

**Procedures for Recommending Optimal Sustainable  
Planning of European City Transport Systems**

## **Developing Sustainable Land Use and Transport Strategies**

# **A Methodological Guidebook**

### **Deliverable 14 of PROSPECTS**

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**ENERGY, ENVIRONMENT  
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# A Methodological Guidebook

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# Preface

PROSPECTS (Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems) is a project funded under the European Commission's Energy, Environment and Sustainable Development Programme. It is designed to provide cities with the guidance they need in order to generate optimal land use and transport strategies to meet the challenge of sustainability in their particular circumstances. A set of three guidebooks sums up this guidance. The Decision-Makers' Guidebook covers the basic issues in only 50 pages. The Methodological Guidebook (this volume) is designed to support the Decision-Makers' Guidebook. It follows the same logical structure of planning but treats some of the issues in considerably more detail. Its audience will be the professionals who carry out the job. The third guidebook, the Policy Guidebook, brings up to date experience on a wide range of land use and transport policy instruments that might be used to achieve the objective of urban sustainability.

More information on PROSPECTS and the other guidebooks can be had from the PROSPECTS home page, <http://www-ivv.tuwien.ac.at/projects/prospects.html>. The PROSPECTS consortium is led by ITS, University of Leeds (Great Britain) and includes the partners TUW (Austria), TØI (Norway), KTH (Sweden), UPM (Spain) and VTT (Finland).

The PROSPECTS project has also been supported by national governments and agencies, including the UK Department for Transport, the Ministry of Transport and Communications and the Road Administration of Norway, and others. We are grateful to all these for their support.

We want to thank all who contributed their advice and comments to various drafts of this guidebook. We welcome comments from readers of the current version. Comments can be posted on our home page.

Leeds and Oslo, January 2003

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# Summary and recommendations

The Methodological Guidebook is aimed at practitioners. Building on the logical structure set out in the Decision-Making Guidebook, it presents a coherent but flexible general approach to planning for a sustainable urban land use/transport system (Chapters 1-2), then goes on to offer methods of carrying out the steps of that logical structure (Chapters 3-7). To be useful in a variety of circumstances, it offers a choice of methods and approaches, all compatible with general rules of good planning and with the overarching sustainability objective. Particular emphasis, however, is on a new logical method of appraising land use/transport strategies with respect to sustainability (Chapter 3), and on optimising with respect to sustainability (Chapter 7). Even if in the end, the planner will have to apply methods prescribed to her by national rules and regulations, we are confident that there will be ideas to be picked up from this part of the book.

For each of the objectives set out in the Decision-makers' Guidebook, performance indicators will have to be devised. The Methodological Guidebook suggests such indicators (Chapter 3) and how to present them (Chapter 4). Chapters 8-16 provides detailed advice on how to compute them, including the elements of cost benefit analysis, equity indicators and environmental and accident indicators. Thus a large part of the book is concerned with performance indicators.

The art of strategy formulation (combining policy instruments to achieve good results with respect to all objectives) is still in its infancy. However, Chapter 5 of the Methodological Guidebook takes us a little further. Advice on the use of models to predict impacts is given in Chapter 6.

The new opportunities for visualisation of model results provided by GIS can only be exploited to the full if one respects simple rules for effective visual communication. This is the topic of Chapter 17. Chapter 18 treats the subject of optimisation algorithms.

Finally, Chapter 19 provides experience, taken from PROSPECTS case studies, with many of these methods in use.

Given that the Methodological Guidebook sees the planning process from the viewpoint of the planner, the analytical stages of the process are covered in detail, while planning context and the higher-level decisions are often covered in more detail in the Decision-Makers' Guidebook. Thus at various such points, the planner may want to consult the Decision-Makers' Guidebook. The relationship between the Methodological Guidebook and the third of the PROSPECTS guidebooks, the Policy Guidebook, is rather different. Policy instruments are given a very rudimentary treatment in the Methodological Guidebook, which means that the reader will in all cases need to consult the Policy Guidebook (KonSULT 2003) to learn more about instruments. That way, the interactive Policy Guidebook can reach an audience that has something to contribute back. Too little is still known about the impacts of even the most common instruments, like road building. We therefore invite all planners to contribute their experience to the Policy Guidebook, whether it is experience from modelling tests or from monitoring actual implementation.

The overall message that can be distilled from the Methodological Guidebook is that there are indeed numerous ways of improving the analytical parts of the process of

planning for sustainability. These methods are useful regardless of whether the city adopts the plan-led, consensus-led or vision-led approach to planning, or some combination of these.

