and/or outcome. Most of the aspects found were produced by the human actors involved in the DSS development process and their skills within the development process. Other impacts have included economic issues determining input data and models and the technical equipment used. When choosing a system for his/her own use, the DSS user ought to be conscious of all these aspects in order to adjust his/her expectations to the possibilities of the development process. In order to produce a DSS welcomed by both user and client, both have to be introduced to the DSS development process as a whole and the limiting factors as well as the opportunities opened by specific aspects within it. This way problems are no longer perceived as shortcomings caused by the technical developers’ incompetence, but are understood as the results of specific circumstances.

The approach proposed in chapter 5 has been followed throughout the MATADOR DSS development process. The result is illustrated below.

6.2 DSS REQUIREMENTS

Even though the user had been defined within the project proposal, direct contact between technical developers and DSS users took place only during the first project implementation phase, the user assessment phase. Originally, the user had only been informed that the project was carried out with the help of EC funding. After the first assessment phase, it was noticed that several user requirements existed that could not be fulfilled because of the client’s requirements, e.g. the availability of the final DSS in the user’s native language or the inclusion of specific aspects of their fleet or urban environment. This lead to user assessment interviews that included an explanation of the list of requirements defined by the client, to avoid unduly high expectations which were not to be fulfilled. This integrated the client into the list of actors included in the DSS-maker’s script approach.

6.2.1 Conceptual problem modelling

According to the methodology described in chapter 5, the actors in the DSS development process and the conceptual model have been defined as follows.

6.2.1.1 The client

Apart from specific reporting schemes, the client’s requirements included:

- exclusively an English language version of the final tool;

- the use of an existing database resulting from a former project as the basic database;
- a project duration of 30 months;
- a tool that would be useful for users all over Europe, i.e. not a solution tailored to a specific user;
- access to the final digital version available to the whole user group;
- no additional funding for unforeseen aspects;
- understandable language also on the European policy level.

6.2.1.2 The DSS user

To understand the mental schemes that represent the real world for the MATADOR decision-makers, the profiles of these actors have been assessed through questionnaires and interviews [Moser et al. 1998] with vehicle fleet owners and managers all over the EU, using the methods described in section 4.4. The questionnaire [41] was developed in co-operation with experts in sociological assessment, alternative propulsion system implementation and DSS development. After an initial overview of the actors' cultural backgrounds based on former EC projects and databases, a questionnaire and interviews were carried out, including questions about the mental schemes traditionally employed as well as questions about tools used in the work environment and questions about the decision space.

The process of gathering information through questionnaires was very time-intensive, but it provided an initial overview of different parts of the decision-space and the DSS's requirements. During the interviews it became clear, that some questions had not been precisely understood during the questionnaire phase. A more detailed explanation of why some questions had been asked was required in order to make the potential DSS user understand her/his part in the DSS developing process. These gaps in integrating the users resulted in several misinterpretations detected only during the testing phases of the DSS interface dummies. This lead to an intensification of the user integration process and an understanding of the need for DSS experts to work with the users. These requirements have been integrated into the methodological approach of the DSS-maker's script including the integration of decision theory and DSS that is presented in chapter 4.

The questionnaire did not ask the exact questions that follow in the initial assessment of the problem space, but became important during the DSS's development and were therefore answered later in the development process.

What is perceived as disturbing now or is expected to disturb the harmony of the situation in the view of the decision-maker? What would he/she like to be different?

Client (strategic goal): The noise and pollution load within European cities is too high. It has to be reduced. Fleet managers should achieve part of this reduction.

What would have to be done to change the situation, i.e. what is the disturbing factor observed?

DSS user (implementation method): The vehicle fleet pollution must be reduced.

What would happen if the disturbing element were eliminated without substitution?

---

[41] The analysis of questionnaires and interviews is recorded in MATADOR deliverable 1 and [61].

Which sub-systems would be influenced? Who would react?

Eliminating some vehicles could reduce the pollution produced by the fleet, but their service could no longer be guaranteed, which would be bad for the business. Other services would therefore add vehicles to their fleets or private owners would use additional vehicles, causing additional pollution.

Are there possible "substitutes" for the disturbing factor, i.e. are there alternative solutions to the problem?

Alternative propulsion systems (APS), low-consumption engines, light vehicles or other vehicle concepts could replace the conventional ones.

How would they work and what would their impact be on which other sub-systems?

APS would not impact on the trip organisation within the fleets, but on the possible maximum trip lengths between fuelling stops. Economic and technical aspects are the major concerns of the fleet managers, but environmental, image and political aspects should also be considered.

Who would gain or lose?

Losers: Petrol industry, conventional car manufacturers

Winners: Urban environment, inhabitants.

Which background factors are not impacted by the disturbing factor, but influence the factor itself and/or the usefulness and/or support of substitutes? Are there "visions" for the future that could change the behaviour of the problem space? Does the decision-maker want to take into account their possible change over time?

Other solutions could be reached through advanced transport concepts or changes in behaviour patterns, but these are outside the impact range of the fleet manager. Urban administrative policies could mandate the implementation of APS in the future. The project ought to find out if this kind of substitution could make sense and thus support the EC policy makers with the decision of mandating such policies. The participating DSS users base their decision processes on the supposition that there will be more pressure for the implementation of such systems in urban public and private fleets, such as the exclusion of conventional vehicles from the city centre or other measures.

The professional background of the users was also assessed:

1. *What is the DSS user's educational background?*

   About two thirds of the fleet managers had a technical background. A business background was more common among the decision-makers and the bigger fleet operators. The educational level varied a lot; with about 50 percent holding academic degrees, but also of a high number of specialists with long employment times and much experience.

   Their computer knowledge is judged by many fleet managers themselves to be very low.

   Most users asked for a translation of the interface into their native language. After a discussion with the EC officer, this was omitted but may later be developed.[42]

   Are there schemes linked to this?

   Because of users' differing backgrounds, a scheme had to be developed to enter the decision process by analysing different aspects and with a very clear user interface.

   Which sources of information are usually accessed?

   Magazines, conferences, seminars, books, experts' knowledge, commercials and sales representatives. Use of the Internet to gain information was surprisingly low. Practical experience is a major source of information about alternative driveline technologies and motor fuels.

2. *Were there former projects? Were schemes worked out for them?*

   Some fleet managers had been involved in former APS implementations, mainly of electric vehicles. Therefore typical schemes for APS implementation were adopted by these actors. None had been involved in a DSS development so far.

These inputs were used to define the goal definition module introduced in section 6.3. The result is described in section 6.4 and was discussed by the technical project development team and the EC officer. It was presented to the user only at a later stage in the development process, through the first DSS dummy interface. Fortunately the sequence of the goal definition module was accepted by the decision-makers as it was, but the absence of the direct testing module within the work-plan could have lead to difficulties at a later stage. It would be interesting to know whether acceptance at this stage could have been due to a loss of interest as consequence of the impression that despite the intention to include the users in the development process, they had not been considered in this important step.

To summarising the practical results of the MATADOR project, the problem space was assessed in terms of possible alternative solutions: vehicles with alternative propulsion systems. A set of evaluation criteria was set up and presented to the users to understand the relative importance the users assigned to each of these criteria within the evaluation.

---

[42] This is an example of the influence of the client to the final DSS structure.

Inputs to the DSS-maker's script framework gained from the initial phase of this application include introducing the client as an important actor in the DSS development process and needing to introduce the user(s) to decision theory and DSS methods. This enables them to better understand the support they can expect from the DSS and thus motivates them to perform their part in the development process.

After the problem space had been described in a conceptual model, the approach with which the decision-maker will face it had to be designed.

6.2.2 Decision process model

Again according to the methodological structure developed in chapter 5, the decision-process model was formulated. The decision-process to be supported by the specific DSS was related only to the user. The client's requirements limited the tool's possible implementation and required that the user interface be relatively general. The client determined that a European group of possible users would be analysed to define the decision process model, but the process model itself was defined by this group of possible users without any additional input from the client.

A step-by-step decision process model was developed to solve problems, as described in section 6.2.1.2. This model was produced through a theoretical analysis of the decision-maker's traditional selection process on the basis of a set of documented case studies. After this the users were asked to check the general decision steps that were derived .The framework contains different evaluation steps, which may be followed sequentially or entered alternatively through individual steps or information sources. The model itself is meant to offer an overview of the decision process and a basis for the module structure of the DSS, distinguishing different points of entry to the process through determining the related user requirements.

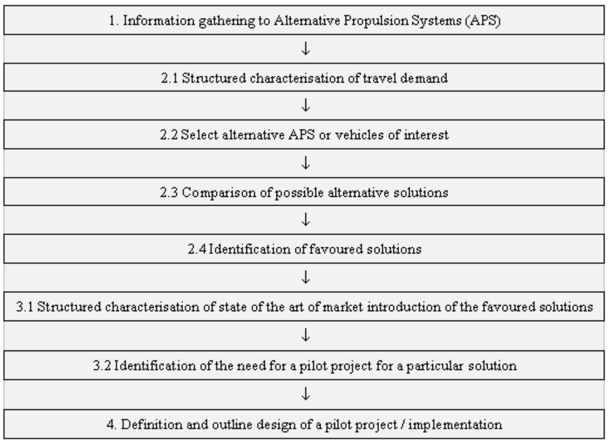


Figure 6.2: Schematic flowchart model of the decision framework.

The flowchart represents the basic steps within the specific process of problem-solving.

The sequential arrows represent only one possibility for accessing the process. Block 1 consists of a step that runs parallel to all other decision steps, but is most often performed at the beginning of the problem-solving process. Block 2 consists of the evaluation process itself. Block 3 preserves additional information, which may cause a loop back to block 1 or 2. Block 4 is the implementation phase. This very general process was developed by the DSS developing team according to the interview results and was accepted by the possible end users. No existing systems have been found that were specifically developed for this kind of application.

The development of this step emphasised the usefulness of preparing initial framework layouts to focus on the model definition and to show the decision-maker what is intended by the theoretic notion of "model" in order to gain the user's contribution to the modelling process. As a possible method for reaching this understanding role-play methods have been included in the short introduction to assessment techniques contained in chapter 4.

After the problem has been modelled and the process of finding a solution approached, the following section introduces other actors who may influence this process.

6.2.3 Actors in the decision process

As described in section 5.3.3, in order to finalise the problem description, the actors have to be placed into the problem model, i.e. the actor's impacting actions within the evaluation process supported by the DSS have to be translated into variable impact factors. This is related to the decision process, not to the DSS development process.

The project requires the development of a DSS for a specific user group. But a different actor has commissioned the DSS. Other stakeholders in the decision process include the fleet manager's customers, infrastructure mangers, local policy makers and possible funding institutions, such as pilot projects. Apart from the fleet manager's customers, all other stakeholders have opinions that impact on the problem environment, which is considered to be strongly influenced by the client. Those stakeholders are therefore not considered within the evaluation process but for their input to the problem space definition. The client is considered by the fleet manager by assigning specific weights to user acceptance of vehicle image and comfort within the vehicle descriptions to be stored in the DSS database.

Different possible users have been distinguished for the DSS, even though the final design was tailored to the specific requirements of fleet managers, as requested by the client. Other users could be:

a) groups of *stakeholders,* characterised by an interest in detailed information about specific areas of interest and their impact on the global decision process;

b) decision-makers and *consultants* expert on parts of the decision-spac,e characterised by an interest in an overview of the evaluation process, in the relevance of their interests to the whole process, and in detailed information on specific areas of interest. Sometimes these actors require that it be possible to introduce of specific information and/or models to the evaluation module;

c) *consultants* to the decision-makers supporting the final decision, characterised by an interest in a structured approach to all details of the whole evaluation process and the different stakeholder profiles;

d) *institutions for education*, characterised by an interest in an overview of the problem, but eventually requiring details on specific areas of interest.

All these possible users may be served through a structured approach allowing them to enter the decision process from different points.

6.2.4 The role of DSS within the decision process

Due to the reasons included in section 5.3.4, the role of the DSS within the decision process to be supported was defined. During the user assessment phase it became clear that the fleet managers had initially asked for an interactive information system and for information on case study applications as support to their own decision process. A structured approach to this process was required mainly to support information handling. The nature of the considered evaluation criteria required a multi-criteria approach to the evaluation phase, but the tool was supposed to support the full process, as described in section 6.2.3. Different options were considered; some of the possible theoretical approaches, evaluation methods and tools at hand are described in chapter 4. The final result consists of an on-line-help information system including modules 1, 3 and 4 of figure 6.2, an interactive goal-definition module for 2.1 and a multi-criteria module including fuzzy information handling for 2.2 and 2.3. Some of the information was the output from other EC projects.

The DSS has, due to the nature of the information system including the evaluation module, been called the MATADOR Interactive Guide (MIG).

The client required the DSS as a tool to support the users on the one hand and to produce a structured overview of the evaluation process on the other hand. The client was interested in both supporting and understanding the user's decision process. The user was interested in interactive information access and in the structured layout of the problem to be solved, while the client was interested in the recording of the method followed to reach the final decision. This reflects a conflict of interest between users and clients. Within MATADOR it was decided that each step of the evaluation process interface may be printed for documentation, if required by the user. The client reduced the specific initial request to one for a documented final DSS testing workshop to show the user's understanding of the final tool and his/her willingness to use it. The request for a controlling module, which might have hindered practical use of the tool was turned down in favour of method more appealing to the user.

6.3 WORKPLAN FOR DSS SOFTWARE IMPLEMENTATION

The work-plan was developed according to the structural basis presented in section 5.3.

6.3.1 Roles in DSS development

Possible methods for analysing the actor's viewpoints and requirements are reported in section 4.4. Within this specific project, paper questionnaires and interviews with individual actors were used since the geographical distance between the actors did not permit group interviews or workshops.

6.3.1.1 The client [43]

The client commissions the DSS's development. The client was the Directorate General of Research of the European Commission (EC), JOULE IV Programme, sub-programme Energy Conservation and Utilisation, i.e. he belonged to a European governmental institution with an interest in generally improving the impact of traffic and emissions on environmental urban areas in particular. This client provides funding, but also has power over general policy strategy. He is thus a stakeholder in the decision process. In this particular analysis, he is taken into account because his specific system requirements conflict with the interests of the stakeholder. For the

---

[43] For more information on this topic, see section 4.4.2.5.

cultural background of this actor as it relates to the urban environment, please refer to section 2.2.3.

Does the client have specific preferences in terms of reporting and/or display?

Yes, the client requires the tool to :

- be a prototype application for different fleet managers throughout Europe;
- not be translated into national languages;
- include the data gathered for the COEP project;
- be consistent with other previous and parallel EC funded projects;
- be developed within 30 months;
- be documented and presented at events and conferences;
- be usable on different digital platforms in its prototype version.

6.3.1.2 The decision-maker/DSS user

For the MIG development process, a single decision-maker was considered the user for the whole decision process, even though other stakeholders might profit from the final version. The decision-maker, like the manager of urban vehicle fleets, is a specific actor in urban transport planning. For the specific cultural backgrounds of these actors, please refer to section 2.3.3.2. Because the client requires that the final application be usable for different fleet manager situations throughout Europe, the specific situation of the user has to be redefined for each session. Such a general application does not permit a very detailed representation of the specific decision space. The goal modelling session includes rather general questions about different major aspects of the specific decision space. If the MIG is used in a large evaluation campaign, additional aspects may be added in campaign's the specific requirements and the underlying database.

Requirements for the tool's interface are derived from the user assessment:

- a simple intuitive graphic user interface is required, since the users are not very familiar with digital tools. Initial training is required to use the tool;
- user interaction should be as intuitive as possible;
- the tool must be portable to the platforms available at the user's offices;
- the information should be accessible even outside the evaluation module.

Which type of display is the user/are the users familiar with?

The users are familiar with Microsoft Office environments and often with vehicle location programmes.

What digital means are at the user(s) disposal?

Desktop PCs running under Microsoft Windows NT or 95

Does the user have specific preferences in terms of reporting and/or display?

Web-like interfaces that allow interaction through forms and hyperlinks are preferred, even though information is usually not researched through this medium.

6.3.1.3 The DSS designer

As described in section 5.4.1.3, the DSS designer is the director of the DSS development process, and is the one who tranforms the process' workflow, translation requirements and informational input into technical input for the other technical developers. The cultural background of this actor lies in decision theory and tool development, as detailed in chapter 4. The professional background of the specific MIG designer includes a degree in architecture and urban planning and knowledge of working environments similar to those of the DSS users. In addition, the MIG designer has experience in software and interface design and programming, especially for urban environmental and transport management on the basis of specific expert systems and on the WWW. Knowledge of several of the users' native languages and support from local project development partners facilitated communication with policy makers, planners and the client.

6.3.1.4 The specialist in user/stakeholder assessment

A general introduction to the cultural background of this actor is given in section 4.4. For this specific application, a non-profit association for scientific research in the field of mobility and transport assigned a sociologist with experiences in the field of transport and traffic user assessment to perform the fleet manager profile assessment, and the problem and DSS requirement definitions. As mentioned above, questionnaire and interview techniques were used by this actor.

6.3.1.5 The toolsmith

The methodological approach developed in chapter 5 offers insight into the role of the toolsmith, especially in section 5.4.1.5. The toolsmith's general cultural background consists of programming knowledge of tools, as explained in section 4.5.8. The toolsmith co-operated closely with the DSS designer[44]. She developed the digital DSS code and an interface based on the DSS dummy interface that was designed and implemented by the DSS designer in co-operation with the DSS users. She also developed the internal modular structure and the digital models, in accordance with the conceptual DSS design.

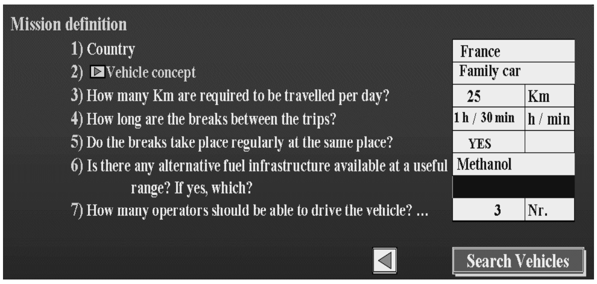
6.3.2 The decision space

In accordance with the structure detailed in chapter 5, the decision space was modelled as is described in section 5.3.2. The user needs defined above were taken into account, along with the methods of decision space representation described in chapter 4. Changes in the overall problem environment were not considered.

The client described the overarching goal as reducing noise and air pollution by introducing alternative propulsion systems into existing vehicle fleets. The alternative options to be evaluated include vehicles with different propulsion systems.

---

[44] Pamela Guiduzzi was the toolsmith.



Mission definition

1) Country: France

2) ▷ Vehicle concept: Family car

3) How many Km are required to be travelled per day? 25 Km

4) How long are the breaks between the trips? 1 h / 30 min h / min

5) Do the breaks take place regularly at the same place? YES

6) Is there any alternative fuel infrastructure available at a useful range? If yes, which? Methanol

7) How many operators should be able to drive the vehicle? ... 3 Nr.

Figure 6.3: Defining the vehicle mission.

The user's specific goal and the related physical environment are defined through the specific requirements to which the vehicle must respond, its mission.

The evaluation criteria were defined during the user assessment phase. They consist of five (classes of) criteria:

1. technical criteria
2. economic criteria
3. organisational criteria
4. environmental criteria
5. user criteria.

These were considered the major evaluation criteria during the evaluation process. They were defined in terms of consistent sets of factors characterising the relevant criterion (sub-criteria), definition of variables (indicators) that define them unambiguously, the relevant data sets and the rules for combining the indicators into sub-criteria and the final criterion (models). The models and indicators should describe the characteristics of the vehicle as a whole or they should be combined with a model integrating the relevant information on components into a description of the whole vehicle.

The description of the sub-criteria includes conceptual details and their interaction with other criteria required for modelling the related major evaluation criterion. Every sub-criterion has to be described in terms of a consistent set of characteristic indicators and the rules or models according to which the indicators can be combined to represent the sub-criterion. Meta-information about the sub-criteria contained within the MIG include:

1. conceptual description of the sub-criterion;
2. links with other sub-criteria;
3. the name of related model(s);
4. description of the interaction between models;
5. description of the indicators relevant for criterion model.

The preferences for specific criteria are set flexibly for each criterion during the evaluation process.

6.3.3 Decision steps and their requirements

Each step modelled conceptually in section 6.2.3 is analysed in terms of its modelling and input data requirements, as described in section 5.3.3. The most common way to do this is to represent each step as an empty box, and to record the conceptual model input (I) to its left side, and the conceptual model output (O) to its right. In this way the role of the system module supporting the step is defined: it is the agent that transforms I to O. The following scheme shows these input and output requirements.

1. Information gathering to Alternative Propulsion Systems (APS)				
Data input on APS	⇒	Module 1	⇒	Structured APS query output
2.1 Structured characterisation of travel demand				
Characteristics of vehicle mission	⇒	Module 2.1	⇒	List of vehicles corresponding to mission requirements (possible alternative solutions)
2.2 Select alternative APS or vehicles of interest				
List of vehicles corresponding to mission requirements (possible alternative solutions)	⇒	Module 2.2	⇒	List of vehicles to be evaluated
2.3 Comparison of possible alternative solutions				
List of vehicles to be evaluated	⇒	Module 2.3	⇒	Performance of vehicles in relation with evaluation criteria and user preferences
2.4 Identification of favoured solutions				
Performance of vehicles in relation with evaluation criteria and user preferences	⇒	Module 2.4	⇒	Ranking of vehicles in relation with evaluation criteria and user preferences

Figure 6.4: Schematic input and output flowchart for MIG modules.

Module 1. requires that it be possible to query a database on APS, i.e. a database management system (DBMS) accessible through a specific graphic user interface.

Module 2.1 is the specific goal definition module. It consists of a graphic user interface permitting the definition of the specific urban and fleet environment for which the decision is to be made and the application characteristics, or mission, the vehicle will have to fulfil. Such a module was not found within other applications and therefore had to be developed specifically for this project.

Module 2.2 consists of a selection from the set of vehicles found through Module 2.1 and thus has to permit selection from this list through an interface module.