Some of the key messages and recommendations of this guidebook are:

- Define the overarching objective of the plan. We suggest that sustainability should be the overarching objective, define what we mean by a sustainable land use and transport system and show that this concept can be made operational.
- All the objectives that legitimately belong under the sustainability objective must be clearly defined. We suggest seven such objectives: economic efficiency, liveable streets and neighbourhoods, protection of the environment, equity and social inclusion, safety, contribution to economic growth and intergenerational equity.
- Simple performance indicators covering (almost) all objectives can be devised, so that all of the objectives legitimately belonging under sustainability may be taken into account in appraisal and evaluation.
- Assumptions on economic growth, population growth, national policy, vehicle technology development and car ownership in a number of possible “futures” must be very worked out and assembled to a small number of scenarios that span a reasonable range of uncertainty. These assumptions are vital to the selection of strategies and the level of achievement of the objectives that can be obtained.
- Utilise all existing and emerging knowledge in selecting policy instruments to be tested and combining them into strategies in efficient ways.
- A range of types of model is available to test the strategies. Models should include the important links between transport, land use and the environment. Simple sketch planning models, also including the transport/land use link, will be useful at exploratory stages and for cities who for the moment lack the capability to develop a large scale integrated land use/transport model.
- A comprehensive appraisal of the sustainability of strategies, using the full set of objectives and their performance indicators, and based on the output of the models, is shown to be feasible and not overly complex. Some of the indicators are joined together to form an objective function, while targets are set for others. Intergenerational equity is achieved by setting targets for the environmental and social indicators at the end of the period, and by giving more weight in the objective function to the net economic benefits at the end of the period than what is done in ordinary cost benefit analysis.
- Constrained optimisation and other innovative methods are available to discover new strategies that perform well with respect to all objectives, and to study trade-offs between the objectives and between the policy instruments.
- We believe that this approach and these methods are well suited for interaction with decision-makers and the public. In fact, they require extensive consultations and dialogue with all concerned parties about objectives, scenarios, policy instruments and lessons from the tests.

Most of our suggested methods were tested in the PROSPECTS case studies (Shepherd et al 2003). These tests confirmed the usefulness and workability of our ideas. In particular, it proved quite feasible to optimise dynamic (or rather quasi-dynamic) strategies where policy instruments are applied at different levels as the land use and transport system develops. The basic tenets of our appraisal framework worked well. This broad approach to appraisal, combining many objectives and using

a mixture of an objective function and target setting, will in general produce “greener” and more intuitively sustainable best strategies. However, the following qualifications must be made:

- The indicator of liveable streets and neighbourhoods is still experimental and has not been tested sufficiently.
- Too little is still known about how land use and transport strategies affect economic growth. This situation is not likely to change much soon.
- Much more experimentation is needed to get familiar with the equity indicators, to set parameters in them to reflect decision-makers’ preferences and to choose the equity indicators that are the most important in each case.
- More research is needed on into the art of building simplified models (sketch planning models) and calibrating them to fit the circumstances of each particular city.
- In one of our test cities, our proposed method of computing user benefits seemed to work less well, and the reasons for this are being looked into.
- Optimisation with respect to dynamic strategies (strategies that change over the years) does raise a host of new questions, for instance about how financial constraints, environmental targets for the end of the appraisal period, technological change and the weight given to the welfare of future generations interact. Some of these interactions may cause problems in optimisation.

The user of the guidebook might want to join us in experimenting and further research in these areas, or she might want to apply our general approach without the more experimental tenets. In any case, her experiences will add to existing knowledge on how to combine policy instruments to achieve the complex goal of urban sustainability. The KonSULT knowledgebase aims at collecting and synthesising this knowledge as it develops, and we hope to stay in touch with the user through it.



# Introduction

This Methodological Guidebook, together with the accompanying Decision Makers' Guidebook and the Policy Guidebook, is part of the final output from PROSPECTS: Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems. PROSPECTS is funded under the European Commission's Energy, Environment and Sustainable Development Programme. It is designed to provide cities with the guidance they need in order to generate optimal land use and transport strategies to meet the challenge of sustainability in their particular circumstances.

The Guidebook was developed in cooperation with six Core Cities: Edinburgh, Stockholm, Oslo, Vienna, Helsinki and Madrid. To ensure the widest possible applicability, a survey of 54 cities of different sizes throughout Europe was conducted. The material of this Guidebook was also discussed at a series of workshops with national and local authorities taking part.

## **Purpose and applicability**

Whereas the Decision-Makers' Guidebook will provide politicians, senior officials, and the public with advice on planning and decision-making for a sustainable urban land use/transport system, the Methodological Guidebook is designed for planning professionals. It goes through the same logical sequence of planning as the Decision-Makers' Guidebook, but is considerably more detailed on issues such as formulating objectives, defining indicators, setting targets, formulating strategies, identifying barriers to the implementation of these strategies, testing and appraising the strategies, and optimisation. On the other hand, the reader is referred to the Decision-Makers Guidebook for more details on issues such as the decision-making context, approaches to decision-making, the identification of problems now and in the future, public participation, as well as implementation and monitoring. The reader is referred to the Policy Guidebook (KonSULT 2003) for detailed information on the available policy instruments and their effects.

The planner is usually not free to conduct her planning and present her results as she likes. Very often, the high-level objectives, the problems to be solved, the policy options to consider and the available finance are prescribed to her. Also, the planning process has to comply with rules and regulations set by national authorities. To be useful in all circumstances, the Methodological Guidebook will have to be flexible. As far as possible, we are not advocating any particular method or approach. Rather, we want to advocate good practice in general and to offer a choice of methods and approaches, all compatible with general rules of good planning and with the overarching sustainability objective.

But inevitably we have our particular preferences. Thus we have very definite suggestions on how to measure sustainability, a detailed list of indicators, definite prescriptions on how to perform optimisation, etc. These particular PROSPECTS methods and applications are offered as suggestions and examples. The reader might disagree or be constrained to do things in another way, but at the same time she might

learn from them and develop ideas of her own. If however a particular method or an approach is chosen, we want to be rather prescriptive on how to carry it out. We hope that our instructions on how to carry it out can be followed as closely as possible.

The purpose of the book, then, can be summed up thus:

1. To present a coherent but flexible general approach to planning for a sustainable urban land use/transport system, building on the logical structure set out in Chapter 6 of the Decision-Making Guidebook
2. To offer innovative methods of carrying out the steps of that logical structure, especially regarding appraisal of land use/transport strategies with respect to sustainability, and optimisation with respect to sustainability
3. To provide detailed advice on a number of issues in the planning process

The Decision-Makers' Guidebook introduces a typology of planning approaches. The vision-led approach usually involves an individual decision-maker with a clear view of the future city he wants and the policy instruments needed to achieve it. The focus is then on implementing the vision as effectively as possible. Plan-led approaches might proceed from clearly specified broad objectives, specific targets or a clear view of the problems that need to be solved. The next step in planning will then be to find the combination of policy instruments that fulfil the objectives, reach the targets or solve the problems. The consensus-led or participatory approach involves discussions between the stakeholders to try to reach agreement on objectives, policy instruments and implementation. Most cities, of course, adopt a combination of these approaches.

*Our* general approach might be described as rational and objective-led. That does not make the guidebook useless to cities with other approaches. In fact, discussions among all stakeholders on the objectives, targets or problems seem to be a vital step to get the plan-led approach on the right track. Consensus-seeking later in the process could benefit greatly from knowledge about the relationships between objectives and policy instruments produced in a plan-led stage of the planning process. Even the visionary might want his visions to be subjected to quality assessment or his implementation plans to be monitored in a scientific way.

We believe that the problems facing European cities – congestion, traffic accidents, environmental degradation, social exclusion and unsustainable levels of fossil fuel use – call for more, not less rationality. They certainly also call for consensus and cooperation between stakeholders, as well as visionary leadership. We believe that sustainability should be the overarching objective of all urban land use/transport planning. If the reader and her city share that view, we are confident that she will be able to pick up some new and interesting suggestions from the guidebook.

## **Advice on use**

The Guidebook contains three main *layers*:

- Layer 1: *The Approach* (Chapters 1 and 2), which provide the basic tenets of our approach.
- Layer 2: *Suggested Methods*, which contains material on *Appraisal, Presentation and Strategy Formulation* (Chapters 3 to 5), *Predicting Impacts* (Chapter 6), and *Optimisation* (Chapter 7).
- Layer 3: *Some Specific Issues* (Chapters 8 to 18) on how to implement the suggested methods of Layer 2 in practice, consisting of *Calculation of Indicators*

(Chapters 8 to 16), *Visualisation/Presentation* (Chapter 17) and *Optimisation Algorithms* (Chapter 18).

Selected case study material, exemplifying different methodological points, is gathered in Chapter 19. Lists of possible indicators and policy instruments are given in appendices. Finally, there is a glossary and a subject index.

We suggest that you start by reading Chapter 1 and 2. You might then go directly to the chapters of interest to you, or use the subject index to search for particular subjects. You might of course also read through the Guidebook as an ordinary textbook. It is hoped that the Guidebook could also be used for study groups or in-house professional meetings.

With respect to Layer 2, it is intended that Chapters 3 to 5 should be relevant to those both with and without computer-based modelling packages. Chapter 6 discusses the need for mathematical models in land use / transport planning, whilst Chapter 7 introduces optimisation as a new way of producing strong candidate strategies and studying the implications of the assumptions made.

In general, the more theoretical and mathematically-oriented explanations of methods are held back to Layer 3.

For easy navigation, the following table relates the subjects of chapters 1 and 2 to the places where the subject is treated more in full, either later in the Methodological Guidebook or in the Decision-Makers' and Policy Guidebooks.

**Table 0. Cross-references between the guidebooks**

1.1 Decision-making context	DMG Chapter 3
1.2 Approaches to decision-making	DMG Chapter 4
1.3 Planning horizons	DMG Chapter 3
1.4 Participation	DMG Chapter 5
2.3 Sustainability	MG Chapter 3, DMG Chapter 7
2.4 Sub-objectives to sustainability	MG Chapter 3, DMG Chapter 7
2.6 Problem identification	DMG Chapter 8
2.7 Policy instruments	PG (KonSULT), DMG Chapter 9
2.8 Barriers to implementation	MG Chapter 5, DMG Chapter 10
2.9 Strategy formulation	MG Chapter 5, DMG Chapter 11
2.10 Predicting impacts	MG Chapter 6
2.11 Appraisal and evaluation	MG Chapter 3, 4, 8-16 and 17
2.12 Optimisation	MG Chapter 7 and 18
2.13 Implementation and monitoring	DMG Chapter 15

DMG = Decision-Makers' Guidebook

MG = Methodological Guidebook

PG = Policy Guidebook





# **The Approach**



# **1 Decision-making processes**

## **1.1 The decision-making context**

Cities' decision-making contexts may have substantial differences depending on the operational environment and the administrative structure adopted in each country and city (Le Gales, 1998; Page, 2000). Some cities have a single, fairly autonomous governing body. Others are composed of several autonomous municipalities, perhaps with joint bodies of decision-making in some of the policy areas. Internal coordination, particularly between departments in charge of land use and transport, is an issue in many cities. National and regional government often control some of the policy instruments. Some decisions are left to the private sector. Decisions made by the commuting municipalities may also need to be considered.