Module 2.3 is an evaluation module permitting the definition of the evaluation criteria and the setting of user preferences. The module generates an overview of the overall performance of each vehicle selected for evaluation in Module 2.2 in relation to each evaluation criterion. The user is able to perform "what-if" requests regarding vehicle performance as it relates to specific preferences and criteria by looping back from the presentation of the results to change some of the inputs. This permits an in-depth understanding of the influence of these settings on the final decision.

Module 2.4 permits the comparison of the performances derived from module 2.3. A ranking of the overall performances of the vehicles is created according to the user settings.

The final DSS is composed of:

- a DBMS storing information on APS, market implementation stages, case study applications and the data required for the models contained in the model management module;
- a model management module containing the goal definition, or "vehicle mission" model, models for the generation of the evaluation criteria, models representing the related sub-criteria, a multi-criteria model for the evaluation of individual

alternatives, and a multi-criteria module that generate a ranking from the single alternative evaluation;

- a display generator permitting the creation of on-the-flow displays representing queries from the DBMS, from the vehicle mission module and the multi-criteria evaluation module;
- A graphic user interface generated by the display generator and consisting of modules for each functional DSS module.

6.3.4 General workplan for the application's development

For a controlled project management process, a workplan must be agreed upon by the actors within the DSS design and implementation teams, according to the methodology developed in chapter 5 and the technical steps as described in section 4.5.8. The MIG workplan consists of framework conditions regarding the economic, time and personnel resources available and the division of responsibilities for each part of the process. Using the methods described above and taking the project partner's responsibilities into account, a project workplan was created. This plan consists of four schemes:

1. A *flowchart reporting each work-package of the DSS implementation* in relation with the other work-packages. For each package a responsible task leader is appointed;

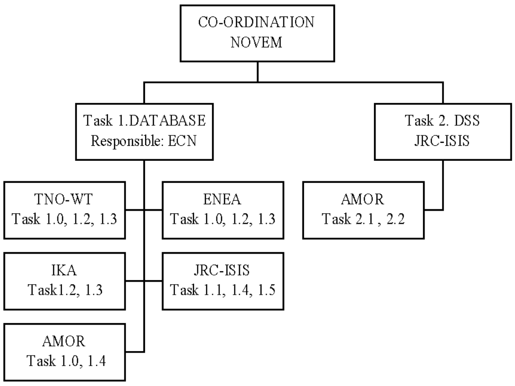


Figure 6.5: MIG-related tasks and responsibilities.

2. The *development timeplan*, depending mainly on the time frame set by the client and on the amount of time required for data collection and implementation. The time plan for DSS development is reported later.

The largest problem occurred when the basic database was found to be incomplete and could not be used as had been expected at the beginning of the project.

This was the reason why the final MIG became only a proof of concept including a very small dataset retrieved from internet sources and the databases available at the project partner's laboratories.

This demonstrates some difficulties caused by assuming that data will be available and will be of good quality at the beginning of a DSS implementation. The DSS application development continued according to the time plan. Please note that the time plan includes two months for reporting and as well as a buffer period at the end of the project.

3. the *list of milestones*, with the responsible actors and their deadline:

4. a list of the economic and institutional resources of each participating actor, divided by workpackage contribution.

This list was obviously confidential for duration of the project. In this specific case, an EC-funded project was initially set up for the project proposal. It terms were negotiated later on between the EC project officer and the project participants.

These elements determine how the project management and co-ordination have been set up. Within this project the role of the project co-ordinator was assigned to a project partner not involved in any other task. The efficiency of this approach depends on the strengths of the individual employed for this task. Some problems occurred in this case because the person assigned this role during the project development phase was changed three times. These project co-ordinators were not familiar with DSS development.

6.4 GRAPHIC USER INTERFACE (GUI)

According to the structure developed in chapter 5, the GUI was laid out. A short description of what the user-interface is and how it works is given in section 4.5.8. On the basis of the workplan described in section 6.3, the process of DSS software implementation is described. This description is structured through the methodology described in chapter 5, and in sections 6.4 and 6.5. The description of this process has been split into two sections, taking the roles of the DSS development actors involved in developing the two parts into account.

6.4.1 User requirements and GUI

The user GUI requirements have been described with the user assessment results. The following flowchart shows the user-system interactions in detail, as derived from the information collected above. The user interface must be accessed through a desktop PC interface running on Microsoft Windows NT or '95. The interface should be designed as intuitively as possible and its use should not require computer experience.

6.4.2 User-system interactions

The decision process model described in sections 6.2.2. and 6.3.2 represents the general structure of the user-system interaction as described in section 4.5.8. For the development of the GUI software implementation, this structure was translated into a detailed input and output scheme taking each required information-flow into account.

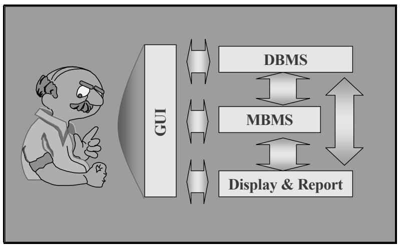
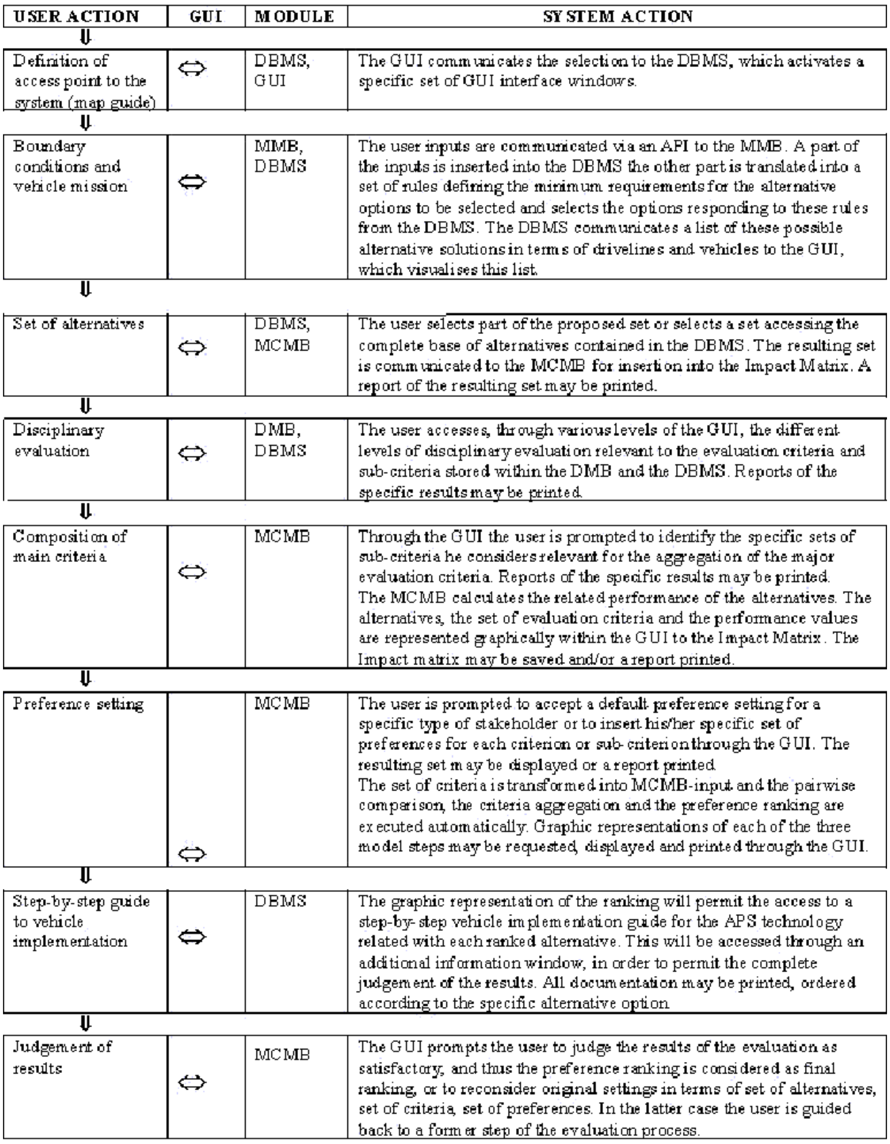


Figure 6.6: User-system interaction

The conceptual scheme prepared by the DSS designer as a development scheme for the software programming (done by the toolsmith) is represented in the accompanying figure. Figure 6.9 contains a summary of the single interaction steps.

In this representation, all user interactions are treated as interaction blocks. To provide a full sample for the toolsmith, each step has been divided into single parameter settings and interactions. To explain these in great detail is beyond the scope of this thesis.



USER ACTION	GUI	MODULE	SYSTEM ACTION
Definition of access point to the system (map guide)	⇔	DBMS, GUI	The GUI communicates the selection to the DBMS, which activates a specific set of GUI interface windows.
Boundary conditions and vehicle mission	⇔	MMB, DBMS	The user inputs are communicated via an API to the MMB. A part of the inputs is inserted into the DBMS the other part is translated into a set of rules defining the minimum requirements for the alternative options to be selected and selects the options responding to these rules from the DBMS. The DBMS communicates a list of these possible alternative solutions in terms of drivelines and vehicles to the GUI, which visualises this list.
Set of alternatives	⇔	DBMS, MCMB	The user selects part of the proposed set or selects a set accessing the complete base of alternatives contained in the DBMS. The resulting set is communicated to the MCMB for insertion into the Impact Matrix. A report of the resulting set may be printed.
Disciplinary evaluation	⇔	DMB, DBMS	The user accesses, through various levels of the GUI, the different levels of disciplinary evaluation relevant to the evaluation criteria and sub-criteria stored within the DMB and the DBMS. Reports of the specific results may be printed.
Composition of main criteria	⇔	MCMB	Through the GUI the user is prompted to identify the specific sets of sub-criteria he considers relevant for the aggregation of the major evaluation criteria. Reports of the specific results may be printed. The MCMB calculates the related performance of the alternatives. The alternatives, the set of evaluation criteria and the performance values are represented graphically within the GUI to the Impact Matrix. The Impact matrix may be saved and/or a report printed.
Preference setting	⇔	MCMB	The user is prompted to accept a default preference setting for a specific type of stakeholder or to insert his/her specific set of preferences for each criterion or sub-criterion through the GUI. The resulting set may be displayed or a report printed. The set of criteria is transformed into MCMB-input and the pairwise comparison, the criteria aggregation and the preference ranking are executed automatically. Graphic representations of each of the three model steps may be requested, displayed and printed through the GUI.
Step-by-step guide to vehicle implementation	⇔	DBMS	The graphic representation of the ranking will permit the access to a step-by-step vehicle implementation guide for the APS technology related with each ranked alternative. This will be accessed through an additional information window, in order to permit the complete judgement of the results. All documentation may be printed, ordered according to the specific alternative option
Judgement of results	⇔	MCMB	The GUI prompts the user to judge the results of the evaluation as satisfactory, and thus the preference ranking is considered as final ranking, or to reconsider original settings in terms of set of alternatives, set of criteria, set of preferences. In the latter case the user is guided back to a former step of the evaluation process.

Figure 6.7: Flow chart for user-DSS interaction and API with internal modules

Once the complete scheme has been created, it represents a framework structure for the toolsmith's design of the API and the GUI's interaction with the internal DSS structure.

6.4.3 GUI conceptual design

The interface configurations (section 6.4.1) and the user-system interaction scheme (section 6.4.2) form a basis for the conceptual GUI layout design.

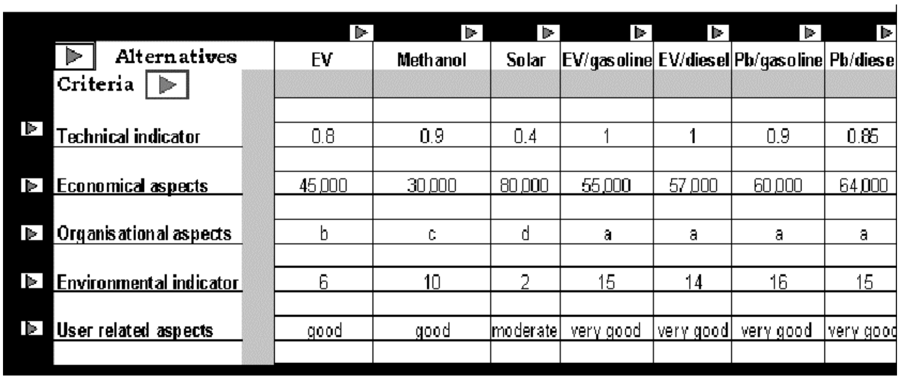
Based on user interaction, the GUI is composed of panels including interactive forms, graphics, alphanumeric and linguistic information. The user follows the decision process from one panel to the next, communicating individual input to the system by inputting forms and pressing buttons to submit form input. Hyperlinks allow access to the on-line-information on the APS and the decision process. All modules are implemented in a single interface container (browser) using the same interface languages (JavaScript & HTML).

To determine whether this approach would be accepted by the user, a dummy version was produced and tested.

Figure 6.8: Dummy version: GUI main menu.

The user was not familiar with the individual model interfaces. The models defining the evaluation sub-criteria consisted of data values and thus were not included in the model base.

Each individual user request action is translated into a GUI panel requesting and receiving this action input. These panels are linked with the on-line-information system through hyperlink buttons. The on-line-information system should provide information without distracting the user from the decision process itself, so direct access to the on-line-information is enivisioned, as well as a pop-up window system providing information for single tasks required during the decision process, without filling the main window completely. This system is based on the typical on-line-help systems of Microsoft Office, the environment familiar to the user.



▶ Alternatives Criteria ▶	EV ▶	Methanol ▶	Solar ▶	EV/gasoline ▶	EV/diesel ▶	Pb/gasoline ▶	Pb/diese ▶
▶ Technical indicator	0.8	0.9	0.4	1	1	0.9	0.85
▶ Economical aspects	45 000	30 000	80 000	55 000	57 000	60 000	64 000
▶ Organisational aspects	b	c	d	a	a	a	a
▶ Environmental indicator	6	10	2	15	14	16	15
▶ User related aspects	good	good	moderate	very good	very good	very good	very goo

Figure 6.9: Dummy version: Evaluation module central GUI module.

The sequences and linking systems have been translated into a digital interactive dummy [45] that does not contain the underlying databases or evaluation models. This dummy interface was tested within the project group and with a number of fleet managers. This testing clearly showed that the intended DSS users, the fleet managers, did not have a distinct idea of what the DSS would look like or how it would function before they were confronted with this dummy. They did, however,

---

[45] This dummy is available on the attached CD-ROM.

request some technical specifications and corrections along with internet access to the tool, which required a change in the software graphic interface layout. After this was discovered during the first tests, additional interviews were done on the basis of the dummy interface after changing some of the sub-criteria. Some parts of the GUI structure have been redefined and its expressions have been reviewed on the basis of the user comments. An additional user request was one for introductory training on the software tool for a better understanding of the DSS and the information bases.

Many additional requests including those for translation of the application into the users' native languages could not be fulfilled because of the client's request for a proof of concept application only. Finally, agreement on the DSS's GUI layout was reached with the client, but only partly with the DSS users.

6.4.4 GUI implementation

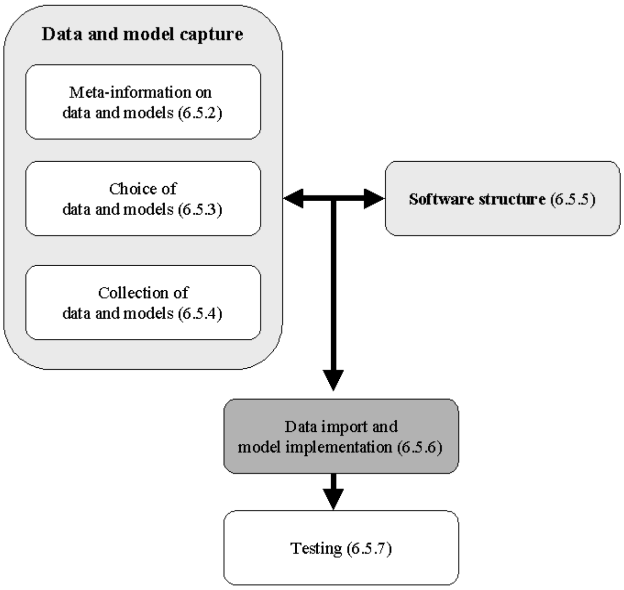
The GUI-user interaction dummy (section 6.4.3) and the GUI-DSS model API scheme (section 6.4.2) were two parts of the GUI layout then ready to be translated into digital code. In order to finalise this script for the toolsmith, checks for congruence between the internal and external schemes had to be performed and the languages and tools for programming had to be selected (as described in chapter 5 on the basis of notions introduced in section 4.5.8)

In accordance with the user's requirements for interactive windows and on-the flow interface generation as well as for existing interfaces to different models, a common digital interface language was chosen for all modules: JavaScript (and HTML). ODBC interfaces were available for all models in this language. The GUI of the evaluation modules was also available in a compatible format (JAVA). This combination of interface languages is also designed for use through the Internet. An experienced programmer with JAVA/JavaScript development and DSS applications was chosen as toolsmith.

6.4.5 Testing

For economic reasons and due to the geographic distance between users and developers, it was not possible to run two distinct prototype testing phases, even though they might have helped avoid mistakes in the interface panel structure. Testing would thus have saved time during the software's development. The testing of the complete prototype software is described in section 6.5.6.

6.5. INTERNAL SOFTWARE STRUCTURE AND CONTENT



Based on the methodological approach defined in section 5.5. and the technical methods explained in section 4.5.8., the internal software structure implementation was developed, in accordance with the scheme shown in figure 6.12.

Figure 6.12: Structure of chapter 6.5.

6.5.1 Meta-information on data and models

The GUI modules shown in figure 6.11 describe the functionalities required for the DSS implementation. These functionalities may be achieved partly through static data requests from the DBMS, and partly through interactive modelling. The modules requiring system reply are:

- the vehicle mission module: Collects indicators of the specific application environment and requirements and selects corresponding vehicles from the database. This module requires an initial API collecting the variables and querying the database and a second API part collecting the Database query output and inserting it into a GUI display.
- the selection of the vehicles to be evaluated: Collects a selection of the displayed set of vehicles and requires an API to compose a new display for the reduced set.
- the evaluation of single vehicles against the criteria: Collects, through different modules, the specific definition of the evaluation criteria (composed of a set of chosen sub-criteria) and the related preference settings. A specific evaluation method is applied via a model evaluating the characteristics of the vehicle, as reported in the DBMS, against the evaluation criteria. An API generates a display of the vehicle's performance compared with each evaluation criterion.
- the ranking of a set of evaluated vehicles: Collects the performance of different vehicles from the display or through indexes referring to the complete performance information stored in an internal intermediate database capture. Compares, pair-by-pair, the performance of each vehicle against the single evaluation criteria and creates a relative ranking of these performances. An API

generates one or more feasible GUI displays of the rankings and the intermediate results.

Data required for the different models include: vehicle characteristics responding to values described as evaluation criteria and responding to vehicle mission characteristics, information on legal and environmental aspects related to vehicle characteristics, images of vehicles for vehicle schedules and information on pilot projects. Information on how to use the DSS and where to enter the system is also required.

The API programme codes are stored within a distinct part of the directory structure that composes the DSS. The codes are written in JavaScript and, within the evaluation module, in JAVA. The JDBC-ODBC module is used to communicate with the database.

Since the MIG input data were supposed to consist mainly of COEP database elements, no specific meta data scheme was developed for data collection..

6.5.2 Choice of data and models

The MIG was supposed to present an opportunity to use the data contained in the COEP database. Data collection was therefore initially limited to the use of this input. It was envisioned that additional input would be directly input by the user.

The vehicle mission model was developed specifically for MATADOR and consists of an input request form that is translated through the API into a DBMS query. This query attempts to select the number of vehicles corresponding to the defined vehicle mission. This information must thus be present in the database, using the same code as used by the API and connected with an index identifying the vehicle.

The evaluation modules required had to be:

- applicable to discrete cases (finite set of alternatives)
- able to permit preference settings without pre-weighting
- able to permit the evaluation of single vehicles against the criteria and preference settings
- able to perform impact analysis, creating a final ranking of alternatives with a pair-by-pair comparison technique
- able to allow the use of information subject to different types of uncertainty, such as
    - precise numbers
    - stochastic distributions
    - fuzzy sets
    - linguistic evaluations.

The need for these types of uncertainty to be considered, along with the need for easy access to the implemented software and to available expertise, lead the team to decide which evaluation method to choose: NAIADE [Munda 1994], a JRC in-house production which had been translated to JAVA for use in earlier projects.

6.5.3 Data and model collection

The COEP database was supposed to provide the information on vehicles and demonstration cases as well as the characteristics for vehicle comparison. Additional material was required only for the implementation phase. This material was developed in parallel within the MAESTRO project and was supposed to be connected via a hyperlink through the Internet.

The NAIADE evaluation method had been developed and translated to JAVA code in former projects at the JRC-ISIS and thus was available for this implementation.

6.5.4 Software structure

After the inputs were defined, the software structure was created, in accordance with the indications given in section 5.5.4.

As described in detail in chapter 4, DSS are composed of three modules:

- a Database Management system (DBMS),
- a Model Management System (MMS),
- and a Graphic User-Interface (GUI), including display and report generators.

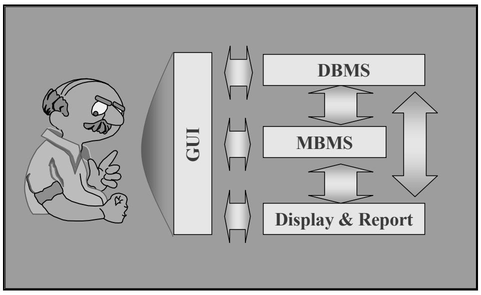


Figure 6.13: User-DSS-internal API.

The GUI design is described in detail in section 6.4 along with its linked display and report generator requirements. The structural development process described here relates to DBMS and MMS and to the implementation of the complete structure.

The definition of data and models described in section 6.5.4 explains the software requirements for the structures hosting these elements.

DBMS for UDST Microsoft Access was chosen, because it is part of the Microsoft Office package and thus available within the DSS user's standard equipment. This DBMS offers, in addition, a standard ODBC interface to JAVA and permits the storage of complex data structures such as texts and images as well as pointers to other documents.