Thus cities are rarely able to make decisions on land use and transport strategies on their own. Three types of constraints on decision-making are identified in the Decision-Makers' Guidebook: Lack of direct control, intervention from other levels of government and involvement of other stakeholders.

In most cities, land use and traffic management are the sole responsibility of the city. Conversely, infrastructure projects are predominantly the responsibility of others. The responsibility for bus and rail service levels, information and pricing are shared in different ways in different cities. Regional cooperation is a key issue for most cities (May et al 2001).

Even where the responsibility lies with the city, plans and strategies at the regional and local levels may be to some extent regulated or supervised by authorities at a higher level.

The private sector has over recent years been taking an increasingly greater role in public transport operation and pricing. Business, environmentalists, transport users, the general public and the media are other stakeholder groups with a legitimate influence on decision-making.

If then, as is likely, there is no regional authority in charge of all the policy instruments that one would consider using, how can we make and implement a comprehensive plan for the whole urban land use and transport system? A first step will be to understand who can influence decisions and to what extent. Next, except for the unlikely case that the plan can be carried out regardless of what they do, we will obviously have to seek cooperation and partnership. All stakeholders should be encouraged to participate fully in strategy formulation. That way, it should be possible to develop a common understanding of objectives, the problems to be tackled, and the possible strategies and implementation sequence. It will involve compromises, but at least it will provide the planning exercise with a solid foundation on which to proceed. To secure consistent implementation, it is often advisable to develop cooperation further at this stage and to form a permanent joint monitoring body. In the extreme, where an agency prohibits progress towards an otherwise agreed strategy, it may be necessary to seek changes in legislation to permit more effective strategy formulation and implementation.

## **1.2 Approaches to decision-making**

Three distinct approaches to decision-making may be adopted in any particular city:

1. Vision-led: an individual or committee has a clear vision of the measures needed to improve transport and land use in the city, and focuses all action on implementing them.
2. Plan-led: objectives are specified or problems identified, and the measures which best satisfy the objectives or solves the problems are determined; the resulting plan is then implemented.
3. Consensus-led: discussions take place between the stakeholders involved in transport and land use. The discussions are aimed at agreement on a set of objectives and/or at a set of measures to carry out and their implementation plan.

As long as the approach is pursued consciously with an aim to tackling the challenges of unsustainability which we face, there is no simple answer to which approach is best. The most common approach is some mix of plan-led and consensus-led decision-making and the least common approaches are those which tend either towards vision-led or towards plan-led decision-making. This makes sense: There is certainly a need to seek cooperation and partnership to achieve sustainability, as well as a need for disinterested analysis of the issues involved. The plan-led and consensus-led approaches may be combined by letting objectives and targets be determined by initial discussions, and by inviting public participation at various stages of the planning process. At times, visionary leadership will also be needed.

The emphasis of this Guidebook is on the plan-led approach. The consensus-led approach might apply our methods to inform the processes of discussions. The vision-led approach might apply our methods to monitor and evaluate implementation.

## **1.3 Planning horizons**

Medium-term plans (4-10 years) are generally considered more binding than long-term plans (10-25 years). Partly, this is because they are related to budgetary resources, and partly because they are more often subject to public hearings. Long-term plans are more likely to be used as guidelines for the city authorities rather than strict requirements on them.

From a sustainability point of view, it is important that planning has a long-term perspective. Even 25 years is far too short to assess the full consequences of some of our actions today, like the building over of green land and CO<sub>2</sub> emissions. On the other hand, there are two forces that tend towards a shorter perspective: (a) uncertainty increases rapidly beyond a certain horizon, making planning less useful, and (b) long-term plans tend to have less influence on actual policy, making the whole exercise somewhat abstract. A balance must be struck. Provided we take due account of the various forms of uncertainty and do our best to avoid very long-term damage, it makes sense to produce combined land use and transport plans over a 15 to 20 year period, and to develop shorter and medium term plans in that context. A permanent body to monitor the implementation of the long-term plan will probably contribute to increased consistency between the long and short-term plans.

## **1.4 Participation**

Participation involves stakeholders in the development of a transport strategy. This

involvement can occur on a number of different levels, from merely keeping those with an interest in the strategy informed, to consultations that actually make a difference to strategy formulation, and further on to joint decisions and joint implementation.

There is increasing emphasis on public participation in land use and transport planning. In many cases it is now specified as part of the planning process, and in some countries it is required under law. Participation is central to the consensus-led approach to decision-making, but it can also increase the success of vision-led and plan-led approaches. Wide participation can ensure that the full range of objectives is considered, and that the strategy is consistent with those in other sectors such as health and education. It can provide a better understanding of transport problems, help generate innovative solutions and be a key factor in gaining public support and acceptability for the final mix of policies needed to deliver a transport strategy. Participation can save time and money later in the process, particularly at the implementation stage, as potential objections should have been minimised by taking stakeholders' concerns into account.

It is important to consider carefully what level of participation is appropriate and why participation is being sought. A key question is what is negotiable and what is not. It is counter productive to involve the public in decisions which are not negotiable or which have already been made. There will however be decisions to make all along the planning process, from determining objectives to implementation and monitoring. Participation may play a role at all these stages.