The evaluation module NAIADE was available in two versions. The JAVA version was chosen for compatibility reasons. All evaluation criteria were represented statically within the Microsoft Access database or through weighted sums executed as Microsoft Access macros. These macros were the only additional models used for criteria simulation.

The display and report modules were appositely developed. GUI modules were programmed in JavaScript and HTML, and the API mainly in JAVA code to take advantage of the available JDBC/ODBC interface. These models do not usually possess ready-made APIs. So the second large task of the toolsmith, apart from the translation of the GUI design to GUI source code, was the generation of the APIs between the models to build the MMS. The model input and output scheme forms a basis for this programming effort (section 6.5.1), as do the model specifications described within the model meta-information (section 6.5.2).

6.5.5 Data import and model implementation

A specific directory structure was developed consisting of modules for database files, NAIADE generated files, the GUI prototype file structure and the API programmes.

The original COEP database was stored in Microsoft Excel and was thus easily portable to Microsoft Access format. A time-intensive problem was encountered when it was discovered that the database was incomplete for all entries of the case study applications it reported. For the DSS development process, some dummy inputs have been inserted to enable the development to continue. After this it was discovered that only unstructured intuitive inputs had been made to the database, so that no structured queries were possible and the database inputs had to be reviewed individually. A set of cases were selected and reviewed by the project partner, who has also taken part in the original COEP database construction. As this problem had not been foreseen for the project, the time assigned to database enrichment had to be reduced to a minimum. It was thus decided that the whole MIG would become a proof of concept instead of a complete DSS application.

The GUI was developed on the basis of the dummy described in section 6.4.The NAIADE Java version was implemented on the test platform. Elements of the database individuating vehicle mission inputs and aspects of evaluation criteria were identified. . The prototype was then finalised through the API code implementation.

6.5.6 Testing

After this prototype version had been developed, a first testing was conducted, in which fleet managers were asked to test the tool over the Internet and to fill in an on-line questionnaire. This was seen as the method that would gather user feedback as quickly as possible while consuming a minimum of time and resources. For a short introduction to questionnaires and other assessment techniques, please refer to section 4.4. The number of replies was very low. Additional telephone interviews were therefore used to collect initial user feedback.

The user acceptance was very much influenced by the reduced data set produced by the client's initial request. It was only possible to check this through telephone interviews in which questions were asked about the interface itself. The on-line-information system was considered very useful. Since this was the only part of the system containing consistent information, this was what has been developed further. An additional GUI module was developed for DSS user data-input to the vehicle descriptions, so that the DSS user would be able to compare known vehicles.

The proof of concept was integrated through a workshop near the end of the project, where the MIG was approved as a concept. The scarcity of data input lead to a negative reaction to the idea of direct MIG implementation, but the system does function as an educational tool for newcomers to fleet management and alternative propulsion systems. The final DSS was approved by the client as a proof of concept based on his specific request, but it is not possible to use the tool as it is and thus the possible users approved only the framework produced, but could not use the tool. The client refused to provide further funding for data input and thus the final version may only serve as an educational tool for fleet managers requiring a first introduction to alternative propulsion systems, not as a specific implementation. The possibility of data input at least supports a superficial comparison of a specific vehicle with the small data set available.

6.6 CONCLUSIONS

The MATADOR project application case illustrates the use of the methodology described in chapter 5 as a management method for DSS design and implementation. It also shows why the usual project management approach for DSS development should be modified into the interactive co-operative process called the DSS-maker's script. This project also illustrates some of the problems that may be encountered during the development process, as well as the influence of the client and the user on the DSS development and its success. The MATADOR project also shows the importance of the role of information within DSS applications.

This project development thus illustrates perfectly the steps of decision space description and DSS development. It does not offer a good opportunity for understanding the tool's ultimate relevance or user acceptance in a real evaluation process, because of the incomplete database. This does offer insight into one case of DSS development that can be called a success with regard to the DSS structure and its development, as considered from the client's point of view, but that does not result in a direct implementation. It offers another case of DSS development for the reference shelf, with a positive outcome for one of the participating parties.

This project also demonstrates the importance of the background conditions formulated by the client. The requirement that the COEP database be the basic data input, the time limit of 30 months and the missing resources for additional testing (which had been cut during the negotiation phase) transformed a valid approach to application development into a useful proof of concept.

CHAPTER 7 Test 2 of the DSS-maker's script – UTOPIA

7.1 INTRODUCTION

This chapter describes the development of a DSS application to support local administrators with the implementation of advanced propulsion systems in urban transport. This development process is linked with a more differentiated user group. The cultural background of the designated decision-makers is essentially described in the different disciplinary areas and institutional levels included in chapter 2. The process of problem-solving to be supported is also more complex than the first test case. The development process follows the methodological approach presented in Chapter 5. The initial theoretical framework is refined by including some adaptations recommended because of experiences with the first case application. The final versions of the theoretical chapters have been refined in parallel with the case studies' conclusion.

As in chapter 6, this case study description functions in two ways within this thesis: the text version illustrates how the DSS maker's script approach changes the traditional approach to DSS design and implementation, and the CD-ROM is an interactive illustration of the implementation of the methodology. In addition, the CD-Rom version allows access to the interactive interface dummy developed for the project and, if linked with the Internet, to the final on-line-software application produced by the UTOPIA project.

To better understand the structure of this chapter, please refer to the accompanying figure.

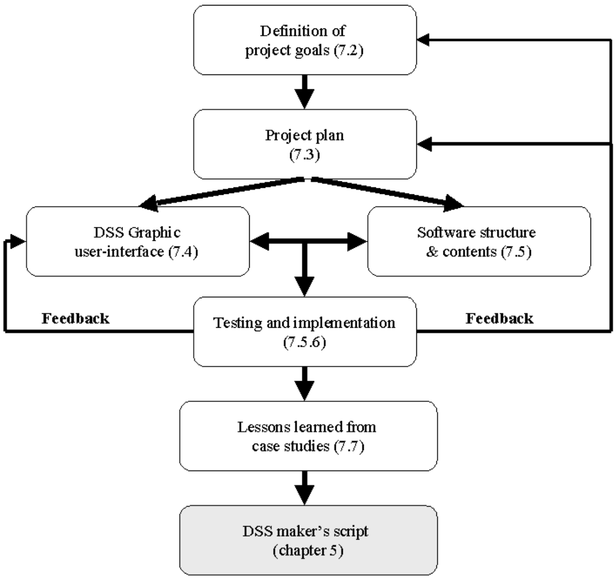


Figure 7.1: Chapter 7's structure.

7.1.1 The UTOPIA project

The main objective of the UTOPIA project was to produce inventories, assessments and decision support tools concerning the market introduction of new propulsion systems and new transport concepts based on these systems. The outputs are intended for the use of both market actors and policy-makers. The DSS was not meant to be the project's only output. This, along with some other problems that arose during the initial phase of development, was due to the fact that the project itself had been formed out of three different project proposals. During the contracting phase three project proposals were merged into one and thus project partners and goals were not very clear even at the beginning.

The UTOPIA project was developed under the EC-DGVII TRANSPORT Programme, Urban Research Task 5.2/12. The goal was to provide structured decision support to transport planners, policy-makers and fleet operators in medium and large cities who perceived that they might need to introduce initiatives based on new transport concepts and cleaner propulsion systems in order to tackle local problems. The project supports the user with various tasks.

- It provides a European approach to the non-technical issues involved in faster introduction of "new market-oriented environmentally-friendly transport concepts".
- It takes a full range of factors and stakeholder perspectives influencing the introduction of new technologies at both market and policy levels into account.
- It provides output that has been validated through on-site testing and stakeholder review.
- It helps policy-makers and other actors to identify what they can do to accelerate the introduction of new systems, and how best to organise markets for this purpose.

Two supporting functions have been implemented within the DSS: it allows the choice of appropriate transport solutions (including technology choices) and the evaluation of case study experiences.

The second tool was used as a framework structure for the description of past decision processes in order to determine the impact of single decision and its implementation steps on the final success of the project. This description has been developed within a decision-tree representation. The evaluation ranking achieved served as a statistical ranking, but no policy strategies have been developed on this basis.

The DSS application to be discussed here assisted with identifying transport solutions for particular urban contexts, helping the decision-maker to make a trade-off between complex quantitative and qualitative factors according to local priorities and values

The tool supporting the choice of an adequate transport concept and/or technology has been developed in order to:

- inform the administrators about state-of-the-art urban traffic systems for road vehicles as well as about developments in vehicle design and construction aimed at reducing energy consumption and emissions;
- identify demand cases and urban traffic patterns for the appropriate applications;
- identify promising technologies for specific applications;
- assess the readiness of technologies for short term market introduction;
- access infrastructure and policy requirements for market introduction of these technologies;
- assist administrators in making decisions about the need for pilot applications.

In this context, a decision support system has been developed to provide urban policy-makers and transport planners with a tool for a structured assessment of information on typical urban travel patterns, demand cases and technical vehicle concepts. The implications of conventional and non-conventional traffic routing is also considered.

This is a case where the DSS development was commissioned by a client at a general level, the European Commission, to support actors in different locations acting within very local urban environments, such as fleet managers.

The time frame of the UTOPIA project's development was 30 months from February 1998 to July 2000. Twenty-four partners were involved in the whole project. Almost all of them participated within the DSS development somehow, from project-management, model implementation, data retrieval and database development, to user assessment, DSS development and testing.

The following sections describe the UTOPIA DSS development, structured by the methodological approach developed in chapter 5, and explain how the application development has influenced the script and how the new methodology formulated has changed the traditional approach to DSS development.

7.1.2 The project in the analysis of the DSS –maker's script

Even in this case, the initial project proposal included a traditional development framework. The proposal had been produced by a group of European researchers and institutions active, in this case, in urban environmental management and related disciplinary areas, but a specific user or user-group was chosen right at the start. In this case, a client wished to introduce a product to the market, and a technical team was available for the DSS development and the data selection and production. The DSS user, however, was not clearly defined and no time was set aside to define this user or to assess her/his requirements. Objectively speaking, a DSS development was not possible. So the first step was a market analysis of the possible decision-makers at the city level responsible for the introduction of the technologies into the market. The market segment of interest had to be defined since this was the client's area of interest. The public transportation sector managers at the city level who were involved with the composition of public transport fleets have been considered the designated users. But this choice had been made only after some of the data collection phases had been finalised and thus the development process had to deal with data collected for an undefined scope.

When first questioned, the designated users stated that they would not require such a tool and thus the problem became even more complex. After further analysis, it was discovered that several decision support or information tools had been produced for these users at different moments in time and that those tools had not fulfilled their promises. Within the project development there did not remain any other choice but to develop a dummy interface to explain to the users what was intended for development. They could then be asked if this was what they did not want. This dummy interface was developed and presented to a selected number of users during a one-day workshop. The result was stunning. The users completely changed their opinions, especially after the dummy character of the demo was used not only to get their approval, but to allow them participate in the development process. User acceptance of the whole product was obtained through allowing the users to participate in the development process. They provided precious input about the user interface, functionalities and the importance of specific modules within the decision-process.

The UTOPIA DSS thus had the chance to be developed only because the methodology of introducing all actors to their individual roles within the development process was followed. The approach refined within this application corresponds to the DSS-maker's script that is the subject of this thesis. User engagement continued to be a source of input for all the choices made during the development process. Problems that arose later were the result of choices made without explaining them to the users. The final evaluation module is probably currently used less than the information system and the models for single aspects. This is probably due to an unexplained change in the evaluation method from the dummy version to the final implementation without a detailed on-line-help system. Even though the final implementation should be less complicated to use, it has yet to be understood by the user and thus explanation this module has not been fully accepted.

The UTOPIA-related implementation of the methodological approach described in chapter 5 is illustrated in detail in the following sections of this chapter.

7.2 DSS REQUIREMENTS

Since no DSS user was defined in the project proposal, the user had to be defined during the first project implementation phase. No end-user assessment was planned, due to a cut in the original DSS project proposal. After a designated user-group had been defined, the representatives of this group who were contacted stated that they did not require the intended tool. In order to continue with the project, as required by the client, the technical project developers decided to draw a user profile oriented at the end-user groups and defined according to the expertise of the project partners. Since the client was well known and had been interviewed about his specific system requirements, the initial user profile was based on this model.

7.2.1 Conceptual problem modelling

Based on these notions, a conceptual model of the problem has been defined following the methodology described in chapter 5.

7.2.1.1 The client

Apart from specific reporting schemes, the UTOPIA client listed his requirements as including:

- a prototype application for different policy-makers and transportation managers throughout Europe;
- only an English language version of the final tool;
- a project duration of 30 months, with no additional funding for unforeseen aspects;
- a final digital version accessible through the Internet;
- the language of the final version had to be understandable on the European policy level.
- consistency with other previous and parallel EC- funded projects;
- documentation and presentation of the project at events and conferences;
- portability to different digital platforms.

7.2.1.2 The DSS user

In order to understand the mental schemes representing the real world for the UTOPIA decision-makers, the profiles of these actors have been assessed through literature and interviews with project partners including urban policy makers and transport planners. Chapter 2 offers an overview of the differences in cultural approaches to urban environmental management and the concept of the city as encountered through the different sources. It might provide insight to the complexity of the problems encountered here.

This conceptual model was checked during a workshop on an initial interactive prototype model. A larger user-assessment phase had not been planned within the project. The major problem of the profile definition phase was that it took the very large project group of 24 partners almost a year to decide upon the group of actors to be supported. An initial prototype had to be presented before they reached a decision. Therefore a detailed assessment phase would not have been possible even if it had been planned.

During this phase, the end-user assessment questions reported hereafter were the only guidelines for the initial profile definition from the DSS designer's point of view. This profile has been refined according to the questions and their answers, in co-operation with other project partners.

What is perceived as disturbing now or expected to disturb the harmony of the situation in the view of the decision-maker? What would he/she like to be different?

Client (strategic goal): The noise and pollution load within European cities is too high. It has to be reduced. Fleet managers should achieve part of this reduction.

What would have to be done to change the situation, i.e. what is the disturbing factor observed?

DSS user (implementation method): The road vehicle fleet has to be changed to produce less pollution.

What would happen if the disturbing element were eliminated without substitution? Which sub-systems would be influenced? Who would react?

Eliminating all vehicles would lead to a collapse of mobility and thus of activities within the city. Eliminating some vehicles could reduce the pollution, but might disturb essential activities and thus provoke economic loss and disturb the electors.

Are there possible "substitutes" for the disturbing factor, i.e. are there alternative solutions to the problem?

Alternative propulsion systems (APS), low consumption engines, light vehicles or other vehicle concepts could replace conventional ones, a shift to public transportation use could reduce exhaust and smaller vehicles could reduce the amount of required parking surface.

How would they work and what would their impact be on which other sub-systems?

APS would create additional infrastructure requirements, possible differences in maximum trip lengths between fuelling stops, differences in image and market readiness. As new technologies produced in low numbers, the economic effort required to produce them would be relatively high, even for technology with a lower degree of reliability. With a working environmentally conscious service, the image of the city authorities would grow, especially at a regional, national and international level.

Who would gain or lose?

Losers: Petrol industry, conventional car manufacturers

Winners: Urban environment, alternative car manufacturers, inhabitants, policy-makers (Kyoto and other agreements).

Which background factors are not impacted by the disturbing factor, but influence the factor itself and/or the usefulness and/or support of substitutes? Are there "visions" for the future that could change the behaviour of the problem space? Does the decision-maker want to take into account their possible change over time?

Other solutions could be reached through changing behaviour patterns, but these are outside the range of a government's impact. Urban administrative policies could force the implementation of APS and advanced vehicle concepts in the future, therefore within the UTOPIA project practical guidelines have been produced on those policies. They can be reached through the same web-site as the DSS [UTOPIA project group 2000].

The professional background of the users was also assessed:

What is the DSS user's educational background?

It has been supposed that urban transport planners usually have a background or in urban planning or in traffic flow management, i.e. they usually possess a university degree in architecture, economics or engineering. Urban policy-makers, on the other hand, have been thought of as a much more varied group, depending on how they entered the position (Directly: degree; others: specialists due to long periods of employment). This was the impression of the interviewed project partners also produced, but the assessment did not permit statistical analysis.

Their computer knowledge is judged by many policy-makers themselves to be very low, whereas the transport-planners were more familiar with computers, especially geographic planning tools and traffic flow and signalling models.

Most users asked that the interface be translated into their native language, but for economic reasons this has not been implemented within the project itself.

Are there schemes linked to this?

Because of users' differing backgrounds, a scheme had to be developed to enter the decision process by analysing different aspects and with a very clear user interface that permits recognition of typical material for analysis (e.g. geographic information for planners in traffic pattern description).

Which sources of information are usually accessed?

The main sources have been identified: direct exchange of experiences at seminars and conferences. Other sources include books, expert knowledge, and commercial and sales representatives. The frequency with which the Internet is used to gain information has not been assessed. It has been supposed that transportation planners, with their IT background, would use the internet more frequently, but the project partners, who based their co-operation on internet communication techniques cannot be considered a representative group.
Were there former projects? Were schemes worked out for them?
All representatives within the project group had been part of former APS implementation projects, so they are among the best-informed members of their group. All information about the way that someone completely ignorant of the subject might approach it has been deduced from the representatives' experience. No experiences with advanced vehicle concept implementations were reported in the interviews.

These inputs were used to define the goal definition module described in section 7.4 and discussed by the project development team and the EC officer. It was presented to the users at a workshop about its layout representation by using an initial DSS dummy interface. Many changes resulted from the workshop brainstorming session, but fortunately the general sequence of the goal definition module was accepted as it was. This dummy provided a very useful basis for discussion with the final users, enabling them to better understand what they could expect from the final supporting tool.

To summarising the results of this process, the problem space was assessed in terms of possible alternative solutions. Two steps were distinguished within the decision process:

1. the definition of the problem: the demand case;
2. the evaluation of possible solutions:
    a. vehicles with alternative propulsion systems or
    b. alternative vehicle concepts.

Two sets of evaluation criteria were set up, one for each type of solution (vehicle/vehicle concept) and were presented to the users so that they could understand the relative importance assigned to each of these criteria within the evaluation.

After the problem space was described in a conceptual model, the approach the decision-maker would use to face it had to be designed.

7.2.2 Decision process model

Based on the methodological structure developed in chapter 5, the user's decision-process model was described. The clients were considered as technical system requirements and environmentally fixed values within the user's decision process.

A step-by-step decision process model was developed to solve problems, as described in section 7.2.1. This model contains different evaluation steps, which may be followed sequentially or performed individually based on the information sources. The model itself is meant to offer an overview of the decision process and a basis for the module structure of the DSS. It distinguishes different points of entry to the process based on the relevant user requirements.

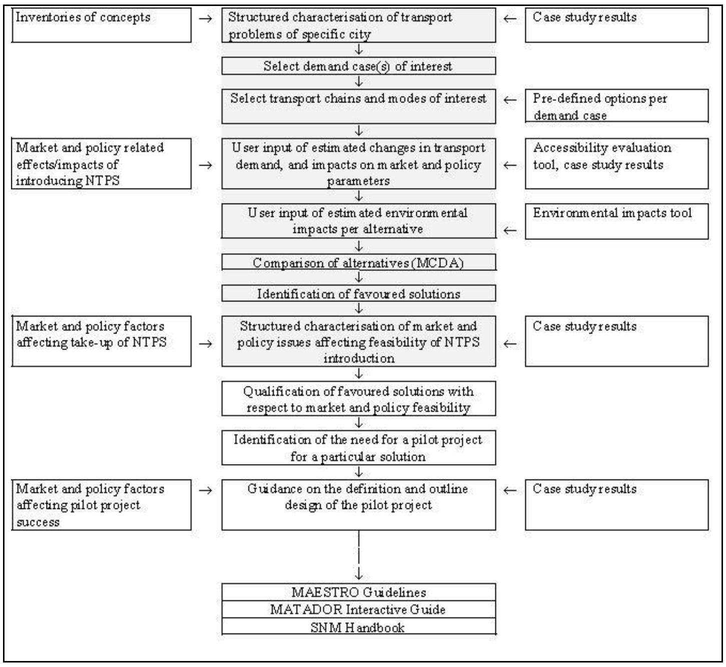


Figure 7.2: Schematic flowchart model of the decision framework.

The actions considered basic within the UTOPIA problem solving process are more complex than those in the MATADOR project described in chapter 6. The whole project aims at providing support to the complete cycle of urban problem identification, evaluation of possible alternative solutions, learning from other case studies, choosing the solution to be implemented, identifying the need for a pilot project, and finally, creating the implementation. Later, the pilot projects are assessed. Different tools are required for the different steps of this complex process. It is essential to identify the different steps and the related type of tools required, and to determine whether they are already available on the market or within other projects. The complete "Decision framework" described in Figure 7.2 was sketched out in co-operation with different project partners and potential DSS users. Each step might produce an unsatisfactory result and thus require a loop back to a preceding step in the framework sequence.

The definition of this framework was the basis upon which the project structure was formulated. It was split into shared work-packages and consumed many months. This time was needed for three reasons: 1) the project group had been formed out of three project proposals and thus had to integrate different subjects and a very large group of partners, so that it was difficult to compromise on an application; 2) the initial projects included pilot project analysis, implementation and supporting policy makers and transport planners, i.e. three different phases of the decision cycle had been targeted and no connection between the results of the different parts of the project was given, so that the roles within the project had to be reassigned, and were not always well understood; 3) the user groups included policy makers and planners, (responsible actors in strategic planning and management control) ,and it took time to define the target groups and the forms of the related tools to be developed.

The DSS development process described in section 7.3 corresponds to the fuzzy core of the decision framework. The rest of the decision process is supported by guidelines for policy-makers and is fed into a database of case study analyses represented in a decision tree model. The final implementation and the operational control support are given in two other projects.

After modelling the problem and the process of approaching a solution, the following chapter introduces other actors who may influence the process.

7.2.3 Actors in the decision process

As described in section 5.2.3's finalisation of the problem description, the actors have been included in the problem model. The actor's impact on the evaluation process supported by the DSS has to be translated into variable impact factors. It must be emphasised that this is related to the decision process, not to the DSS development process.

The project required a DSS developed for two different types of users: policy makers and transport planners. The policy makers act at a strategic level, i.e. their information requirement includes an abstract overview of the whole problem and the problem environment, the pros and cons of the different technical solutions and their impact on the behaviour of the related interest groups. In contrast, the transport planners act at a management level and need to understand the impact of technical solutions on the existing situation in the specific city's transport system. The requirements the DSS needed to address within a single tool were very different.

Other stakeholders in the decision process include urban development planners, infrastructure supply companies, fixed companies, fleet managers, users of the transportation system, and different interest groups among the city's inhabitants including environmentalists. Taxation offices, and officials in the regional, national and European governments also have an interest, especially as possible funding institutions for pilot projects. Apart from the users of the transportation system, all other stakeholders have an interest in the problem environment or in the economic effort to be faced by the implementing institution. Those stakeholders are not considered directly within the multi-criteria evaluation but due to economic factors. They have a large impact on decisions about the need for a pilot project further along in the decision framework. Specific weights are assigned to image and comfort within the vehicle/concept descriptions to be stored in the DSS database in order to enhance user acceptance.

Different possible users of the DSS have been distinguished, even though the final design was tailored to meet the specific requirements of policy makers and transport planners. Other users could be:

- groups of *stakeholders,* characterised by an interest in detailed information in specific areas and its impact on the global decision process;
- decision-makers and *consultants* expert on parts of the decision-space, characterised by an interest in an overview on the evaluation process (drawn from the policy-maker's perspective) and in detailed information on specific areas of interest (drawn from the planner's perspective), which include specific information and/or models for single aspect evaluation, e.g. a spreadsheet model for vehicle emission calculation and one for evaluating the amount of noise that will be generated;

- *Consultants* to the decision-makers who make the final decision, characterised by an interest in a structured approach to all details in the whole evaluation process and the different stakeholder profiles.
- *Institutions for education*, characterised by an interest in an overview of the problem, but eventually requiring details on specific areas of interest.

All these possible users may be served by a structured approach that allows them to enter the decision process at different points.

7.2.4 Role of DSS within the decision process

For the reasons reported in section 5.2.4, the role of the DSS within the decision process to be supported was clearly defined. The strategic goal of the decision process was, in this case, defined by the client, who had direct hierarchical power over the user: the user was required to integrate alternative propulsion systems and vehicle concepts into the city transportation system.

To reach this goal, the users (urban policy-makers) asked for a tool that could support them in analysing the options for this implementation. The transportation planner also needed assistance with evaluating the practical aspects of such an implementation and the related technologies. The role of the DSS therefore became twofold:

1. the definition of the demand case considered the mission for the implementation of the vehicle type;
2. the evaluation of possible alternative solutions.

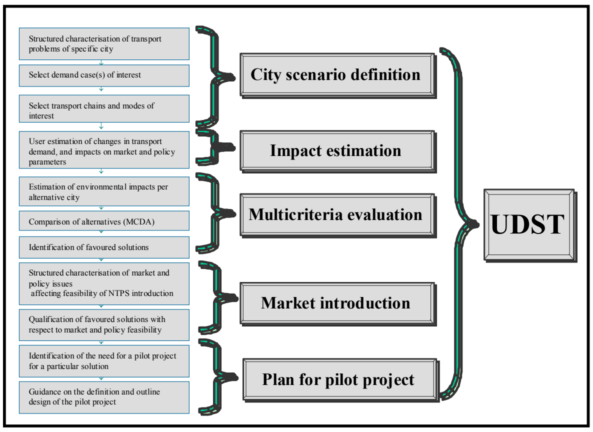


Figure 7.3: Modules of decision making.

The final result consists of an information system that includes three modules:

1. the goal definition module - providing support to the first two steps of the core evaluation described in figure 7.3;
2. the evaluation module – providing support to steps three to seven;
3. a database module on the state-of-the-art of the market implementation of all technological options.

Some of the information and models included were provided by output from other EC projects.

The DSS has been called the UTOPIA Decision Support Tool (UDST).

7.3 WORKPLAN FOR DSS SOFTWARE IMPLEMENTATION

As in chapter 6, the workplan was developed according to the structural basis explained in section 5.3.

7.3.1 Roles in DSS development

An introduction to some of the possible disciplinary backgrounds of the actors and the traditional methods of analysing the urban environment is presented in chapter 3. To discover other aspects of the actor's background, requirements or behaviour, one of the methods for user assessment listed in section 4.4 may be used. Within the specific project, mainly input from literature has been considered. The client profile was assessed through interviews and the general user profile was refined through group assessment during the first workshop on the GUI dummy.

7.3.1.1. The client [46]

The client commissions the DSS's development. In this case, the client was the Directorate General of Transports of the European Commission (EC), TRANSPORT Programme, as represented by its project officer. He belonged to a European governmental institution with an interest in generally improving the impact of traffic and emissions on the environmental in urban areas in particular. This client provided funding, on the one hand, and had power over general policy strategy on the other hand. He was a hierarchical superior of the designated DSS user. In this particular analysis, his interest is taken into account as a strategic goal without considering him as an actor. For the cultural background of this actor in relation to the urban environment, please refer to section 2.2.3.

Does the client have specific preferences in terms of reporting and/or display?

Yes, the client requires the tool to :

- be a prototype application for different policy-makers and transportation managers throughout Europe;
- not be translated into national languages;
- be consistent with other previous and parallel EC-funded projects;
- be concluded within 30 months;
- be documented and presented at events and conferences;
- be usable on different digital platforms.

7.3.1.2 The decision-maker/DSS user

In this DSS development process, two types of individual decision-makers with different requirements for detailed information have been considered the "DSS user" throughout decision process, even though other stakeholders may profit from the final version. For insight into the possible variety of cultural backgrounds for this actor, please refer to chapter 2.

Since the client requires that the final application be relevant to different situations throughout Europe, a general framework was created, and was made more specific during each session. In order to create an application that required an acceptably low

---

[46] For more information on this topic, see section 4.4.2.5.

level of input complexity, a compromise had to be reached that would maximise the amount of detail in the specific application cases while minimising the amount of input required from the user. The two different levels of detail required by the two different user classes were taken into account by pre-defining some details within information clusters, so that the policy-makers did not have to enter each detail of the city description, while the transportation planner could choose to do so. Nonetheless, a certain level of abstraction had to be maintained in order to avoid losing track of the main targets of the goal definition and evaluation processes. In case this DSS should be used within a large evaluation campaign, the current version cannot be used as anything more than as a screening tool. In order to produce a detailed specific case evaluation, additional aspects must added in accordance with individual requirements and with the underlying database.

The user assessment has indicated that the following features are required in the tool's interface:

- a simple and intuitive graphic user interface is required for the policy-makers, since these users are not very familiar with digital tools. The more detailed models and information sources may include more complex digital systems such as geographic information systems (GIS) like those already in use at the user's facility. Initial training is required to use the tool;
- user interaction should be as intuitive as possible;
- the tool must be portable to the platforms available at the users' offices;
- data input interfaces from other database systems should be simple;
- the information should be accessible even outside the evaluation module.

Which type of display is the user/are the users familiar with?

The user is familiar with Microsoft Office environments. Transportation planners are often used to GIS.

What digital means are at the user(s) disposal?

Desktop PCs running under Microsoft Windows NT or 95

Does the user have specific preferences in terms of reporting and/or display?

Web-like interfaces with intuitive interaction modes using forms and hyperlinks are preferred.

7.3.1.3. The DSS designer

As was described in section 5.3.1.3, the DSS designer directs the process workflow and translates the requirements and information input into technical input for the other technical developers. The cultural background of this actor includes decision theory and tool development, as explained in chapter 4.

The professional background of the DSS designer (in this case, the author of this thesis) includes a degree in architecture and urban planning and thus the DSS designer has knowledge of working environments close to those of the DSS user. Other skills consist of experience with software and interface design and programming, especially for urban environmental and transport management applications, on the basis of specific expert systems, including GIS and CAD [47] and WWW distributed

---

[47] Computer Aided Design tools used in planning and architecture.

applications. Knowledge of several of the users' native languages and support from local project development partners facilitated communication with policy makers, planners and the client.

In addition to the DSS conceptual design, this actor also developed the interactive prototype dummy representing the concept.

7.3.1.4 Workshop organiser

To test the DSS dummy prototype version, a workshop was planned that would assess how well the tool's layout corresponded to the DSS user's needs. This workshop was planned by a project partner expert in arranging conferences and workshops. A general introduction to the cultural background of this actor and a short introduction to the brainstorming techniques used can be found in section 4.4.

7.3.1.5 The specialist in DSS testing with the user

Originally the DSS designer anticipated performing the user assessment after the first prototype had been developed. Because this development took place later than expected, an additional actor was introduced to present the adapted DSS dummy prototype to individual users all over Europe and to collect their suggestions for fine-tuning the tool. This task was assigned to a representative from the same institution as the DSS designer, an expert in socio-economic environmental management with expertise in DSS design, who was able to follow the DSS design process from its inception. This actor used questionnaire and interview techniques. The cultural background of this actor coincides with those of the DSS designer and the workshop organiser.

7.3.1.6 The toolsmith

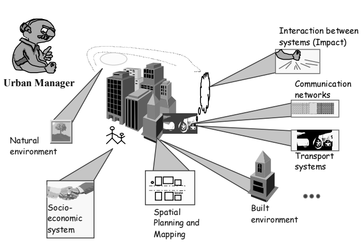
Like it does for the MATADOR project, section 5.3.1.5 offers a brief insight into the duties of the toolsmith. The toolsmith's general cultural background consists of programming knowledge of tools, as explained in section 4.5.8. The toolsmith [48] co-operated closely with the DSS designer. She developed the digital DSS code and an interface based on the DSS dummy interface and on the internal modular structure and digital models given by the conceptual DSS design.

7.3.2 The decision space

According to the structure laid out in chapter 5, the decision space was modelled as described in section 5.3.2, using the user needs defined above and the methods of decision space representation described in chapter 4.

---

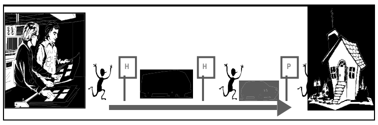
[48] Lia Trovelli was the toolsmith.



Scenarios modelling changes in the overall problem environment are not considered in and of themselves, but might be partly included by changing evaluation criteria or the qualities of the technological solutions, such as economic costs.

Figure 7.4: Boundary conditions.

The client defined the overarching goal of the project as a reduction in noise and air pollution through the introduction of alternative propulsion systems or a reduction in the number of required parking spots through the use of alternative vehicle concepts within the urban transport system.



The alternative options to be evaluated therefore include systems of transport of goods or persons. Within this project this kind of system was called a "transport chain".

Figure 7.5: Transport chain.

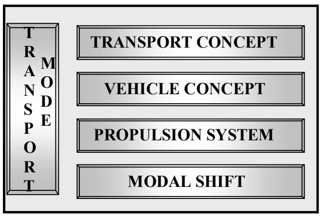


Figure 7.6: Elements of transport chain

These may be conventional vehicles or alternative traffic systems or vehicle concepts. The goal definition module, this time, consisted of an interactive definition module for demand cases and a selection of specific transport chains. The evaluation of the PS and VC was performed according to the vehicle's mission as defined by its role within the transportation chain. Vehicles with alternative propulsion systems or new vehicle concepts could be substituted for conventional vehicles. Thus, the alternative solutions were vehicles characterised by specific vehicle concepts and alternative propulsion systems. The boundary conditions of the user's specific goal and the related physical environment were defined through selecting the "demand case" to be considered. One work package of the project distinguished major European urban patterns and isolated a consistent set of typical demand cases for European urban transports.

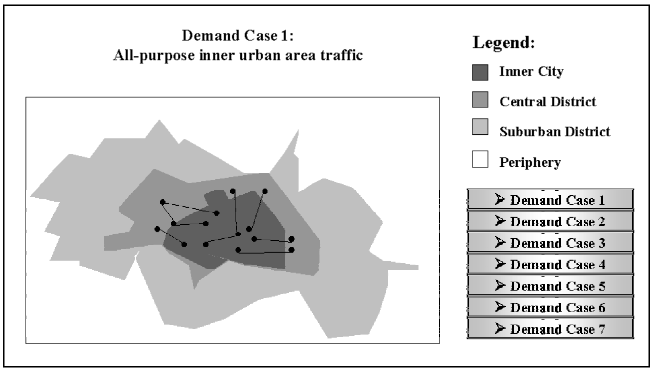


Figure 7.7: Selection of general demand case

A related database of vehicle concepts (VC) and propulsion systems (PS) corresponding to each type of demand case was built.

A specific set of VC – PS combinations were considered the focus of the for the application. In addition, the general set of evaluation criteria was composed of a set of sub-criteria relevant to the specific demand case.

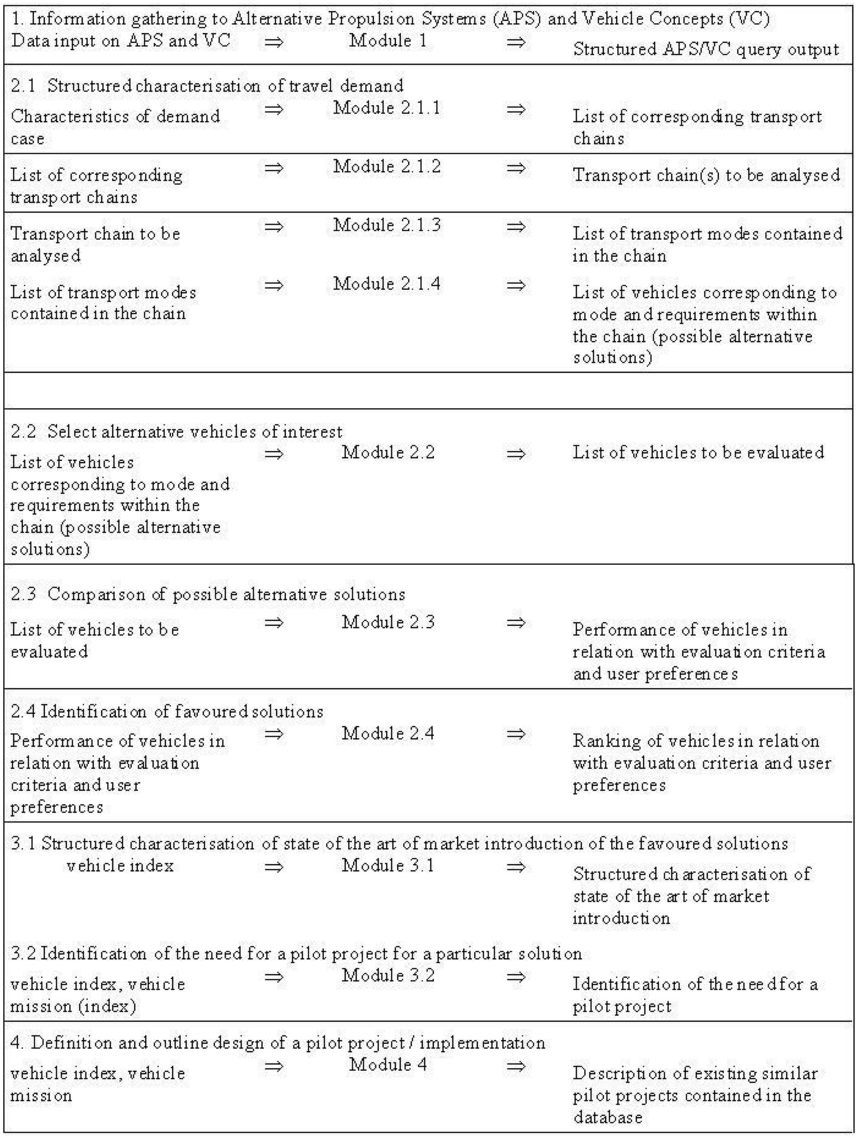
Three major evaluation criteria were defined: environment, policy and market impacts. These classes were used as the major evaluation criteria during the evaluation process. They were defined in terms of consistent sets of factors characterising the relevant criterion (sub-criteria), variables (indicators) that define them unambiguously, and relevant datasets and rules for combining the indicators into sub-criteria and the final criterion (models). The models and indicators could describe the characteristics of the vehicle as a whole or they could be integrated with a model representing the integration of the relevant information on components into a description of the whole vehicle.

The description of the sub-criteria included the conceptual details and rules of interaction with other criteria that were required for modelling the related major evaluation criterion. Every sub-criterion had to be described in terms of a consistent set of characteristic indicators and the rules or models in which the indicators can be combined to represent the sub-criterion. A template for meta-information about the sub-criteria contained within the UDST was defined for use within other workpackages. It contained:

- a conceptual description of the sub-criterion;
- links with other sub-criteria;
- the names of related model(s);
- a description of the interaction between models; and
- a list of the indicators relevant for the criterion model.

The preferences for specific criteria were set flexibly for each criterion during the evaluation process.

7.3.3 Decision steps and their requirements



1. Information gathering to Alternative Propulsion Systems (APS) and Vehicle Concepts (VC)				
Data input on APS and VC	⇒	Module 1	⇒	Structured APS/VC query output
2.1 Structured characterisation of travel demand				
Characteristics of demand case	⇒	Module 2.1.1	⇒	List of corresponding transport chains
List of corresponding transport chains	⇒	Module 2.1.2	⇒	Transport chain(s) to be analysed
Transport chain to be analysed	⇒	Module 2.1.3	⇒	List of transport modes contained in the chain
List of transport modes contained in the chain	⇒	Module 2.1.4	⇒	List of vehicles corresponding to mode and requirements within the chain (possible alternative solutions)
2.2 Select alternative vehicles of interest				
List of vehicles corresponding to mode and requirements within the chain (possible alternative solutions)	⇒	Module 2.2	⇒	List of vehicles to be evaluated
2.3 Comparison of possible alternative solutions				
List of vehicles to be evaluated	⇒	Module 2.3	⇒	Performance of vehicles in relation with evaluation criteria and user preferences
2.4 Identification of favoured solutions				
Performance of vehicles in relation with evaluation criteria and user preferences	⇒	Module 2.4	⇒	Ranking of vehicles in relation with evaluation criteria and user preferences
3.1 Structured characterisation of state of the art of market introduction of the favoured solutions				
vehicle index	⇒	Module 3.1	⇒	Structured characterisation of state of the art of market introduction
3.2 Identification of the need for a pilot project for a particular solution				
vehicle index, vehicle mission (index)	⇒	Module 3.2	⇒	Identification of the need for a pilot project
4. Definition and outline design of a pilot project / implementation				
vehicle index, vehicle mission	⇒	Module 4	⇒	Description of existing similar pilot projects contained in the database

Figure 7.8: Schematic input and output flowchart for UDST modules.

Each step modelled conceptually in section 7.2.3 was analysed in terms of its requirements for modelling and input data, as described in section 5.3.3. The most common way to do this is to represent each step as an empty box, and to record the conceptual model input (I) to its left side, and the conceptual model output (O) to its right. In this way the role of the system module supporting the step is defined: it is the agent that transforms I to O. The scheme reported in figure 7.8 shows these in- and output requirements.

Module 1 requires that it be possible to query databases APS and VC, through means such as a database management system (DBMS) accessible through a specific graphic user interface.

Module 2.1 is the specific goal definition module. It consists of a graphic user interface permitting the selection of the specific demand cases, transport chains and vehicle modes to be analysed as possible applications for APS and VC. It permits analysis of the mission, the vehicle will have to fulfil. Such a module was not found within other applications and therefore had to be developed specifically for this project.

Module 2.2 permits the user to make a selection from the set of vehicles found through Module 2.1. It offers a list of vehicles that could be implemented within the specific transport mode application. The user has the opportunity to choose the evaluation set.

Module 2.3 is an evaluation module permitting the definition of the evaluation criteria and the setting of user preferences. The module generates an overview of the overall performance of each vehicle selected for evaluation in Module 2.2 in relation to each evaluation criterion. The user is able to perform "what-if" requests regarding vehicle performance as it relates to specific preferences and criteria by looping back from the presentation of the results to change some of the inputs. This permits an in-depth understanding of the influence of these settings on the final decision.

Module 2.4 permits the comparison of the performances derived from module 2.3. A ranking of the overall performances of the vehicles is created according to the user settings.

Module 3.1 permits access to additional information on the state-of-the-art of the market introduction of the vehicles investigated.

Module 3.2 offers a checklist that enables the user to identify whether there is a need to implement a pilot project for a selected solution.

Module 4 offers a graphic user interface module that allows access to a database containing information from stored case study applications structured through a decision-tree. The interface permits a query about selected vehicle or demand case applications.

The final DSS is composed of:

- a DBMS storing information on urban traffic patterns, demand cases, transport chains, vehicle modes, APS, VC, market implementation stages, case study applications and the data required for the models contained in the model management module;
- a model management module containing the goal definition model (demand case definition model, traffic chain selection model and transport mode selection model), models for the generation of the evaluation criteria, models representing the related sub-criteria, a multi-criteria model for the evaluation of individual alternatives, and a multi-criteria module that generate a ranking from the single alternative evaluation;
- a display generator permitting the creation of on-the flow displays representing queries from the DBMS, the goal definition module and the multi-criteria evaluation module;

- a graphic user (GUI) interface generated by the display generator and consisting of modules for each functional DSS module.

7.3.4 General workplan for the application's development

For a controlled project management process, a workplan must be agreed upon by the team of actors within the DSS design and implementation teams, according to the methodology developed in chapter 5 and the technical steps as described in section 4.5.8. This workplan consists of framework conditions regarding the economic, time and personnel resources available and the division of responsibilities for each part of the process. Using the methods described above and taking the project partner's responsibilities into account, a project workplan was created. This plan consists of four schemes:

1. a *flowchart reporting each work-package* of the DSS implementation in relation with the other work-packages. For each package a responsible task leader is appointed. The major DSS development tasks (4.1, 4.7 and 6.3) are imbedded into the complete scheme of supporting the users to perform different tasks in APS and VC implementation.
2. The *development timeplan*, depending mainly on the time frame set by the client and on the amount of time required for data collection and implementation. The time plan for DSS development is reported later.