The need to communicate with stakeholders should be reflected in the work of the planner. It may influence the choice of indicators, the forms of presentation of results etc. All of this need to be thought through well in advance. Presentation is treated in Chapter 4 and 17 of this Guidebook.

## **1.5 Summary**

Strategic decision-making processes are complex, and are often carried out in a less than clear-cut context. As a planner, the reader might increase the chances of success by contributing to clarity around the following questions:

- What can be done to make the plan a comprehensive plan for the entire urban land use and transport system, even if responsibilities are split?
- What will be the favoured approach to decision-making in our case, and what can we do to make it a success?
- Who should have a fair say in the strategic planning process?
- How do we plan to get all interested parties to agree to the objectives as a first step in the strategic planning process? And how do we communicate the issues at stake in later stages of the process?
- What are the aspects of the land use/transport system with really long term, irreversible effects, and how can we keep them in mind while still keeping inside a planning horizon with a reasonable level of uncertainty?

## 2 Planning for sustainability

### 2.1 The scope of our planning

The target we are aiming at with our planning is sustainable urban development. Some might argue that the history of city planning proves that plans are always wrong, never solve the problems they aim to solve and sometimes produce planning disasters, so the whole idea of planning should be abandoned. However, there is ample evidence that the problems of traffic congestion, accidents, badly functioning labour and housing markets, environmental degradation and social deprivation, over-utilisation of resources such as energy and land, and the destruction of natural habitats and cultural heritage, will not be solved by markets alone.

Planning for sustainable urban development focuses on improvements in all of these characteristics of the functioning of cities. However, this Guidebook narrows down the scope of objectives to those that pertain to the transport and land use systems. We want to avoid objectives that are so broad or difficult to quantify that we cannot tell from an analysis whether they are fulfilled in a certain transport and land use plan or not. This leaves out important objectives with regard to quality of life and social issues, to the extent that they are not directly influenced by and measurable in the transport and land use system. The implication is that the issues left out are best dealt with by other forms of planning.

In particular, it needs to be pointed out at the start that we do not intend to assess the sustainability of the global patterns of production and trade of which the economic activity of the city is a part. This issue cannot be adequately addressed at the level of the single city. The Guidebook will probably be useful even if the scope of planning is extended from the transport and land use system to the whole system of consumption in the city. But the sustainability of *the industry structure* of the city can only be assessed in a wider context than the one we adopt here.

### 2.2 A logical structure

Having clarified the scope of our planning, we now suggest a logical structure that should help all cities to develop their strategies in a convincing and defensible way. The structure that we recommend still permits considerable flexibility in the decisions taken at each stage.

Figure 2.1 presents the logical structure. In it:

- scenario description (Section 2.5) and a clear definition of objectives (Section 2.3-2.4) is the starting point;
- objectives are used to identify problems, now and in the future (Section 2.6);
- an alternative is to start with identifying problems, while checking that all objectives have been covered (Section 2.6);
- possible instruments are suggested as ways of overcoming the problems which have been identified (Section 2.7);
- barriers to implementation will arise for certain policy instruments (Section 2.8);

- strategies are developed as combinations of instruments, packaged to reduce the impact of the barriers (Section 2.9);
- the impacts of the individual instruments or the overall strategies are then predicted using a model (Section 2.10);
- the results for these options are then compared using an appraisal method based on the objectives (Section 2.11);
- this process may well identify ways in which the instruments or strategies can be improved (Sections 2.7, 2.9);
- it is possible at this stage to use optimisation techniques to help identify better strategies (Section 2.12);
- the preferred instrument or strategy is then implemented, and its performance assessed against the objectives; these results may help improve future predictions (Section 2.13);
- on a regular basis, a monitoring programme assesses changes in problems, based on the objectives (Section 2.13).

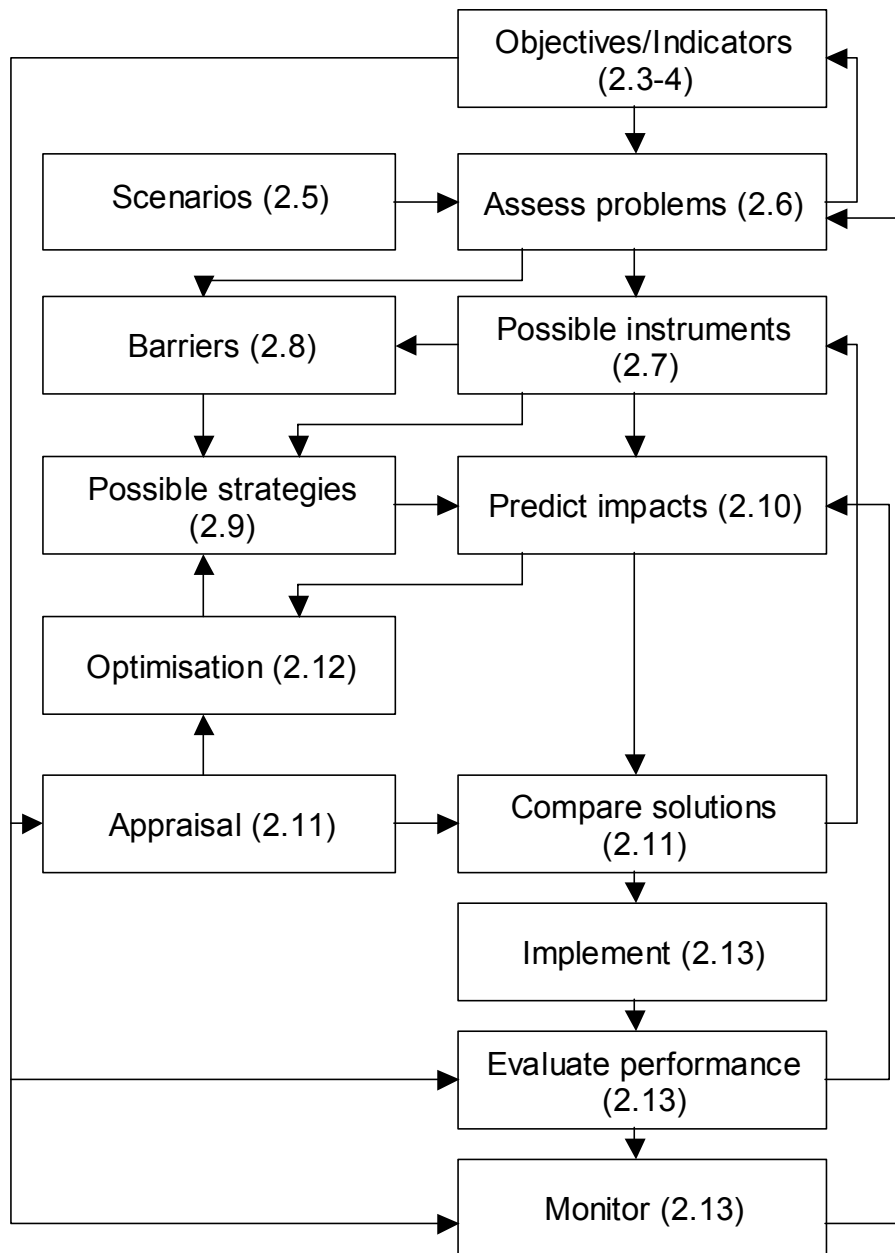
This process may seem somewhat idealised, but it has several virtues. It provides a structure within which participation can be encouraged at all the key stages in decision-making. It offers a logical basis for proposing solutions, and also for assessing any proposals suggested by others. If the answer to the question "what problems would this strategy solve?" is unconvincing, the solution is probably not worth considering. It ensures that the appraisal of alternative solutions is conducted in a logical, consistent and comprehensive way against the full set of objectives. It provides a means of assessing whether the implemented instruments have performed as predicted, and therefore enables the models used for prediction to be improved. It also provides the essential source material for our Policy Guidebook. Finally, regular monitoring provides a means of checking not just on the scale of current problems, but also, through attitude surveys, on the perception of those problems.

The real planning process is likely to be more complex than the neat structure of Figure 2.1. Results at one stage may throw a new light on decisions made at an earlier stage and call for revisions. Since time and resources are limited, it is important to avoid too many such surprises. From the planner's point of view, then, Figure 2.1 is not to be understood as a linear process, but as a process that needs to be performed at least *twice*; first as preparations and planning for the planning process, and then as the actual execution of it.

Some tasks will occupy the planner more than the decision-maker. First, regardless of whether she is going to use computer-based models or not, an important early task will be to describe and delineate the system under study. As a part of this task, she will have to describe the outside forces that are not going to be affected by the land use/transport strategies, but which nevertheless exert an influence on the system, now and in the future. This given background, consisting of factors such as demography, economic development, income, car ownership, technology and national and EU policy, is what we call the *scenario*. Scenario description (Section 2.5) forms a basis for problem identification, modelling and appraisal, and is vital to the analysis of uncertainty.

To assess the level of achievement of the objectives, indicators must be devised. A major part of this Guidebook is concerned with this task, which is first addressed in section 2.4. And finally, the choice of modelling tools is another important task. It is not explicitly featured in Figure 2.1.

Figure 2.1. The logical structure. Numbers indicate sections covering the steps.





## **2.3 Sustainability – the basic objective**

Even if the practical content of a sustainable urban development plan will have to be constantly revised in the light of new external pressures and new knowledge, there is a need for a fixed and clear conception of what sustainability *is*. Without it, sustainability will only be a catchword.

Our definition of sustainability follows Chichilnisky (1996) and Heal (2000), see Minken (1999, 2002). According to them, one of the two defining characteristics of sustainability as an objective is that it includes both the welfare of the present society and the society of the very distant future. The second defining characteristic of sustainability is that it implies conservation of natural resources. Put in other words: natural resources should be valued not only as something that may be consumed (in production or consumption), but also as stocks that benefit us even when not being consumed. The fundamental reason for this is that we are dependent on some basic qualities of our surrounding ecosystems for our quality of life and indeed to continue to exist.

If our strategies now had negligible long run effects, sustainability would not be an issue. The concerns about sustainability arise precisely because our actions now may constrain the opportunities of future generations and diminish their maximum attainable welfare. The aspects of our actions that are most likely to do so, are energy consumption, CO<sub>2</sub>-emissions, emissions of other pollutants with long term or irreversible effects, and the running down of non-renewable resources like various kinds of green areas and cultural sites inherited from the past. Some forms of long-term investments are also highly relevant.

Our definition of a sustainable urban transport and land use reflects these considerations.