   The largest problem lay in the difficulty of integrating the different targets identified in the original three proposals, as well as the development teams who prepared them. Initially, the work of data collection, case study analysis and reporting and DSS development was not focused on the common problem definition required for DSS development. The time between this stage and the focus definition stage had to be used for data collection and documentation and thus resources needed to collect and analyse some input were not available when needed. This demonstrates the necessity of an early and precise problem definition and the difficulty of managing large and geographically scattered teams.
3. a list of five *major milestones,* defined at the end of the key phases:

   M1: month 6, Inventories of new propulsion systems, transportation concepts in which they can be deployed, existing demonstration projects, and the factors influencing large-scale market entry

   M2: month 12, Analysis of factors influencing market penetration based on case study results

   M3: month 18, Framework and methods for evaluating market penetration: market, policy and environmental perspectives

   M4: month 24, Results of on-site testing of the evaluation methodology

   M5: month 30, Final output:
   - Decision Support System
   - guidelines for market actors
   - guidelines for policy-makers
   - assessment of most promising systems
4. the *list of deliverables*, with their responsible actor and their deadline;

5. a list of the economic and institutional resources of each participating actor, divided by workpackage contribution.

   This list is obviously confidential for duration of the project. In this specific case, an EC-funded project was initially set up for the project proposal. It terms were negotiated later on between the EC project officer and the project participants. These elements comprise the measurement rules for project management and co-ordination.

   In this case, the efficiency of project management determined the complete outcome of the project. The ability of the project manager to co-ordinating the non-homogeneous project group into a focused working team lead to a set of output for the project that was consistent with that of other EC projects developed in parallel. A less adept project manager might have achieved results through a reduction in the scope of the three original project proposals. This shows how the project co-ordinator of such large development teams becomes the key figure in guaranteeing the project's outcome. The DSS designer often performs the role of a project manager for the DSS's development. This case shows that in large projects a different actor in administrative project management might perform the technical management. In this situation, very close co-operation is required.

7.4 GRAPHIC USER INTERFACE (GUI)

A short description of what the user-interface is and how it works is given in section 4.5.8. On the basis of the workplan described in section 7.3, the process of DSS software implementation is described. This description is structured through the methodology described in chapter 5, and in sections 7.4 and 7.5. The description of this process has been split into two sections, taking the roles of the DSS development actors involved in developing the two parts into account.

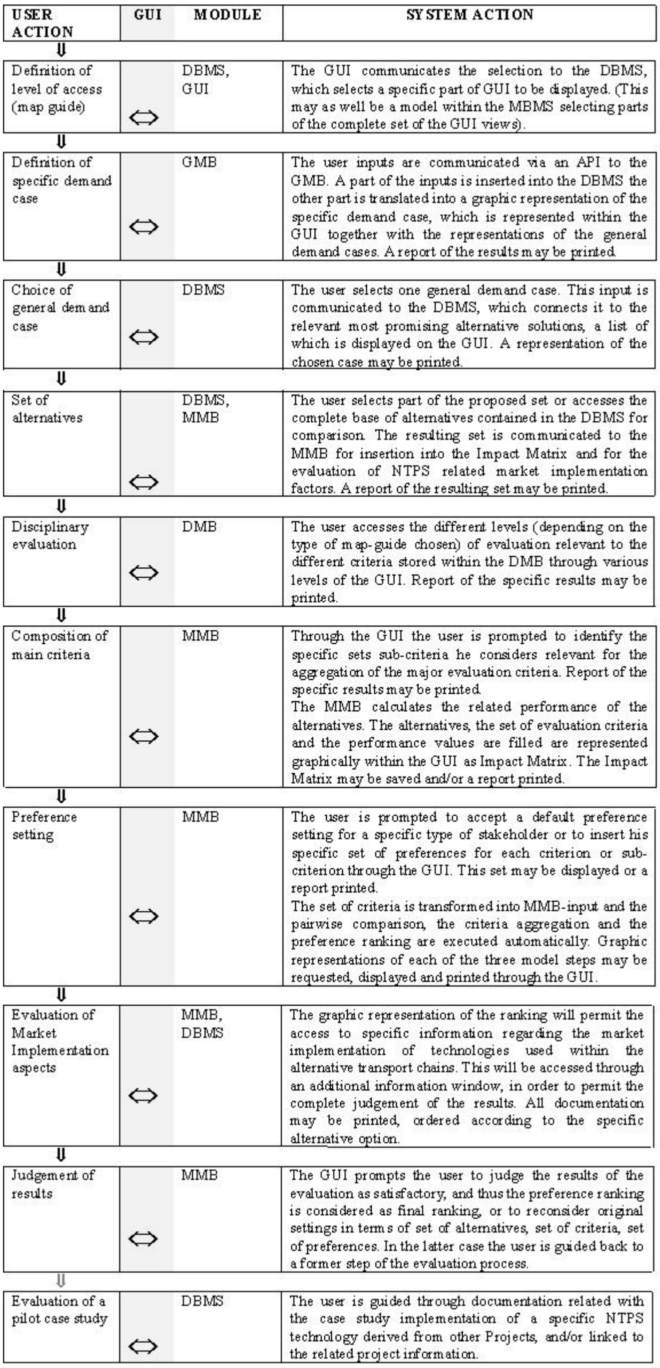
7.4.1 User requirements and GUI

The user GUI requirements have been described with the user assessment results. The following flowchart shows the user-system interactions in detail, as derived from the information collected above. The user interface must be accessed through a desktop PC interface running on Microsoft Windows NT or '95. The interface to the overview functionalities should be designed as intuitively as possible and its use should not require computer experience. Specific, more detailed information could be treated by more complex systems. Different points of entry to the system must be available.

7.4.2 User-system interactions

The decision process model described in sections 7.2.2. and 7.3.2 represents the general structure of the user-system interaction as described in section 4.5.8. For the development of the GUI software implementation, this structure was translated into a detailed input and output scheme taking each required information-flow into account.

The conceptual scheme prepared by the DSS designer as a development scheme for the software programming (done by the toolsmith) is represented in the following figure. Figure 7.12 contains a summary of the single interaction steps. In this representation, all user interactions are treated as interaction blocks.



USER ACTION	GUI	MODULE	SYSTEM ACTION
Definition of level of access (map guide)	⇔	DBMS, GUI	The GUI communicates the selection to the DBMS, which selects a specific part of GUI to be displayed. (This may as well be a model within the MBMS selecting parts of the complete set of the GUI views).
Definition of specific demand case	⇔	GMB	The user inputs are communicated via an API to the GMB. A part of the inputs is inserted into the DBMS the other part is translated into a graphic representation of the specific demand case, which is represented within the GUI together with the representations of the general demand cases. A report of the results may be printed.
Choice of general demand case	⇔	DBMS	The user selects one general demand case. This input is communicated to the DBMS, which connects it to the relevant most promising alternative solutions, a list of which is displayed on the GUI. A representation of the chosen case may be printed.
Set of alternatives	⇔	DBMS, MMB	The user selects part of the proposed set or accesses the complete base of alternatives contained in the DBMS for comparison. The resulting set is communicated to the MMB for insertion into the Impact Matrix and for the evaluation of NTPS related market implementation factors. A report of the resulting set may be printed.
Disciplinary evaluation	⇔	DMB	The user accesses the different levels (depending on the type of map-guide chosen) of evaluation relevant to the different criteria stored within the DMB through various levels of the GUI. Report of the specific results may be printed.
Composition of main criteria	⇔	MMB	Through the GUI the user is prompted to identify the specific sets sub-criteria he considers relevant for the aggregation of the major evaluation criteria. Report of the specific results may be printed. The MMB calculates the related performance of the alternatives. The alternatives, the set of evaluation criteria and the performance values are filled are represented graphically within the GUI as Impact Matrix. The Impact Matrix may be saved and/or a report printed.
Preference setting	⇔	MMB	The user is prompted to accept a default preference setting for a specific type of stakeholder or to insert his specific set of preferences for each criterion or sub-criterion through the GUI. This set may be displayed or a report printed. The set of criteria is transformed into MMB-input and the pairwise comparison, the criteria aggregation and the preference ranking are executed automatically. Graphic representations of each of the three model steps may be requested, displayed and printed through the GUI.
Evaluation of Market Implementation aspects	⇔	MMB, DBMS	The graphic representation of the ranking will permit the access to specific information regarding the market implementation of technologies used within the alternative transport chains. This will be accessed through an additional information window, in order to permit the complete judgement of the results. All documentation may be printed, ordered according to the specific alternative option.
Judgement of results	⇔	MMB	The GUI prompts the user to judge the results of the evaluation as satisfactory, and thus the preference ranking is considered as final ranking, or to reconsider original settings in terms of set of alternatives, set of criteria, set of preferences. In the latter case the user is guided back to a former step of the evaluation process.
Evaluation of a pilot case study	⇔	DBMS	The user is guided through documentation related with the case study implementation of a specific NTPS technology derived from other Projects, and/or linked to the related project information.

Figure 7.12: Flow chart for user –DSS interaction and API.

To provide a full sample for the toolsmith, each step has been divided into single parameter settings and interactions. To explain these in great detail is beyond the scope of this thesis.

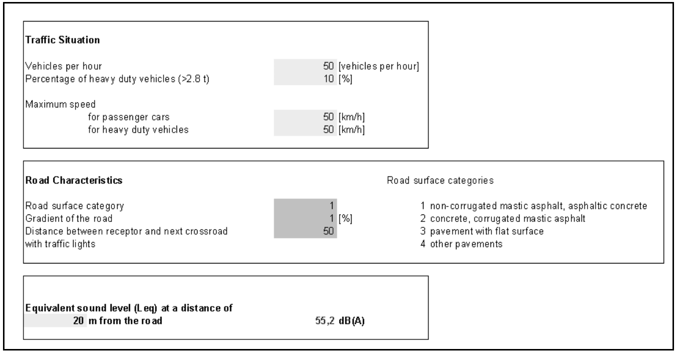
Once the complete scheme has been created, it represents a framework structure for the toolsmith's design of the API and the GUI's interaction with the internal DSS structure.

7.4.3 GUI conceptual design

The interface configurations (section 7.4.1) and the user-system interaction scheme (section 7.4.2) for a basis for the conceptual GUI layout design.

Based on user interaction, the GUI is composed of panels including interactive forms, graphics, alphanumeric and linguistic information. The user follows the decision process from one panel to the next, communicating individual input to the system by inputting forms and pressing buttons to submit form input. Hyperlinks allow access to the on-line-information on travel patterns, transport chains, transport modes, specific vehicles, technical information, case studies and the decision process. All modules are implemented in a single interface container (browser) using compatible interface languages (Java, JavaScript and HTML).

To determine whether this approach would be accepted by the user, a dummy version was produced and tested.



Traffic Situation

Vehicles per hour 50 [vehicles per hour]
Percentage of heavy duty vehicles (>2.8 t) 10 [%]

Maximum speed
for passenger cars 50 [km/h]
for heavy duty vehicles 50 [km/h]

Road Characteristics

Road surface category 1
Gradient of the road 1 [%]
Distance between receptor and next crossroad with traffic lights 50

Road surface categories

1 non-corrugated mastic asphalt, asphaltic concrete
2 concrete, corrugated mastic asphalt
3 pavement with flat surface
4 other pavements

Equivalent sound level (Leq) at a distance of 20 m from the road **55,2 dB(A)**

Figure 7.13: Individual model interfaces.

The user was not familiar with the individual model interfaces. Most of the sub-criteria consisted of data values combined in weighted sums, but some were calculated through spreadsheet models, originally accessed through different DBMS interfaces. Specific GUI modules were needed, and/or access to the original GUI modules had to be integrated into the system.

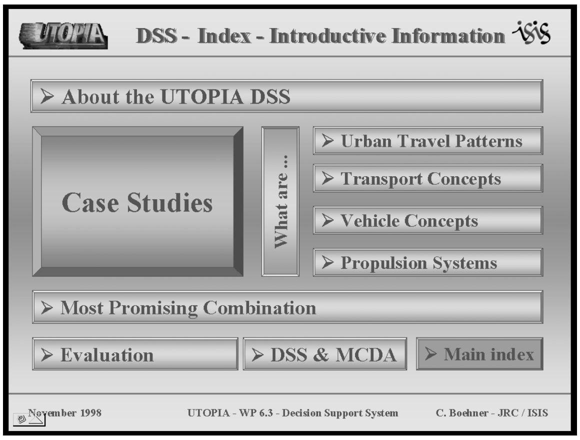


Figure 7.14: Dummy cover

Each individual user request action is translated into a GUI panel demanding and receiving this action input. These panels are linked with the on-line-information system through hyperlinks and form request functions. The flow of the decision process ought to be apparent during all steps in interacting with the system and in the on-line-information requests. A pop-up window system has therefore been created. It provides information on single tasks performed during the decision process, without filling the main window completely. The user's the position within the general sequence of steps in the decision process is represented continuously within a window frame. This system is based on typical windows on-line-help systems familiar to the user.

The sequences and linking systems have been translated to a digital interactive dummy [49] that does not contain the underlying databases or evaluation models. This dummy interface was first tested within the project group, afterwards in a user workshop brainstorming session and finally during interviews with a number of fleet managers from across Europe.

The need for different entrance points into the problem solving process was demonstrated in this testing. Several specific requests were made for modifications of the digital interface and the representation of the case studies. It became clear that the term "DSS" and its possible function within the decision process had not yet been made obvious to the users in the theoretical descriptions and examples of other DSS applications that were given to the users before the workshop.

After discovering the possibilities thought of by the project partners, the users became much more interested in co-operating. Some parts of the GUI structure have been redefined and its expressions have been reviewed on the basis of the user comments. The originally envisioned evaluation method was discarded because the users indicated that the complexity of the input and the interaction structure, combined with a low frequency of use, might hinder the system's applicability to real cases. A simpler evaluation methodology was introduced: the reference point model, which seemed to be very handy as a theoretical model description and which is able to support the core of the evaluation process. This demonstrates the large influence that user interaction requirements can have on the choice of an evaluation method. This requirements may be more important than the immediate utility of the tool.

Another option requested by the users was access to the source-code so that they could introduce user-owned information systems into the DSS input module. This

---

[49] This dummy is available on the CD-ROM version of this thesis.

request could be fulfilled only in part, for copyright reasons and because of time constrictions on software development. This demonstrates that some requests can be anticipated and a software structure should be designed to be as open as possible to modular expansion.

Some additional requests including those for translation of the application into the users' native languages could not be fulfilled because of the initial cut in the project budget for this task. Finally, agreement on the DSS's GUI layout was reached between the client and representatives of the DSS users.

7.4.4 GUI implementation

The GUI-user interaction dummy (section 7.4.3) and the GUI-DSS model API scheme (section 7.4.2) were two parts of the GUI layout then ready to be translated into digital code. In order to finalise this script for the toolsmith, checks for congruence between the internal and external schemes had to be performed and the languages and tools for programming had to be selected (as described in chapter 5 on the basis of notions introduced in section 4.5.8). According to the user requirements for interactive panels and on-the flow interface generation as well as for use of existing interfaces to different models, a common digital interface language was chosen for all modules: Java , JavaScript (and HTML).

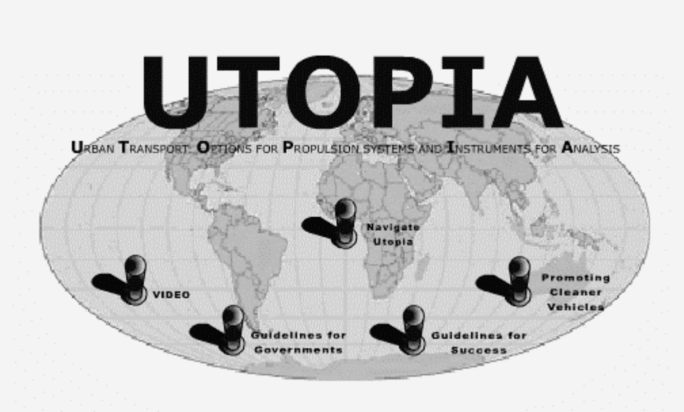


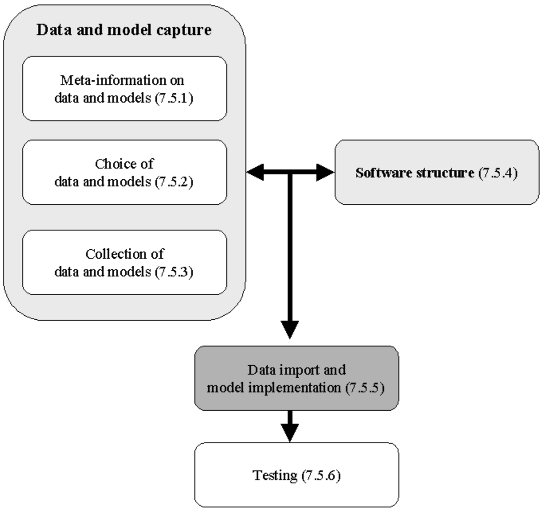
Figure 7.15: GUI cover page.

The spreadsheet models are accessed through their original GUI interface through Microsoft Office database modules. These were familiar to the transportation planners and available on all user platforms. ODBC interfaces were available to all models for this language. The GUI of the evaluation modules was also available in a compatible format (JAVA). This combination of interface languages also permits the application to be used through the Internet. A programmer experienced in JAVA/JavaScript development and DSS application development was chosen as toolsmith.

7.4.5 Testing

The testing of the DSS dummy interface is described in section 7.4.4, and the testing of the complete prototype software in section 7.5.7.

7.5 INTERNAL SOFTWARE STRUCTURE AND CONTENT



The internal software structure implementation was developed according to the scheme shown in Figure 7.16, which is based on the methodological approach defined in section 5.5 and the technical methods described in section 4.5.8.

Figure 7.16: Structure of chapter 7.5.

7.5.1 Meta-information on data and models

The GUI modules shown in figure 7.12 describe the functionalities required for the DSS implementation. These functionalities may be achieved partly through static data requests from the DBMS, and partly through interactive modelling. The modules requiring system reply are:

- the demand case module: Collects indicators of the specific application environment and travel patterns and selects the corresponding general demand case from the database: This module requires an initial API collecting the variables and querying the database and a second API part collecting the Database query output and inserting it into a GUI display.
- the transport chain module: Collects a specific demand case as input and selects the transportation chains satisfying the requirements of this case from the database. This module also requires API collecting the variables and querying the database and a second API part collecting the Database query output and inserting it into a GUI display.
- the transport mode module: Collects a specific transport mode out of a chain of input and selects the vehicles satisfying the requirements of this case from the database. This module again requires an initial API collecting the variables and querying the database and a second API part collecting the Database query output and inserting it into a GUI display.
- the selection of the vehicles to be evaluated: Collects a selection of the displayed set of vehicles and requires an API to compose a new display for the reduced set.
- the evaluation of single vehicles against the criteria: Collects, through different modules, the specific definition of the evaluation criteria (composed of a set of chosen sub-criteria) and the related preference settings. A specific evaluation method is applied via a model evaluating the characteristics of the vehicle, as

reported in the DBMS, against the evaluation criteria. An API generates a display of the vehicle's performance compared with each evaluation criterion.

- the ranking of a set of evaluated vehicles: Collects the performance of different vehicles from the display or through indexes referring to the complete performance information stored in an internal intermediate database capture. Compares, pair-by-pair, the performance of each vehicle against the single evaluation criteria and creates a relative ranking of these performances. An API generates one or more feasible GUI displays of the rankings and the intermediate results.
- the market-performance and the on-line-information module: Fixed displays are chosen through hyperlinks or hyperlink indexes. The pages are selected out of a complete dataset or composed on-the-flow from database inputs. The best implementation with respect to data updates is generated from the DBMS, the fastest reply through the Internet is guaranteed through a request for static pages.
- the evaluation of the need for a pilot project and the design of the pilot project implementation: Because the MAESTRO project (developed in parallel with this one) was dedicated to this subject a hyperlink to this project's Internet site will be provided. MATADOR contains only a static set of pages describing existing pilot applications.

Data required for the different models include: the characteristics of the urban environment in terms of geographic and travel patterns, the composition of transport chains in terms of transport modes, modal shifts and their connectivity, vehicle characteristics responding to values described as evaluation criteria and responding to characteristics of the transport modes and images of vehicles for vehicle schedules. Information on legal and environmental aspects related to vehicle characteristics, information on market introduction and implementation barriers, information on pilot projects, and information on how to use the DSS and where to enter its imbedding information system must also be included.

The API programme codes are stored within a distinct part of the directory structure that composes the DSS. The codes are written in JavaScript and, within the evaluation module, in JAVA. The JDBC-ODBC module is used to communicate with the database.

As the MIG input data were supposed to consist mainly of COEP database elements, no specific meta data scheme was developed for data collection.

7.5.2 Choice of data and models

The UDST was not the first project on APS and VC developed by the project partners and funded by the EC. The results of former projects and the data collected for other parallel projects represented a large resource pool for the DSS's development. The available data and models had to be screened and analysed for their usefulness within the project.

The evaluation modules required had to be:

- applicable to discrete cases (finite set of alternatives)
- able to permit preference settings without pre-weighting
- able to permit the evaluation of single vehicles against the criteria and preference settings

- able to perform impact analysis, creating a final ranking of alternatives with a pair-by-pair comparison technique
- able to allow the use of information subject to different types of uncertainty, such as
  - precise numbers
  - stochastic distributions
  - fuzzy sets
  - linguistic evaluations.

The need for these types of uncertainty to be considered, along with the need for easy access to the implemented software and to available expertise, lead the team to decide which evaluation method to choose: NAIADE[50], a JRC in-house production which had been translated to JAVA for use in earlier projects.

The results of the first user workshop showed that users felt that this method was too complex for the specific application. For greater ease of interaction, the preciseness introduced via fuzzy sets could be left out and the use of a simulation of linguistic evaluation could be replaced by a scale of numbers (1 to 7) mathematically translated to percentages, which are presented to the user as linguistic variable selections.

After the users made this request, it was decided to use the Reference Point Method instead.

7.5.3 Data and model collection

In work-package two a common database was built out of the different disciplinary information previously gathered. Environmental impact data had been collected for a long time, but different measurement groups have collected this data using different methods and equipment. The available data had already been integrated into a common database system and values had been adapted for compatibility. Some information was available only for the APS, and not for the complete vehicle. This portion of the data was modelled for the project database. These collected data have been kept on a rather general level, since they were collected before the end user had been defined.

In order to enhance an understanding of important aspects of environmental impact, two simple calculation formulas were translated into screening spreadsheets to allow the user to evaluate these factors without performing the complete vehicle evaluation.

No models were found in literature or former projects that were useful as goal modelling elements, but information input on travel patterns, demand cases and transport modes was found. The composition of transport chains corresponding to the demand cases had to be composed appositely for the project in project work-package 2.2.

Unfortunately no complete data set seemed to exist for the full decision process from the evaluation of alternative solutions to the implementation. In work-package 3, existing application data were therefore structured and additional information was collected on-site.

---

[50] See chapter 6.

Though the choice of this structure was a logical one, the choice of an evaluation methodology and the related implementation had to be based on this completed database, and thus the data structure had to be readapted, which wasted time.

The Reference Point Method had already been implemented at the JRC in a Perl/HTML version and was translated into JAVA code for UTOPIA at the JRC-ISIS.

7.5.4 Software structure

After the inputs were defined, the software structure was created, in accordance with the indications given in section 5.5.4. As described in detail in chapter 4, DSS are composed of three modules:

- a Database Management system (DBMS),
- a Model Management System (MMS),

and a Graphic User-Interface (GUI), including display and report generators. The GUI design is described in detail in section 7.4 along with its linked display and report generator requirements. The structural development process described here relates to DBMS and MMS and to the implementation of the complete structure.

The definition of data and models described in section 7.5.4 explains the software requirements for the structures hosting these elements.

DBMS for UDST Microsoft Access was chosen, because it is part of the Microsoft Office package and thus available within the DSS user's standard equipment. This DBMS offers, in addition, a standard ODBC interface to JAVA and permits the storage of complex data structures such as texts and images as well as pointers to other documents.

The evaluation module was available as a desktop version and as a Perl/HTML implementation.

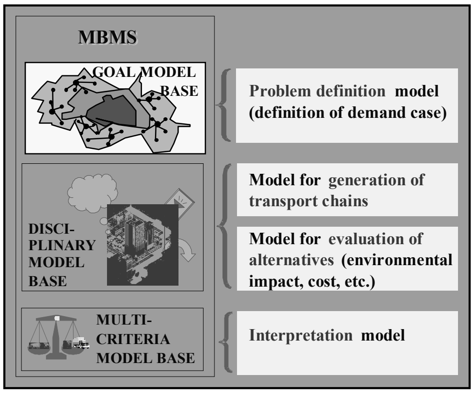


Figure 7.17: Model Base Management System.

To meet the requirements of the DSS users working over the Internet, the Perl/HTML version could have been implemented, but because this version was situated on a UNIX server system, it was decided to port the software to JAVA. All evaluation criteria were represented statically within the Microsoft Access database or through weighted sums executed as Microsoft Access macros. These macros were the only additional models used for criteria simulation. The two related spreadsheet models were used to create fixed database inputs for processing speed reasons.

The display and report modules were appositely developed. GUI modules were programmed in JavaScript and HTML, the evaluation module interface in JAVA and the API in JAVA as well, to take advantage of the available JDBC/ODBC interface.

The models and the DBMS possessed JDBC/ODBC interfaces but no ready-made APIs. So the second large task of the toolsmith, apart from the translation of the GUI design to GUI source code, was the generation of the APIs between the models to build the MMS. The model input and output scheme forms a basis for this programming effort (section 7.5.1), as do the model specifications described within the model meta-information (section 7.5.2).

7.5.5 Data import and model implementation

A specific directory structure was developed consisting of modules for database files, evaluation module generated files, the GUI prototype file structure and the API programmes.

The databases produced within work-package 2 were stored in Microsoft Excel and Microsoft Access and thus were easily portable to Microsoft Access format. Their structure had been described in detail by the project partners and could therefore be adapted easily to the foreseen structure for the goal models and the evaluation module. For the first steps in the DSS development process, initial dummy inputs were inserted into the database structure to determine the most suitable program structure. The initially predicted direct use of the spreadsheet models was discarded in favour of a completely pre-produced database of model results, which was faster to implement.

The GUI was developed on the basis of the dummy described in section 7.4. The Reference Point tool version was implemented on the test platform. Elements of the database individuating demand case, transport chain, transport mode and aspects of evaluation criteria were identified. The prototype was then finalised through the API code implementation.

7.5.6 Testing

After this prototype version had been developed, a second testing phase was conducted, in which the project partners were to test the tool over the Internet and to comment on it. For a short introduction to questionnaires and other assessment techniques, please refer to section 4.4. After these mainly technical and functional comments were analysed and worked into the software the prototype was presented at conferences and to the EC project officer.

Positive feedback was given about the structure of the information system, but the evaluation method implementation itself was still judged very difficult for non-experts to use. Nevertheless the EC project officer was very pleased with the outcome of the development and additional resources were not spent on this aspect during project development. This effort will instead later be spent on the implementation in a later in-house development phase at the JRC, since their in-house graphic interface developer had created this version of the evaluation method implementation.

The author of this paper left the project after the finalisation of the DSS dummy prototype version and handed it over to the toolsmith and a senior researcher to co-ordinate work with the project team, so that there was no longer a direct connection with this phase of development.

7.6 LESSONS LEARNED THROUGH THE CASE STUDY APPLICATIONS

The UTOPIA project application case illustrates the use of the decision-maker's script as a management method for DSS design and implementation. It also illustrates some of the problems that may be encountered during the development phase. These are due to the influences of the personnel and to the importance of co-operation within the team to ensure success in DSS development.

This project development thus perfectly illustrates the steps in a decision space description and in DSS development. It does not provide a good opportunity to analyse the tool's final applicability and acceptance by the user in his/her real evaluation process, because the application itself have still not been assessed.

This project demonstrates the importance of the client, but it also shows the importance of the technical development team. In this case, the developing research partners formulated the initial idea. After this, the client agreed to finance the project. The last actor to join the DSS development process was the designated user. If case study applications are required to introduce a new technology such as DSS into a specific market, this process can be considered a typical case study development. For the first case study, described in chapter 6, the end-users were already on board at the beginning of the development process only because they were involved in the introductory project of database development. This situation does not correspond with the typical process described in decision theory, in which the client corresponds to the user and the decision-maker and makes the original request for a DSS.

The typical case of DSS development in European urban environmental management, and maybe also in other fields of new application, is initiated by the technical development group or an external financing client. The user always has to be introduced to her/his role within the development process and sometimes even to be convinced of the usefulness of the tool within the designated evaluation process. To convince someone that the tool is useful, and to gather the required input, one should introduce this actor to the logic of the tool and the possibilities for using it within the decision-process. The DSS designer ought to understand the cultural background of the decision-maker in order to capture the structure and meaning of the decision process model. To gather this description, the decision-maker has to understand that the user's participation is useful. Not only does the role of the DSS in the decision process have to be understood, but also the decision-maker's role within the tool development process. In this way, an interview or a testing phase is not understood as an advertisement for the technical developers, but as a common workshop session to increase the user-orientation of the tool under development.

The fact that there is a need to convince the decision-maker that playing a role in developing the tool is important is a result of the typical way of obtaining tools: usually one receives a tool as a consumer receives a product. The DSS is not, however, a standard tool or a piece of software with some user-defined features. Its nature depends on the user and thus the designated user has to understand that he/she is not merely a consumer. The tool cannot be useful in her/his decision-process if this process is not reflected in the tool development process.

The case studies also indicate that many requirements formulated by the client may initially seem unimportant, but may ultimately have a very strong impact on the tool's applicability and final form. The requirement that a specific database be used in case study 1 finally resulted in the development of only a proof of concept, since most of the database inputs could not be used for the tool and thus were not available as resources for data retrieval and collection. The limitation that the interface be produced in a single language reduced the size of the area where the application would be useful to northern Europe, because of the professional background of the designated users.

Different actors impact the DSS development process in different ways, thereby influencing the final tool, without being conscious of it. This has caused the author to believe that there is need for a method to raise consciousness among the actors. The DSS-maker's script approach answers this need. The need was felt and translated into a framework approach at the beginning of the case study applications. It has proven to be even more important during later phases of the application's development.

CHAPTER 8 Lessons learned and needs for further investigation

8.1 INTRODUCTION

This thesis attempts to improve the acceptance of DSS applications by those involved in European urban environmental management by considering the impact of the tool development process on the final product. This improvement is to be brought about by introducing the actors in the tool development process to improvisational role-plays. These role-plays introduce the different actor profiles and rules of interaction, the given evaluation methods and requisites, specific milestones and a final common goal. The DSS designer assumes the director's role and the individual parts are performed improvisationally by the actors, so that the use of the requisites and the form of the final output are dependent on the performance of the actors. This thesis is thus based on the recognition that the specific DSS implementation and its use strongly depend not only on the methods and techniques implemented, but also on the development process itself and on the performance of the actors involved.

The DSS users and other actors who define the requirements of the DSS's development are introduced to the logic of decision theory and DSS, while the technical experts in DSS development are introduced to the cultural backgrounds of the non-technical actors and to the methods they use. The DSS maker's script introduces the fields of expertise of all actors involved in the case study applications in its approach to DSS development. After this introduction, the backgrounds of all actors are known, so their specific parts in the tool development process can then be introduced. After the assignment of roles, a framework for the tool development process is given to support the formulation of a workplan for the application. This indicates the relevant rules of interaction and responsibilities for each actor. The development of this interactive process is described in chapter 5. This chapter was developed initially as a theoretical framework that was then verified by being applied in two case studies. The development of these two case studies illustrates the steps described in chapter 5. It put to use the method of introducing the fields of experience of the actors developed in chapters 2 to 4.

This chapter contextualises this work and its results within the fields of DSS research and urban environmental management research by describing the novelty of its approach, the scientific questions it answers and the additional questions posed by or discovered during this research. The structure of this chapter is sketched in figure 8.1.

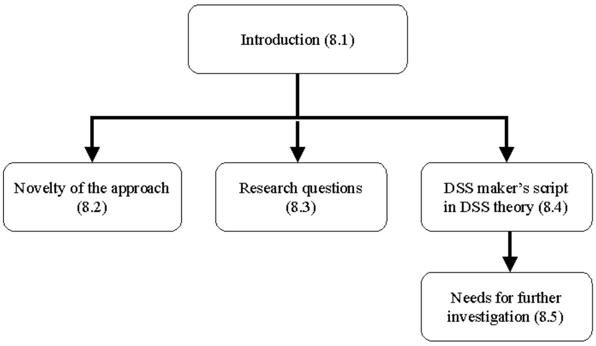


Figure 8.1: Chapter 8's – structure.

8.2 RESEARCH QUESTIONS

How can DSS's utility for decisions about European cities be increased?

The need for the development of a more user-oriented DSS has been pointed out frequently in literature, but until now the request for a more user-orientation approach has lead only to requesting the user to participate more frequently in testing sessions. This is a typical approach to increasing user-friendliness in IT and it is useful for improving the graphic user interface of tools whose uses and functions are known to their users. It is presumed that the user understands what the tool does, what it can be used for and under which conditions it can be used.

DSS are tools developed for specific applications and thus the user should know what they can be used for before they even exist. This presents a problem that has not yet been resolved. The final system will be based on the theoretical and technological background of DSS development and on the disciplinary and cultural background of the problem, the designated decision-maker(s) and other actors who might impact the tool development process. So who could explain to the technical developers what would need to be developed? Or should the question be: who could explain to the decision-maker(s) and other actors what to expect of the tool? Both questions have to be answered before the system can be developed. In the literature the users answer the question of what they expect to be developed through their definition of the problem and their typical decision process. Answers to the question about what to expect from the system are rarely documented: this is sometimes attempted through the presentation of an application case of the evaluation method to the decision-maker(s). This gives an overview of what DSS can or cannot provide, but the nature of the different methods and technical solutions remains unknown to clients and decision-makers. This again limits the amount of information the actors may provide when defining their requirements regarding the tool. But:

What instrument can support the actors in formulating what they expect the DSS to support?

IT-based descriptions of the DSS development process describe the actors involved in the DSS development process as including software developers, programmers and, sometimes, sociological analysts who define the end-user profile. The user(s) are introduced to the development process through profile descriptions from literature or through direct interviews and/or questionnaire analysis. Their needs are analysed and considered as an input to tool development. After this, the user is usually confronted with pre-existing tools and asked for specific inputs. The user is mainly treated as a data source, and the questions he/she is asked are not put into the context of the tool development process. The questionnaires and interviews have to be prepared and directed according to a pre-defined scheme by the technical developers.

Even though the list of actors in DSS development given in literature seemed to be accepted as complete, the two case studies reported in chapters 6 and 7 lead to the introduction of another actor who has been called "the client". This actor represents the party initiating and/or financing the development process. Even though this might appear to be a specific case encountered only in these two case studies, DSS are being newly introduced to questions of European urban environmental management, and thus most existing applications have been funded as case studies for the larger introduction of these systems. In addition, institutional decision-makers are usually forced to use specific types of IT by their hierarchical structures, and thus often additional actors, who have a powerful impact on the DSS's requirements, are involved in decisions about the development of the tool.

This circumstance might appear insignificant to the development process as long as it impacts only the decision to initiate the development of such a tool, but it implies two additional things:

1. the decision-maker has not directly asked for the tool and thus has to be convinced of its utility for the proper decision process;
2. in most cases the client has an individual strategic goal that may be supported by the DSS, so specific requirements defined by the client have to be taken into account and the DSS should no longer be developed to meet the user's needs exclusively.

Several approaches might be taken to supporting the client and the decision-maker(s) in formulating their requirements and to supporting the technical developers in defining DSS corresponding to these requirements. The DSS-maker's script not only includes contributions from the non-technical actors, i.e. clients and user(s), during their formulation of their requirements, but also during the whole DSS development process. This enables them to verify that their originally formulated requirements are correctly translated into the technical structure of the DSS. This approach requires the technical developers to understand the cultural background of the user(s), their decision processes and the background conditions to the client's requests. In addition, the DSS user must have an understanding of the theoretical background of decision theory and DSS technology and the opportunities they offer.

To enhance the actors' understanding of the different disciplinary backgrounds a theoretical introduction to the specific backgrounds involved should be provided. A sample of this kind of general introduction is given within this thesis in chapters 2 to 4. Obviously it will never be possible for all actors to obtain complete knowledge of all the aspects of the DSS that are considered the speciality of others. It is hoped, however, that a background of understanding can be generated as a basis for the discussion needed to optimise the tool according to existing needs and expectations and the possibilities offered by DSS.

The process of introducing the technical and non-technical actors involved in the DSS development process may be split into the process of responding to two questions:

How can DSS technical developers better understand the needs of actors in European urban environmental management?

To introduce the technical DSS developers to the professional background and requirements of the DSS clients/users, the profiles of some major actors in urban environmental management and their traditional decision support tools and methods are included. This serves as a summary introduction that will prepare the technical actor for her/his dialogue with a client or user. Even though chapters 2 and 3 do not present a complete overview, which would exceed the frame of this thesis, they do introduce the complexity of European urban environmental management and the roles a client/actor may play in the case-studies described in chapters 6 and 7. They also attempt to show the technical DSS developers the need for a detailed analysis of the client or user's requirements so that a common goal can be reached within the tool definition process.

Urban environmental managers on the other hand are usually unfamiliar with decision theory and tools for decision support. Thus an answer to the following question is necessary:

How can European urban environmental managers understand the services that could be provided by decision support methods and instruments?

DSS clients/users are introduced to the area of decision support and methods and tools that might support the solution of their specific in chapter 4. This introduction attempts to provide a clear description of how decisions can be characterised technically, what a model can handle and what it can't handle, how a tool can support its user and where the user's decision takes place within the context of the supporting information.

Firstly, these chapters introduce the user/client to the importance of his/her role within the DSS development process and to the consequences of explaining the process' specific aspects. Secondly, they introduce a set of tools and methods that could be used within a DSS development process such as the ones illustrated in chapters 6 and 7.

This initial approach provides a basis for the process and thus needs further investigation, especially in terms of time optimisation. The actors' willingness to invest in an in depth understanding of the other actors differs from application to application and from phase to phase during an application. Solutions other than a theoretical introduction might therefore be useful. One possible approach might be to offer an initial group workshop in order to introduce the requirements and the tool facilities. Once they have been well documented, these notions could provide guidelines for the process, not only on a theoretical basis, but also by providing important practical information about the interests and personalities involved. But so far this has not yet been further investigated.

Up to this point the discussion of the expectations of the tool and the requirements of the individual actors has centred on a theoretical introduction. Unfortunately the initial inputs given by the users are based only on the degree to which they understand the theoretical introduction. Often expectations become clearer once the system has begun to have a more specific form and thus the user is required to follow the DSS development step by step, so that no gap forms between what she/he expects and what kind of product is developed. The client usually expects to receive reports of the status of the development process and milestone briefings. All actors should continue to be involved during the whole process.

In the literature only the decision-maker is mentioned as having a role to play in the IT testing phases, but in order to increase the testing phase's utility, the decision-maker ought to be aware of what the testing is used for. The decision-maker should also remain aware of the stages of development and of what he/she can expect from the intermediate product presented. The next question that comes to mind is thus:

What could support the actors during the developing process?

After understanding that each actor has a different role within the DSS development process, each actor must be informed about the specifics of his/her role, and must grasp the need for interaction with other actors and their parts in the process of DSS development. This thesis has developed an approach that supports the actors when they are introduced to the role-play of DSS development, the DSS maker's script. This approach, summarised in chapter 5 and demonstrated in chapters 6 and 7on the basis of two case-studies, outlines typical roles within the development process. Reading these specifications, the actors in a specific application discover their impact on and their responsibilities in the DSS development process. After this, they are introduced to the typical structural framework of the process and, at the same time, to the nature of the interaction of their parts. This introduction to the interactive nature of the process ought to induce the actors to participate by making them aware that the product is not simply a technical implementation, but requires continuously formulated input from the user side.

In addition to the definition of the client and her/his requirements, a framework is given explaining what the technical developers are allowed to develop, so that the decision-maker is made aware of the limitations that must be accepted. The designated user's expectations must be reduced according to institutional and technical limits. The client is also introduced to the impact of individual requests and thus informed about the way that limits are set through them.

8.3 THE NOVELTY OF THIS APPROACH

Decision theory focuses on the process of decision-making. Information technology research includes the study of the technical structure of the decision support system (DSS), the inputs and the models included, along with the user's interaction with the system. Sociological and psychological research treat the collection and analysis of opinions and cultural and intellectual models. All these areas of research can contribute to the improvement of DSS applications.

The process of DSS development on the other hand has so far been described only from an information technology point of view and through project management plans. The roles and actors in the development process and their impact on the decision as it is supported by the final tool have not yet been analysed. Nonetheless support for the decision process is based on a description of the problem and the decision space modelled within the DSS.

The DSS maker's script approach developed within this thesis is an initial attempt to analyse the actors in the DSS development process, their interaction and their co-operation. Each actor should be introduced to their proper part in the process and should come to an understanding of the link between DSS and the requirements identified for them. The approach thus considers the expectations of the users and other actors in relation to their contributions to the development process. In this way, the actors' expectations are no longer detached from the development process.

This approach opens a new field of research in the area of decision support. It focuses on the development process of decision support systems as the place where the goals of DSS application and use are defined. The development process is thus no longer considered a pure sequence of inputs and digitalisation steps, but instead a creative process of defining and implementing the goals of the actors who influence it.

Without this new focus, no attention had yet been paid to one actor who profoundly influences the DSS development process and thus the resulting DSS: the client.

The involvement of clients and actors into the development process and the introduction of all actors to the fields of expertise of the other developers is intended to achieve a correlation of user and client expectations. By making users more aware of what can be offered by the DSS that is to be produced, this process is intended to increase user acceptance of the final product.

As an initial approach within this field, the DSS-maker's script also offers a methodological approach to defining the user's, decision-maker's and client's requirements of the DSS and to defining the co-operative development process as demonstrated in two case study applications.

An additional novel feature of this thesis is its double use of the text that describes the methodological approach: it is used once in a text document presenting the theoretical approach and a second time in an interactive digital version that could accompany an actor in DSS development through the implementation steps. Chapter 5 provides the core methodology, which is illustrated via an on-line hyperlink system and by the other chapters, the linked dummy and on-line interfaces of the case-study applications.

8.4 AREAS FOR FURTHER INVESTIGATION

Developing a new approach to DSS development has led to several new questions. Individual questions have been posed within each individual chapter. This section considers areas that might lead to further groundbreaking research.

Other possible actors in DSS development

The research contained in this thesis has discovered a previously undescribed actor in DSS development, but this may not conclude the list of actors impacting on this process. Further analysis of different case study implementations show the nature for a typical case of DSS development, even though a specific application might require that additional actors not included in the DSS maker's script approach be taken into account.

The client's impact on the DSS development process

The client has had considerable impact on the two applications described in chapters 6 and 7, even though literature considers generally the client to be the same as the decision-maker. This thesis shows that the specific requirements formulated by the clients of the two case studies observed, a general analysis of the impact of the client's requirements and their effect on the acceptance of the developed DSS has not yet been fully researched. Investigating these issues would offer very interesting insights into the usefulness of the current way of funding DSS sample applications.

Methods for introducing the actors to a common basis of understanding

This thesis introduced one initial approach to providing the actors in DSS development with a basis of common understanding. This approach consists of a theoretical overview of the different disciplinary backgrounds, considered as they relate to the case study applications. Researching these different backgrounds is resource consuming and thus is not adequate for practical applications. Methodologies should be provided for a more practical method of assessing the backgrounds of each actor with a stake in the process, so that their contributions can be understood without reducing the introduction to a simple list of requirements.

Dynamics of the ways user inputs to element definitions impact the final DSS

Different inputs are provided with the help of those who are not DSS experts. These inputs are very important and include the problem model, the decision process model, the technical system specifications, the details of user-interaction and the graphic user interface. This thesis has focused on the actors and their performance within the DSS development process. Other studies should determine how important the appropriate definition of each element is for the ultimate acceptance of the DSS, as this would show how to intensify the group work and how to begin the development of methods and tools.