*A sustainable urban transport and land use system*

- *provides access to goods and services in an efficient way for all inhabitants of the urban area,*
- *protects the environment, cultural heritage and ecosystems for the present generation, and*
- *does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.*

What are we to make of this definition? How are we to use it in practice? What we do is that we make a list of objectives that covers all legitimate aspects of sustainability. This is done in the next section. Then we develop indicators to measure goal achievement with respect to these objectives, both in the short and long term. In a final judgement, we have to apply the concept of intergenerational equity to make sure that the level of achievement of the objectives in the short run is compatible with achieving at least a similar level in the long term. All of this is treated in detail in Chapter 3.

## **Definitions of sustainability**

The standard definition of sustainability is of course due to the Brundtland Commission (1987), who defined sustainable development as *development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs*.

A necessary condition for securing the ability of future generations to meet their own needs is that each generation provides the next generation with the opportunity to do so, even if they too make provisions for the generation after them. Taking into account that the consumption of each generation depends on the stock of man-made and natural capital, and that the returns on this capital are uncertain, Asheim and Brekke (1997) arrive at the following shrewd definition:

*A generation's management of its stocks of man-made and natural capital is sustainable if its level of consumption can be shared by the next generation (in the sense of certainty equivalents) even if the latter abides by the requirement of sustainability.*

A hotly debated issue is if this requires the natural capital to be maintained (strong sustainability), or if some substitution of man-made capital for natural capital may take place (weak sustainability). Adopting the strong sustainability view, Daly (1991) states that

*Development is sustainable if the rates of use of renewable resources do not exceed their rate of regeneration, the rates of use of non-renewable resources do not exceed the rate at which sustainable renewable substitutes are developed, and pollution rates do not exceed environment's assimilative capacity.*

Note that Asheim and Brekke's as well as Daly's criterion may be fulfilled by many different development paths, some of which may be judged better than others. To be able to rank all development paths, an intergenerational welfare function incorporating the concerns for sustainability must be applied. This is what Chilchilnisky (1996) and Heal (2000) do. Heal requires that a sustainability welfare function places a positive value on the very long run by treating the present and the long-term future "symmetrically", and that it recognises explicitly the intrinsic value of environmental assets.

A definition of *urban* sustainability that broadly accords with these requirements is due to Breheny (1990). He defines urban sustainability as:

*...the achievement of urban development aspirations, subject to the condition that the natural and man-made stock of resources are not so depleted that the long term future is jeopardised.*

## 2.4 Sub-objectives to sustainability

Look at our definition of a sustainable urban transport and land use system above (Section 2.3). Note first that welfare in the form of efficient provision of goods and services seems to be a legitimate sub-objective of sustainability – at least as long as it does not hinder the attainment of environmental objectives. In economics, this sub-objective is termed “economic efficiency”. Whether or not a strategy or a project improves economic efficiency is usually measured by cost-benefit analysis (CBA). So there seems to be a place for CBA in our planning approach.

Next, there will obviously be a place for environmental sub-objectives as well. Finally, please note the little word “all”. It refers to objectives of fair distribution, equity and social inclusion. All such objectives should legitimately be sub-objectives of sustainability. This is often expressed by saying that we require economic sustainability, environmental sustainability and social sustainability.

But the fundamental thing is that we require that all of these sub-objectives should be reached both now and in the very long term. This is often expressed by saying that we require *intergenerational equity*.

Our suggested list of objectives (sub-objectives of sustainability) covers:

- economic efficiency
- liveable streets and neighbourhoods
- protection of the environment
- equity and social inclusion
- safety
- contribution to economic growth
- intergenerational equity

Some of these have many aspects and need many indicators for their measurement. This is all covered in Chapter 3.

Cities will of course have different priorities among these objectives according to their particular circumstances. We strongly recommend that at an early stage in the planning process, decision-makers and stakeholder discuss what sustainability means in their particular circumstances, and what the most important aspects of it are. It will then be possible to decide on the relative importance of the objectives on our suggested list.

The World Summit on Sustainable Development (WSSD), held in Johannesburg 2002, set out the actions necessary if we want to achieve sustainability. Under the heading of *Changing unsustainable patterns of consumption and production*, the agreed Implementation Plan tells us to:

Promote an integrated approach to policy-making at the national, regional and local levels for transport services and systems to promote sustainable development, including policies and planning for land-use, infrastructure, public transport systems and goods delivery networks, with a view to providing safe, affordable and efficient transportation, increasing energy efficiency, reducing pollution, reducing congestion, reducing adverse health effects and limiting urban sprawl, taking into account national priorities and circumstances. (UN, 2002, p. 9)

### **2.4.1 The importance of objectives**

Generally, objectives serve several functions:

- they help to identify the problems to be overcome, both now and in the future;
- they provide guidance on the types of solution that might be appropriate and the locations in which they are needed;
- they act also as constraints, in clarifying what should be avoided in pursuing any particular solution;
- they provide the basis for appraisal of alternative solutions, and for monitoring progress in implementation.