Motivations for choosing evaluation methodologies

The DSS application developments included in this thesis demonstrate that tools for DSS application development are often chosen because they are familiar to the DSS designer or because the software package is readily available from the software developing partner. This reduces the cost of software and the training time of the DSS designer and the toolsmith. It does not, however, necessarily lead to the development of the most appropriate final tool for the specific application.

It would be useful to investigate whether this way of selecting a tool is specific to the two applications followed during the thesis research, or if this method is typically used for certain types of projects, e.g. prototype developments initiated by a client and not by the final user. It would also be useful to investigate whether the strategy of forming a structured co-operative approach before starting the project design phase induces a more problem-oriented choice of decision support method.

Models representing the complexity of the European urban environment

Chapters 2 and 3 introduce the complexity of the European urban environment and provide selected approaches to modelling this space as a system. In the last few decades some interdisciplinary models have been produced because some researchers have felt that the disciplinary models preferred until that time did not represent the complete decision space and environment.

Nevertheless, no detailed classification of the range of aspects represented within the existing models seems to exist yet. In addition, no one has yet considered how different tools represent the interaction between these models and whether the quality of the modelling results is related to the aspects represented. An overview of the available modelling tools and methods should be produced, including a comprehensible description of the modelling process and its inputs and outputs and a qualitative classification of the output's relation to specific questions. This classification would permit

1. efficient selection of a set of tools to model the specific problem space at hand;
2. detection of gaps within the range of modelling methods and tools to initiate further investigation.

8.5 FINAL CONSIDERATIONS

All these open questions seem to indicate that not much has been achieved by the work of this thesis. It is true that the results achieved during these years of research cannot answer all questions, but opening a new field for further investigation is part of a fruitful contribution to research.

One specific contribution of the approach developed here is a demonstration that DSS acceptance and use does not depend only on the right evaluation methodology, the user-friendliness of the information technology employed or the accuracy of the data and models implemented. This thesis puts a new focus on the process of DSS development, considering the ways this process and its stages of development contribute to the final acceptance of the tool produced. The major contribution of this thesis is that it opens a new field of research: the roles and contributions of each actor in the DSS development process should be investigated.

This new field sets DSS research into a new light shifting the emphasis from the implementation of evaluation methods and the analysis of the phases of DSS sessions to the development process itself, i.e. the route by which the tool is defined. The development process can no longer be considered solely a pure digital programming and database construction process. Instead it must be seen as an interactive design process merging the contributions of digital programmers and experts in decision theory with the expectations and requirements of the designated decision-makers and system users. The DSS designer must remain aware of the background conditions represented by the requirements of the initiator/financing source for the DSS development: the client.

REFERENCES

Academic Press Dictionary of Science and Technology, on-line version, on-line in 2000, http://www.harcourt.com/dictionary/def/6/1/8/4/6184300.html

Aiken, L.R., *Personality Assessment methods and practices*, 3rd revision, Hogrefe & Huber Publishers, Kirkland, 1999

Aiken, Lewis R., *Questionnaires and inventories – Surveying opinions and assessing personality*, John Wiley & Sons, 1998

Alberti M., Bettini V., Falqui E, 1984, quoted in Alberti M., Solera G., Tstsi V., *La citta' sostenibile - analisi, scenari e proposte per un'ecologia urbana in Europa*, Franco Angeli, Milan, 1994

Allen P.M., *Cities and regions as self-organizing systems - models of complexity*, Gordon and Breach Science Publishers, Amsterdam, 1997

Anthony, R. N., 1988, quoted in Anthony, R. N., *Planning and Control Systems: A Framework for Analysis*, Harvard University Graduate School of Business Administration, Boston, 1965

Anthony, R. N., *Planning and Control Systems: A Framework for Analysis*, Harvard University Graduate School of Business Administration, Boston, 1965

Bell D. E., Keneey R. L., Raiffa H., *Conflicting objectives in decision*, in "International Series on Applied Systems Analysis", John Wiley and Sons, London, 1977

BEQUEST (Building Environmental Quality Evaluation for Sustainability through Time) project glossary, on-line in 2000, http://www.surveying.salford.ac.uk/bqextra/index.htm

Betuglia C.S., Leonardi G., Occelli S., Rabino G.A., Tadei R., Wilson A.G., *Urban Systems: Contemporary approaches to modelling*, Croom Helm, New York, 1987

Breuste, J., *Indicators of urban ecology*, in "Indicators for sustainable urban development – Proceedings of the European Commission (Environment and Climate Programme) Advanced Study Course", Delft, 1997

Breuste, J., *Stadtökologie und Stadtentwicklung: Das Beispiel Leipzig*, Analytica, Berlin, 1996

Castells, N., "International Environmental Agreements", Joint Research Centre of the European Commission, 1999

Cetica P.A.., *Progettazione Ambientale*, text to the lecture at Florence University, Florence, 1994

Colombo, A.G., "La valutazione di impatto ambientale" in Facchetti, S., Bandirali, A., Paruccini, M., "La protezione civile – Lezioni di una scuola residenziale", EUR 16473 IT, Joint Research Centre of the European Commission, 1996

Densham P.J., *Spatial Decision Support Systems*, in Maguire D.J., Goodchild M.F., Rhind D.W., eds. "Geographical Information Systems: Principles and Applications", vol.1, London, 1991

Douven W., *Improving the accessibility of spatial information for environmental management - An application to pesticide risk management*, PhD publication, Free University of Amsterdam, Amsterdam, 1996

Enache M., *Integrating GIS with DSS: a research agenda*, in proceedings to URISA 1994, URISA, Washington, 1994

Euopean Commission, "Environmental Assessment – EIA legal context", in "EUROPA" Website,on-line in 2001, http://europa.eu.int/comm/environment/eia/eia-legalcontext.htm

European Commission, Amended EIA Directive (97/11/EC) COM(2000)839, 1997

European Commission, EIA Directive (85/337/EEC), 1985

Fjermestad J., Hiltz S. R., *An Assessment of GDSS Methodology*, in proceedings to "Second Americas Conference on Information Systems", http://hsb.baylor.edu/ramsower/ais.ac.96/papers/hiltz.htm, Phoenix, 1996

For further reading see Nijkamp P., Voogd H., *An informal introduction to multicriteria evaluation*, in Fandel G., Spronk J., "Multiple Criteria Decision Methods and Applications", Springer Berlin Heidelberg, 1985

Freyer, K., Müller, U., Popp, P., Treutler H., Schuhmann, G., *Untersuchungen zu Stadtklima und ausgewählten Luftschadstoffen unter Berücksichtigung der Flächennutzung am Beispiel der Stadtregion Leipzig*, in Breuste, J., "Stadtökologie und Stadtentwicklung: Das Beispiel Leipzig", Analytica, Berlin, 1996

Gilpin A., "Dictionary of Environment and Sustainable Development", Chichester, UK, 1996

Goeffrin A.M., quoted in Enache M., *Integrating GIS with DSS: a research agenda*, in proceedings to URISA 1994, URISA, Washington, 1994

Jaquet-Lagreze B., *Basic Concepts for Multicriteria Decision Support*, in Fandel G., Spronk J., "Multiple Criteria Decision Methods and Applications", Springer Berlin Heidelberg, 1985

Keenan P., *Using a GIS as a DSS Generator*, University College Dublin, http://mis.ucd.ie/staff/pkeenan/gis_as_a_dss.html, 1997

Klaassen L.H., *Economic and social projects with environmental repercussions: a shadow project approach*, in "Regional and Urban Economics", vol. 3, 1973

Kostka, D., Gesellschaftwissenschaftliche Grundlagen – Planungsmethoden, Institut für Landesplanung und Raumforschung, University of Hannover, Hannover 1998, available (08.99) at: http:// www.laum.uni-hannover.de(ilr/lehre/Ptm/Ptm_KoopMod.htm

Labreque E., *L'analyse multicritère et les systèmes d'information géographique (SIG) comme outils d'aide à la décision*, http://www.er.uqam.ca/nobel/m312204/texte/inter3.htm, Université du Québec à Montréal, 1998

Lichfield N., Kettle P, Whitbread M., *Evaluation in the Planning Process*, Pergamon Press, London, 1975

Maccobby, Maccobby, 1954 in Aiken, L.R., *Personality Assessment methods and practices*, 3rd revision, Hogrefe & Huber Publishers, Kirkland, 1999

Mandl P., *Räumliche Entscheidungsunterstützung mit GIS: Nutzwertanalyse und Fuzzy-Entscheidungsmodellierung*, in "AGIT'94 Tagungsband", Institut für Geographie der Universität Salzburg, Salzburg, 1994

Moser M., Andrae A., Smokers R., Böhner C., *Characterisation of Fleet Managers and their Demands in Relation with the Deployment of Alternative and Electric Driven Vehicles*, in proceedings to the "15th Electric Vehicle Symposium", Brussels, 1998

Munda, G., *Fuzzy Information in Multicriteria Environmental Evaluation Models*, EUR 15602 EN, Joint Research Centre of the European Commission, 1994

Nijkamp P., Reggiani, The economics of complex spatial systems, Elsevier, Amsterdam, 1998

Nijkamp P., Voogd H., *An informal introduction to multicriteria evaluation*, in Fandel G., Spronk J., "Multiple Criteria Decision Methods and Applications", Springer Berlin Heidelberg, 1985

Norberg-Schulz C., Esistenza Spazio e Architettura, Officina Edizioni, Roma, 1982

Norman D.A., *Some observations on mental models*, in Gentner, D., Stevens, A.L., "Mental Models", Lawrence Erlbaum Associates, Hillsdale, 1983

Paruccini M., *Decision Support Systems for environmental management*, EUR 14087, ECSC EEC-EAEC, Brussels-Luxembourg, 1992

Pumain D., Saint-Julien T., Cattan N., Rozenblat C., *The Statistical Concept of the Town in Europe*, EUROSTAT, Office for Official Publications of the European Communities, Luxembourg, 1992

Roy B, quoted in Jaquet-Lagreze B., *Basic Concepts for Multicriteria Decision Support*, in Fandel G., Spronk J., "Multiple Criteria Decision Methods and Applications", Springer Berlin Heidelberg, 1985

Roy B., *Methodologie multicritere d'aide a la decision*, Economica, Paris, 1985

Satti E.M., *Sociologia dello Spazio - Testi e Documenti*, promanuscritto, University of Florence, Florence 1991

Scheper W.J., *Group Decision Support Systems – An inquiry into theoretical and philosophical issues*, De Betuwe B.V., Beusichem, 1991

Scheper W.J., *Group Decision Support Systems – An Inquiry into theoretical and philosophical issues*, De Betuwe B.V., Beusichem, 1991

Seiler K., *Introduction to Systems Cost-Effectiveness*, Wiley, New York, 1968

Simcity Website, on-line in 2000, at: http://simcity.ea.com/us/guide/

Sprague, R.H., Watson H.J. editors, *Decision Support Systems – putting theory in practice*, second edition, p. 62, Prentice Hall International, London1989

Stone D.A., 1988, in Alberti M., Solera G., Tstsi V., *La citta' sostenibile - analisi, scenari e proposte per un'ecologia urbana in Europa*, Franco Angeli, Milan, 1994

Taylor, N, *Urban planning theory since 1945*, SAGE Publications, London, 1998

The Worldbank, *Identifying Stakeholders*, in "The World Bank Participation Sourcebook", 1998, http://www.worldbank.org/wbi/sourcebook/sb03.htm

Thierauf, R., User-oriented Decision Support Systems – Accent on Problem Finding, Prentice Hall, New Jersey, 1988

Turban, E., *Decision Support and Expert Systems: Management Support Systems*, p. 32, Macmillan Publishing Company, New York, 1988

U.S. Department of Energy, "The National Environmental Policy Act of 1969, as emended", Pub. L. 91190, 42 U.S.C. 4321-4347, January 1, 1970, as emended by Pub. L. 94-52j, July 3, 1975 and Pub. L. 94-83, August 9, 1975, http://ceq.eh.doe.gov/nepa/regs/nepa/nepaeqia.htm

UTOPIA project group, http://utopia.jrc.it , JRC-Ispra, 2000

Van Delft, A., Nijkamp, P., *Multi-criteria analysis and regional decision-making – Studies in applied regional science Vol. 8*, Martinus Nijhoff Social Science Division, Leiden, 1977

Van den Bergh, J.C.J.M., *Ecological Economics and sustainable development – Theory, methods and applications*, Edward Elgar, Cheltenham, 1996

Vincke P., *Multicriteria Decision-Aid a la decision*, John Wiley & Sons, Chichester, 1992;

Yardley-Matwiejczuk, K.M., *Role play – theory and practice*, Sage Publications, London, 1997

Zimmermann H.-J., *Fuzzy Sets, Decision Making, and Expert Systems*, Kluwer, Boston-Dortrecht-Lancaster, 1987

Zwisler, R., *Lösen komplexer Planungsaufgaben: eine experimentelle Untersuchung zum Strategieerwerb*, p. 27, Faculty of Psychology, University of Regensburg, Regensburg, 1998, http://www.zwisler.de/diplom/diplarb.html

APPENDIX I Models for system dynamics

Table I.1: Summary of assumptions and short introduction to the different models described by Betuglia et al. [1987].

LOCATION OF ECONOMIC ACTIVITIES AND COMODITY FLOWS	
Models of flows of a single or multiple commodity towards consumption	
Main assumptions	a) Existence at each point (or in each zone) of a net demand function (local consumption - local production) that depends exclusively on local prices; b) The market equilibrium where the benefit is maximised.
Principle	The city is divided into functional zones. The net demand in each zone includes in one function all intermediate and final consumption in that zone, both for the productive system and the consumer. The level of consumption is determined exclusively by the local price.
Consumer behaviour	The local price is the determinant factor for consumption.
Models of flows of goods towards production, and sectoral interdependencies	
Main News	a) Taking into account sectoral interdependence b) Spatial desegregation is taken into account subtracting transport costs from the total benefit.
Consumer behaviour	The local price is the determinant factor for consumption.
Models of commodity flows, location of economic activities and the employment market	
Main News	a) Manpower is an input factor for production b) Wages deriving from productive activities define user demand for products and services.
Consumer behaviour	The local price is the determinant factor for consumption. The wage for productive activities determines the consumer's demand.
LOCATION OF SERVICES AND JOURNEYS GENERATED BY THEIR USE	
Models considering location based on transport costs	
Main assumptions	a) Single preference indicator based on costs; b) Perfect rationality of decision-makers; c) No technological constraints; d) No plant costs.
Principle	An equilibrium has to be achieved where service suppliers maximise profits and users maximise utility.

Models considering location based on transport and plant costs	
Main News	Plant costs are considered.
Models considering location with technological constraints	
Main News	Technical constraints are considered, solving the location-allocation problem.
Models considering location with multiple objectives	
Main News	The consumer objectives are represented by an objective function permitting us to consider even conflicting objectives (e.g. Multi-criteria models).
RESIDENTIAL LOCATION AND JOURNEYS TO WORK	
Main assumptions	a) Different households are each homogeneous with the utility functions; b) Each household has as certain level of utility and is willing to pay a price for housing consistent with this expected level of utility; c) Competition between households modifies the level of utility so that all housing is allocated (housing market in state of perfect competition).
Principle	Spatial equilibrium of the city from a competitive market for urban land with major emphasis on effects of trade-off between accessibility and space.
RESIDENTIAL LOCATION AND TRANSPORT IN THE URBAN SYSTEM	
Principle	The city is a system made up of a set of sub-systems all interacting with each other through spatial and socio-economic interrelationships.
URBAN FORM AND TRANSPORT	
Principle	Location behaviour of socio-economic activities determines the urban form as a function of the given transport network. The transport network is structured as a function of a certain pattern of socio-economic activities.
Models considering spatial structure and transport	
New Urban Economics approach	

Main assumptions	a) The consumer's level of consumption is limited by a given income; b) The consumer maximises the utility associated with the goods and services to be consumed; c) Utility is defined by: - quantity of consumption goods produced in the city and available in the specific location; - residential services offered in the location by housing suppliers; - unit prices; - transport costs associated with location. d) The urban space is continuous and uniform.
Principle	An equilibrium has to be achieved where all individuals with the same income and same preferences have the same level of utility in different locations.
Urban Form	a) The whole city is constructed at a given moment in time and subsequently is not subject to any change (Instant city); b) The adjustment costs of the land-use pattern are nil, so that at each time interval the spatial structure coincides with the static equilibrium spatial structure at that time (malleable city); c) The short-term land-use pattern in an urban area is rigid, but in the long-term the spatial structure of the city tends to become that predicted by the model (long-run equilibrium city).
Developments	- Spatial differentiation is taken into account in some applications (e.g. poles and environmental quality may impact on the utility function) - **Time** dimension has been implemented, mainly researching impacts of changes of variables in the quality function in time, recognizing that the **urban system is dynamic**.
Functionalist approach	
Urban Form	Result of a set of interactions of goods and people occurring in an urban space which is essentially a function of the interdependence observable in the spatial distribution of activities. Drawing a map of the (potential) accessibilities, given by the interactions of an urban area, that can be interpreted as a representation of its spatial structure.
Developments	- **Time** dimension has been implemented, recognising that the **urban system is dynamic**.
FUTURE DEVELOPMENTS	

- Analysis of externalities;
- Global approach, taking into account the interactions between sub-models;
- Dynamic analysis;
- Taking into account the dynamic aspects of systems analysis in other disciplines (biology, ecology, chemistry, etc.);
- Alternative economic approaches;
- Operational aspects.

APPENDIX II Literature

Author	Title	Year	Editor / URL	City / Institution	Index No	Type	Keywords
A.A.V.V.	International Series on Applied Systems Analysis	1977	Wiley	London			Software development, DSS
A.A.V.V.	The World Bank Participation Sourcebook	1998	http://www.worldbank.org/wbi/sourcebook/sb03.htm	World Bank			Stakeholders, participatory research
A.A.V.V.	Proceedings of the European Commission (Environment and Climate Programme) Advanced Study Course	1997	European Commission (Environment and Climate Programme)	Delft			Environmental Policy
A.A.V.V.	User workshops to define the requirements of town/city local government departments - Final Report	1997	The European Community Joint Research Centre Space Application Institute	Ispra			Urban stakeholders, Indicators
Aifandopoulou, G., Nathanail, T., Panayotakopoulos, D.	ETIS: A GIS technology based tool for supporting strategic environmentally friendly planning of urban transport infrastructure development	on-line in 1997	http://sheroid.otago.ac.nz:808/esriproc/proc95/to250/p237.html	-	-	WWW on-line document	Urban Transport
Aiken, L.R.	Questionnaires and inventories – surveying opinions and assessing personality	1998	John Wiley & Sons	New York			Assessment Methods

Aiken, L.R.	Personality assessment – 3rd edition	1999	Hogrefe & Huber Publishers	Kirkland			Assessment Methods
AIS	Proceedings to "Second Americas Conference on Information Systems"	1996	http://hsb.baylor.edu/ramsower/ais.ac.96/papers/	Phoenix			
Alberti, M., Solera, G., Tstsi, V.	La citta' sostenibile - analisi, scenari e proposte per un'ecologia urbana in Europa	1994	Franco Angeli	Milan			Urban environment, ecology, scenarios
Allen, P.M.	Cities and regions as self-organizing systems - models of complexity	1997	Gordon and Breach Science Publishers	Amsterdam			Urban systems, Regional systems
Anthony, R. N.	Planning and Control Systems: A Framework for Analysis	1965	Harvard University Graduate School of Business Administration	Boston			
Batty, M., Densham, P.J.	Decision support, GIS, and urban planning	1996	http://www.geog.ucl.ac.uk/~pdensham/s_t_paper.html	London			Urban planning, Instruments, DSS
Bauer, P., Nouak, S., Winkler, R.	A brief course in Fuzzy Logic and Fuzzy Control	1996	http://www.flll.uni-linz.ac.at/fuzzy/fuzzy.html	University of Linz	-	WWW site	MCDA

Bender, M.J.	Collaborative Planning Support System	1996	http://www.ce.umanitoba.ca/~mike/cpss.html	University of Manitoba, Department of Civil & Geological Engineering	-	WWW on-line document	MCDA
Bender, M.J.	Fuzzy Compromise Programming	1996	http://www.ce.umanitoba.ca/~mike/cpss.html	University of Manitoba, Department of Civil & Geological Engineering	-	WWW on-line document	MCDA
Betuglia, C.S., Leonardi, G., Occelli, S., Rabino, G.A., Tadei, R., Wilson, A.G.	Urban Systems: Contemporary approaches to modelling	1987	Croom Helm	New York			Urban System
Braun, G., Heymann, TH.	Principles of Urban System Development	1993	http://gauss.geog.fu-berlin.de/~hcwinter/TEAS/TEASmetar.html	Geographisches Institut der FU Berlin	Empirische, Theoretische und Angewandte Regionalforschung, Band 25	booklet	Urban System
Breuste, J.	Stadtökologie und Stadtentwicklung: Das Beispiel Leipzig	1996	Analytica	Berlin			Urban environment, Case study
Camagni, R., Capello, R., Nijkamp, P.	Sustainable City Policy: Economic, Environmental, Technological	1995	Tinbergen Institute	Amsterdam.			Urban policy

Castells, N.	International Environmental Agreements	1999	Joint Research Centre of the European Commission	Ispra	PhD thesis at Free University of Amsterdam		Environmental Policy
Cetica, P.A.	Progettazione Ambientale	1994	text to the lecture at Florence University	Florence			Urban ecological planning
Cadwallader, M.	Urban Geography: An Analytical Approach, 1/e	1996	http://www.prenhall.com/	Prentice Hall (catalogue)		Book, with on-line literature indication	Urban System
Commission of the European Communities	Ammended proposal for a Council Directive amending Council Directive 85/337/EEC	1995	http://apollo.cordis.lu/	Commission of the European Communities	COM(95)720	Directive, with on-line abstract	Policy, Urban System, Environment
Commission of the European Communities	Communication from the Commission. The future development of the Common Transport Policy. A global approach to the construction of a Community framework for sustainable mobility	1992	http://www.cordis.lu/	Commission of the European Communities	COM(92)494 (*)	Communication, with on-line abstract	Policy , Transport, Urban Transport
Commission of the European Communities	Community action plan to assist tourism	1992	http://www.cordis.lu/	Commission of the European Communities	1992 - Official Journal L231/26 (*)	Tender, with on-line abstract	Policy, Urban System
Commission of the European	Community programme for policy and action in relation with	1993	http://www.cordis.lu/	Commission of the European	1993 - Official Journal	Legislation, with on-line	Policy, Transport,

Communities	the environment and sustainable development			Communities		abstract	
Commission of the European Communities	Cost-effectiveness of measures to reduce road transport emissions	1997	http://apollo.cordis.lu/	Commission of the European Communities	1997 - Official Journal S72/p.38	Tender, with on-line abstract	Transport, Environment
Commission of the European Communities	Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment	1985	-	Commission of the European Communities	85/337/EEC;	Council Directive	Policy, Urban System, Environment
Commission of the European Communities	Europe's cities - Community measures in urban areas	1992	http://www.cordis.lu/	Office for Official Publications of the European Communities	ISBN 92-828-0286-8	Publication, with on-line abstract	Policy, Urban System
Commission of the European Communities	Fifth Framework Focus - Priorities for community research and development	1997	http://www.cordis.lu/fifth/src/eea.htm	Commission of the European Communities	-	On-line document	Policy, Urban System
Commission of the European Communities	Green Paper on the impact of transport on the environment. A Community strategy for "sustainable mobility"	1992	http://www.cordis.lu/	Commission of the European Communities	COM(92)46 (*)	Communication, with on-line abstract	Policy, Transport, Urban Transport
Commission of the European Communities	Green Paper on the urban environment. Communication from the Commission to the Council and Parliament	1990	http://www.cordis.lu/	Commission of the European Communities	COM(90)218; EUR 12902 IT	Communication, with on-line abstract	Policy, Urban System

Commission of the European Communities	Indicators for sustainable urban development – Proceedings of the European Commission (Environment and Climate Programme) Advanced Study Course	1997	Commission of the European Communities - Environment and Climate Programme	Delft			Urban Environment, Indicators
Commission of the European Communities	Mobile sources of Air Pollution in Urban Areas	1997	http://apollo.cordis.lu/	CITAIR research group	-	On-line abstract	Urban System, Environment
Commission of the European Communities	Models for Transport Environment and Energy - version 2 Strategic Transport Policy Analysis	1996	http://apollo.cordis.lu/	Commission of the European Communities	-	On-line abstract	Transport, Modelling, Policy
Commission of the European Communities	Passenger Transport	1996	http://apollo.cordis.lu/	Commission of the European Communities	-	On-line abstract	Transport
Commission of the European Communities	Rational use of energy in transport	1990	http://apollo.cordis.lu/	E.N.E.A., Rome, Italy	-	On-line abstract	Transport, Transport Systems
Commission of the European Communities	The method of fuzzy scenarios: principle and application to the future of congestion in urban centres	1996	http://apollo.cordis.lu/	Commission of the European Communities	EUR 16444	Report, with on-line abstract	Urban System, Urban Transport, DSS, MCDA
Commission of the European Communities	Towards an urban agenda for the European Union	1997	http://apollo.cordis.lu/	Commission of the European Communities	COM(97)197;	Communication, with on-line abstract	Policy, Urban System

Commission of the European Communities	Transport research APAS Urban transport: Effectiveness of measures influencing the levels of public transport use in urban areas	1996	http://apollo.cordis.lu/	Commission of the European Communities	EN (1996)	Final report, with on-line abstract	Urban Transport
Commission of the European Communities, DGVII	EC Directorate General for Transport 4th Framework Programme – Section 5: Urban Transport	on-line 1997	http://indis.msu.ru/ftp/cordis/transport/transport_work/A0071ENH.HTM	Commission of the European Communities, DGVII	-	On-line document	Policy, Urban Transport
Commission of the European Communities	Environmental Assessment – EIA legal context	2000	http://europa.eu.int/comm/environment/eia/eia-legalcontext.htm				Environmental Policy
Commission of the European Communities, DGXII	City Action RDT Programme - Towards a better liveable city - background paper	1994	-	Commission of the European Communities, DGXII	DGXII/A/3 fast, ULB/rev		Policy, Urban System
Comte, S.	Response to automatic speed control in urban areas: a simulator study	1996	http://portico.bl.uk/	The British Library - Portico service	DSC:9350.140(LU-ITS-WP--477)	Book, with on-line literature indication	Urban Transport
Czyzak, P., Zak, J.	A Model of an Urban Transportation System Formulated as a ...	1995	http://uncweb.carl.org/	UnCoverWeb database	43 (Journal of advanced transportation, Vol 29, no.1)	Journal Info, with on-line literature indication	Urban Transport, DSS

Deysher, B., Gagliardi, M., Jacobs, M., Lyons, W., Salvucci, F.	Review of the Transportation Planning Process in the Chicago Metro Area	1993	http://www.bts.gov/smart/cat/chi.html	U.S. Department of Transportation, National Transportation Library	RSPA/VNTSC-SS-TM392-02	WWW on-line document	Urban Transport
Douven, W.	Improving the accessibility of spatial information for environmental management - An application to pesticide risk management	1996	PhD publication, Free University of Amsterdam	Amsterdam			Information technology
Dutch Ministry of Transport, Public Works and Water Management	European Conference on Mobility Management	1997	http://apollo.cordis.lu/	Dutch Ministry of Transport, Public Works and Water Management	ECOMM	Event, with on-line abstract	Transport
European Commission	4th framework Programme of the European Community activities in the field of research and technological development and demonstration - Urban Transport	on line 1997	http://indis.msu.ru/ftp/Cordis/transport/transport_work/A0071ENH.HTM#sec5	European Commission (CORDIS service)	-	WWW on-line document	Policy
European Commission	Second Session of the European Competitions - living in the city; re-interpretation of urban sites	on line 1997	http://www.cordis.lu/	European Commission (CORDIS service)		WWW on-line document	Policy
Facchetti, S., Bandirali, A., Paruccini, M.	La protezione civile – Lezioni di una scuola residenziale	1996	Joint Research Centre of the European Commission	Ispra	EUR 16473 IT		DSS, assessement methods, decision processes

Fandel, G., Spronk, J.	Multiple Criteria Decision Methods and Applications	1985	Springer	Berlin			MCDA
Fedra, K., Reitsma, R.F.	Decision Support and Geographical Information Systems	1990	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	RR-90-009	Research Report	DSS
Ferreira, L.J.A.	Modelling Urban Fuel Consumption	1984	http://www.aelmg.adelaide.edu.au/civeng/research/resreport.html	University of Adelaide, Faculty of Engineering, Department of Civil and Environmental Engineering	R67	-	Urban Transport, Transport System
Frieling, D.H.	Designs originate in people	1985	Rijksdienst voor de Ijsselmeerpolders				Stakeholders
Frieling, D.H.	Het metropolitane debat	1998	Thoth	Bussum			Urban context
Gentner, D., Stevens, A.L.	Mental Models	1983	Lawrence Erlbaum	Hillsdale			Conceptual modelling
Grueble, A., Nakicenovic, N., Schaefer, A.	Dynamics of Transport and Energy Systems. History of Development and a Scenario for the Future	1993	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	RR-93-019	Research Report, reprinted in *Energy and Life* World Energy Council, 15th Congress	Transport System

Gruebler, A.	The Transportation Sector: Growing Demand and Emissions	1994	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	RR-94-005	Research Report, in *Pacific and Asian Journal of Energy*, Vol.3, no.2	Transport
Holden, D. J.	Wardrop's Third Principle, Urban Traffic Congestion and Traffic Policy	1989	http://uncweb.carl.org/	UnCoverWeb database	239 (Journal of transport economics and policy, Vol. 23 no. 3)	Journal Info, with on-line summary and literature indication	Policy, Urban Transport
Horridge, M.	A Computable General Equilibrium Model of Urban Transport Demands.	1994	http://uncweb.carl.org/	UnCoverWeb database	427 (Journal of policy modeling, Vol. 16, no. 4)	Journal Info, with on-line literature indication	Urban Transport
Institute for Prospective Technological Studies	IPTS Report - Focus on "Urban Mobility"	1997	http://apollo.cordis.lu/	Institute for Prospective Technological Studies	The IPTS Report No. 11, Feb. 1997 - Urban Mobility Special Issue	Publication, with on-line abstract	Policy, Urban Transport
Kaplan, P., Gallegos, D.	Framework for Environmental Decision Support	on-line in 1997	http://www.nwer.sandia.gov/coalition/framework.html	-	-	WWW on-line document	DSS, Environment

Khattab, M.E., Samy, E.G.	A decision making model for the urban transportation system.	1991	http://uncweb.carl.org/	UnCoverWeb database	513 (Computers & industrial engineering. Vol. 21, no. 1 / 4)	Journal Info, with on-line literature indication	Urban Transport, DSS
Keenan, P.	Using a GIS as a DSS Generator	1997	http://mis.ucd.ie/staff/pkeenan/gis_as_a_dss.html	University College Dublin			DSS generators
Kostka, D.	Gesellschaftwissenschaftliche Grundlagen – Planungsmethoden, Institut für Landesplanung und Raumforschung	1998	http://www.laum.uni-hannover.de(ilr/lehre/Ptm/Ptm_KoopMod.htm	University of Hannover			Urban planning, Decision process, Assessment methods
Labreque, E.	L'analyse multicritère et les systèmes d'information géographique (SIG) comme outils d'aide à la décision	1998	http://www.er.uqam.ca/nobel/m312204/texte/inter3.htm	Université du Québec à Montréal			MCA, DSS application
Lambin, E., Wilmet, J.	Development of a system for monitoring urban environmental quality	1997	http://ewse.ceo.org/	European Wide Service Exchange (EWSE) - Entre for Earth Observation Project (CEO)	demonstration Case study (660492)	WWW on-line document	Urban System

Libbe, J.	Stadtökologische Forschung und Wissenstransfer: Die Perspektive der Kommunen	1999	Berlin	Analytica	in: Friedrichs, J., Hollaender, K., *Anwendungen Stadtökologischer Forschung* . *Reihe Stadtökologie*, Band 6		Urban Environment, stakeholder
Lichfield, N., Kettle, P., Whitbread, M.	Evaluation in the Planning Process	1975	Pergamon Press	London			Planning Process
Mausseau, V.	Analyse et classification de la littérature traitant de l'importance relative des critères en aide multicritère a la décision	1992	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	RAIRO / Operations Research, Vol. 26, no. 4	Paper, with on-line summary	MCDA
Mausseau, V.	Are judgements about relative importance of criteria dependent or independent of the set of potential alternatives? An experimental approach.	1992	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	Cahier du Lamsade no. 111, Université Paris Dauphine	Booklet, with on-line summary	MCDA
Mausseau, V.	Compensatoriness of preferences in matching and choice	1994	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	Cahier du Lamsade no. 12, Université Paris Dauphine	Booklet, with on-line summary	MCDA, DSS

Moore, J.A., Johnson, J.M.	Transportation, Land Use and Sustainability	1994	http://policy.rutgers.edu/cupr/CUPReport81/taxing.htm	University of South Florida, Florida Center for Community Design + Research, Center for Urban Transportation Research (CUTR)	-	WWW site	Transport
Moser, M., Andrae, A., Smokers, R., Böhner, C.	Characterisation of Fleet Managers and their Demands in Relation with the Deployment of Alternative and Electric Driven Vehicles	1998	in proceedings to the "15th Electric Vehicle Symposium", EVS-15	Brussels			User assessment, Case study
Mousseau, V.	Eliciting information concerning the relative importance of criteria	1995	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	Cahier du Lamsade no. 126, Université Paris Dauphine ;	Booklet, with on-line summary	MCDA
Mousseau, V.	Problèmes lies a l'évaluation de l'importance relative des critères en aide multicritère a la décision: Réflexions théoriques, expérimentations et implémentations informatiques.	1993	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	-	Thesis, with on-line summary	MCDA
Munda, G.	Multicriteria Evaluation in a Fuzzy Environment: Theory and Applications in Ecological Economics	1995	Physica Verlag	Heidelberg			MCDA

Munda, G.	Fuzzy Information in Multicriteria Environmental Evaluation Models	1994	Joint Research Centre of the European Commission		EUR 15602 EN		MCDA, evaluation methods
Musters, C.J.M., de Graaf, H.J., ter Keurs, W.J.	Defining socio-environmental systems for sustainable development	1998		in 'Ecological Economics 26' – Elsevier Science			Environment, Indicators
Nijkamp, P., Perrels, A.	Sustainable cities in Europe – A comparative analysis of urban energy-environmental policies	1994	Earthscan Publications	London			Urban environment, Policy
Nijkamp, P., Priemus, H.	Access and capacity of European infrastructure networks	1992	Vrije Universiteit Amsterdam, Faculteit der Economische Wetenschappen en Econometrie				Transports, European transport policy
Norberg-Schulz, C.	Esistenza Spazio e Architettura	1982	Officina Edizioni	Rome			Architecture
Oliver, C.D., Twery, M., Scott, J.M., Cohler, T.	Decision Support Systems/Models And Analyses (ST-28)	1995	http://www.fs.fed.us/eco/St.28.htm	-	-	WWW on-line document (draft)	DSS
Paden, R.	Urban planning and multiple preference schedules: On R.M. Hare's 'Contrasting methods in environmental planning'	1999	Fairfax	Departement of Philosophy and Religious Studies – George Mason University			MCA, Urban environmental planning

Papacostas, C. S., Prevedouros, P.D.	Transportation Engineering And Planning, 2/e	1992	http://www.prenhall.com/	Prentice Hall (catalogue)		Book, with on-line literature indication	Transport
Paruccini, M.	Decision Support Systems for environmental management	1992	Office for Publication of the European Commission	Luxembourg	EUR 14087		DSS, Environmental management
Pumain, D., Saint-Julien, T., Cattan, N., Rozenblat, C.	The Statistical Concept of the Town in Europe	1992	EUROSTAT, Office for Official Publications of the European Communities	Luxembourg			Urban statistics
Radautsan, S., Parissakis, G.	Scientific and Technological Achievements Related to the Development of European Cities	1997	http://www.wkap.nl/kapis/CGI-BIN/WORLD/kaphtml.htm?HOMEPAGE	Kluwer Academic Publishers (catalogue)		Book, with on-line literature indication	Urban System
Rho, J.H.K., Tschangcho, J.	Solving a Three-Dimensional Urban Activity Model of Land Use Intensity and Transport Congestion.	1989	http://uncweb.carl.org/	UnCoverWeb database	595 (Journal of regional science, Vol 29, no. 4)	Journal Info, with on-line literature indication	Urban Transport, MCDA
Roy, B., Mausseau, V.	A theoretical framework for analysing the notion of relative importance in criteria	1995	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	Cahier du Lamsade no. 131, Université Paris Dauphine ;	Booklet, with on-line summary	DSS, MCDA

Roy, B., Mausseau, V.	Prise en compte formelle de la notion d'importance relative des critères en aide multicritère a la décision	1992	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	Cahier du CERO, Vol. 34	Booklet, with on-line summary	MCDA
Roy, B.	Méthodologie multicritère d'aide a la decision	1985	Economica	Paris			MCDA
Roy, B., Mausseau, V., et alii.	Aide multicritère a la décision, bases axiomatiques, conceptuelles et procedurales	on line 1997	http://lamsade.lamsade.dauphine.fr/mcda/meda-papers.html	Université Paris-Dauphine	-	WWW site	MCDA
Salomon, I., Bovy, P., Orfeuil,J-P.	A Billion Trips a Day - Tradition and Transition in European Travel Patterns	1993	http://www.wkap.nl/kapis/CGI-BIN/WORLD/kaphtml.htm?HOMEPAGE	Kluwer Academic Publishers (catalogue)		Book, with on-line literature indication	Transport
Satti, E.M.	Sociologia dello Spazio - Testi e Documenti, promanuscritto	1991	University of Florence	Florence			Urban Sociology
Sassen, S.	Cities in a World Economy	2000	Pine Forge Press	Thousand Oaks, USA			Urban economy, urban policy
Sawaragi, Y., Nakamori, Y.	"Shinyakana" Systems Approach in Developing an Urban Environment Simulator	1989	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	WP-89-008	Working Paper	Urban System
Schaefer, A.	Carbon Emissions in the Passenger Transport Sector; Technology and Alternative Fuels	1992	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	WP-92-004	Working Paper	Environment

Scheper, W.J.	Group Decision Support Systems – An inquiry into theoretical and philosophical issues	1991	De Betuwe	Beusichem			DSS, GDSS, user acceptance
Schlange, L.E. et alii	Systems Thinking Practice	1997	http://www.unisg.ch/%7esgzz/links/stp/	St. Gall Centre for Futures Research (SGZZ)	-	Web site	DSS, MCDA
Schreiber, A.F., Gatons, P.K., Clemmer, R.B. editors	Economics of urban problems; selected readings	1971	http://lcweb.loc.gov/z3950/	Library of Congress (catalogue);	LC Call No.: HT123 .S35	Journal Info, with on-line literature indication	Urban System
Seiler, K.	Introduction to Systems Cost-Effectiveness	1968	Wiley	New York			Software development
Smith, L.G.	Impact Assessment and sustainable resource management	1993	Longman scientific & technical	London			Assessment methods
Southworth, F.	A Technical Review of Urban Land Use - Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies	1995	http://www.bts.gov/smart/cat/chi.html	U.S. Department of Transportation, National Transportation Library	ORNL-6881	WWW on-line document	Urban Transport
Sprague, R.H., Watson H.J. editors	Decision Support Systems – putting theory in practice, second edition	1989	Prentice Hall International	London			DSS, software implementation
Strobel, H.	Computer Controlled Urban Transportation: A Survey of	1982	http://www.iiasa.ac.at/Publications/	International Institute for Applied	BK-82-110;	Book	Urban Transport

	Concepts, Methods, and International Experiences			Systems Analysis			
Strobel, H.	Traffic Control Systems Analysis by Means of Dynamic State and Input/Output Models	1977	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	RR-77-012	Research Report	Transport
Strobel, H.	Transportation, Automation and the Quality of Urban Living	1975	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	RR-75-034	Research Report	Urban Transport
Sui, D.Z.	GIS-based urban modelling: practices, problems, and prospects	1998	in: 'International Journal of Geographical Information Science' Vol 12, No. 7	Departement of Geography, Texas			Urban Model
Taylor, N.	Urban planning theory since 1945	1998	Sage Publications	London			Urban history
Thierauf, R.	User-oriented Decision Support Systems – Accent on Problem Finding	1988	Prentice Hall	New Jersey			DSS, End-user orientation, System development
Tschangho, J. K., Jeong, H. R., Sunduck, S.	Integrated Urban Systems Modeling: Theory and Applications	1989	http://www.wkap.nl/kapis/CGI-BIN/WORLD/kaphtml.htm?HOMEPAGE	Kluwer Academic Publishers (catalogue)		Book, with on-line literature indication	Urban System, Modelling
Tolley, R. editor	The Greening of Urban	1993	ftp://ftp.cordis.lu/p	Commission of the	Transport RTD	WWW down-	Policy, Urban

	Transport: Planning for Walking and Cycling		ub/ECDOCDEL/transport/transport_urban/B0529ENP.DOC	European Communities	work programme - Urban transport	load document	Transport
Turban, E.	Decision Support and Expert Systems: Management Support Systems	1988	Macmillan	New York			DSS, Software development, Decision theory
United States Government	The National Environmental Policy Act of 1969, as emended”, Pub. L. 91190, 42 U.S.C. 4321-4347, January 1, 1970, as emended by Pub. L. 94-52j, July 3, 1975 and Pub. L. 94-83, August 9, 1975	1975	http://ceq.eh.doe.gov/nepa/regs/nepa/nepaeqia.htm				Environmental policy
Universität Salzburg	AGIT'94 Tagungsband	1994	Institut für Geographie der Universität Salzburg	Salzburg			Information Technology
Van den Bergh, J.C.J.M.	Ecological economics and sustainable development	1996	Edward Elgar	Cheltenham			Economics, Environment
van Delft, A., Nijkamp, P.	Multi-criteria analysis and regional decision-making – Studies in applied regional science Vol. 8	1977	Matinus Nijhoff Social Science Division	Leiden			MCA, Regional policy making
Varian, H.R.	Microeconomia	1990	Cafoscariana	Venezia			Economy

Vincke, P.	Multicriteria Decision-Aid a la decision	1992	Wiley	Chichester			MCDA
Voigt, A., Bröthaler, J., Riedl, L., Schrenk, M.	Integration von EDV in die Raumplanerausbildung in Wien	1998	http://www.isw.de/cap98/schrenk.html	Wien	TU Wien, Institut für Finanzwissenschaft und Infrastrukturpolitik		Stakeholder training
Warner, R.F., Yeo, M.F.	Urban Transport Management (UTM) and Energy Consumption – a review of evidence	1983	http://www.aelmg.adelaide.edu.au/civeng/research/resreport.html	University of Adelaide, Faculty of Engineering, Department of Civil and Environmental Engineering	R61	-	Urban Transport
Washington, Highway Research Board, National Research Council	New transportation systems and concepts; 12 reports	1971	http://lcweb.loc.gov/z3950/	Library of Congress (catalogue)	LC Call No.: TE7 .H5 no. 367 HE191	Journal Info, with on-line literature indication	Transport System
Wilson, A.G.	Transport and the Evolution of Urban Spatial Structure	1984	http://www.iiasa.ac.at/Publications/	International Institute for Applied Systems Analysis	CP-84-041	Collaborative Paper	Urban Transport
Yardley-Matwiejczuk, K.M.	Role play – theory and practice	1997	Sage publications	London			Assessment Methods
Zegras, C.	Modeling Urban Transportation		http://www.transpo	The Transport Web –	-	WWW on-	Urban

	Energy & Emissions: Lessons for the Developing World		rtweb.com/publish.html	Internet Information for Transport		line document	Transport
Zimmermann, H.-J.	Fuzzy Sets, Decision Making, and Expert Systems	1987	Kluwer	Boston			DSS, evaluation methods
Zwisler, R.	Lösen komplexer Planungsaufgaben: Eine experimentelle Untersuchung zum Strategieerwerb	1998	http://www.zwisler.de/diplom/diplomarb.html	Diploma at University of Regensburg, Faculty of Psychology			Assessment methods, Planning process