In setting objectives, it is important to avoid including indications of preferred solutions (e.g. ‘improving the environment through better public transport’); this may cause other and better policy instruments to be overlooked. In some countries, local objectives are specified by national government; even so, cities should check whether these represent the full range of their aims. In practice many cities adopt rather similar objectives, and except for the occasional inclusion of objectives that are really disguised statements about means, the list of objectives will probably resemble closely our six points list. The only new thing we suggest is to include intergenerational equity explicitly. But we think that is important and will make a difference.<sup>1</sup>

### **2.4.2 Measuring performance against objectives**

Objectives are abstract concepts, and it is thus often difficult to measure performance against them. We need to make the objectives operational. We do that by specifying them further until each of the sub-sub-objectives can be measured by its own indicator. For example, accident numbers could measure the overall safety objective; locations exceeding a pollution threshold could form a part of the environmental objective. This type of indicator is often called an outcome indicator, in that it measures part of the outcome of a strategy. It is also possible to define input indicators, which measure what has been done (e.g. length of bus lanes implemented) and process indicators, which describe how the transport system is responding (e.g. number of bus users). While these may be useful in understanding what has happened, they are less useful in assessing performance, since they generally say nothing about impact on the key objectives.

A suggested list of outcome indicators corresponding to the list of objectives is developed in Chapter 3. Further details on how to compute them are given in Chapters 8-16.

## **2.5 Scenarios**

By a *strategy*, we mean a package of policy instruments, each with their particular levels of use at a certain point in time or with a time path for their levels of use. The strategies are the actions that are open to the local or regional authorities. These actions are embedded in a wider context, consisting of the given conditions (political, economic, demographic, technological,...) that will apply in the urban area at each

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<sup>1</sup> Our experience suggests that if we form an objective function reflecting intergenerational equity concerns as explained in sections 3.4-3.5, and perform optimisation with this objective function, the optimal strategy will be “greener”.

future point in time. To the extent that these conditions are taken as wholly exogenous, they are called a *scenario*. However, some given conditions might nevertheless perhaps be influenced by political action in the long run. Such conditions, thought to be important for the feasibility or success of strategies, are classified as forms of *barriers* and are treated in Section 2.8.

The major factors that should be considered for inclusion in a scenario are

- population growth (demographic details like the age, sex and household distribution are probably also needed),
- household income growth (particularly because this influences car ownership),
- economic growth and employment rates (which of course are linked to household income),
- national policy (perhaps especially with respect to car and fuel taxation, transfers and subsidies for transport and housing, and infrastructure provision), and possibly the policies of neighbouring municipalities and regions, especially with respect to land use,
- car ownership rates (which of course is influenced by household income and car and fuel taxation),
- vehicle technology changes (fuel efficiency, alternative fuels, vehicle emissions) and the resulting composition of the vehicle fleet,
- the rate of introduction of new technology like e-work, e-commerce etc. and its effects on travel demand.

Of these factors, most cities acknowledge the importance of the demographic and economic variables, but the importance of making assumptions about national policy and technological change is often overlooked. Yet the national policy will influence the penetration rate of new fuel technology, the available budgets, and possibly also the population forecasts. The policies of neighbouring authorities will influence urban sprawl and population forecasts. The vehicle technology changes affect air pollution and energy consumption.

The construction of a scenario, then, involves making predictions about the development of a host of interrelated factors in a consistent way. It is a major task in itself, unless of course much of it exists already in official national forecasts. It is also a very important task. The analysis of future problems depends very much on it. The need for resolute policies to achieve sustainability, and the packaging of policy instruments, may depend crucially on the scenario. Finally, the construction of more than one (usually two, three or four) internally consistent scenarios is our main tool for addressing uncertainty about population growth, economic and technological development and the actions of others.

However, questions arise as to whether particular factors should be treated exogenously as part of a scenario or whether they are influenced by the strategy that is being considered. In the latter case, a subsequent question arises as to whether we can predict how the strategy affects this factor. In practical applications, the answers to these questions depend upon whether a computer-based model system is being used, and, if so, the capabilities of the model. If for instance an integrated urban land use/transport model is used, the location of firms and households is not something that needs to be specified in a scenario, since for any strategy including the base case or do minimum strategy, this information is produced by the model system. The fact that with such a model, change of location is one of the impacts of a strategy, tells us that location is not a scenario variable in this case. If just an ordinary transport model was

used, this would have been different. Sometimes, a land use model is part of the model system but is used only to predict the “do minimum” patterns of location in a test year. These patterns are then assumed to stay the same in all strategies. In this case too, the location patterns then become part of the scenario definition.

Car ownership is another case in point here. If a car ownership model is used in such a way that the predicted car ownership can be changed by the choice of strategy, car ownership is not part of the scenario definition.

Note that a scenario is not the same as a *do minimum strategy*. We need a do minimum strategy to serve as a benchmark in the appraisal of other strategies and to assess the severity of the problems in the future that result from inaction on the part of metropolitan or city authorities. The transport and land use system of the do minimum strategy will be almost totally determined by the forces acting on the system from outside – that is, the scenario. But they are not the same. The same scenario will apply to all strategies, not only the do minimum strategy. Our terminology serves to draw a clear demarcation line between the system we are planning for and its outside environment, and between the actions of those in charge of this system and the actions of others.

Thus strategies are the actions of the urban or metropolitan authorities themselves, with the objective to achieve a sustainable urban land use and transport system. The analytical part of the planning process consists of assessing the impacts of different strategies when compared to a “do minimum” strategy. To be able to do so, we have to know the context within which the strategies will work – that is, the scenario. To cope with the fact that we do not know for certain, we construct different scenarios that span the range of uncertainty. This whole approach is very general, regardless of what models we use or whether we use models at all. It may well be undertaken in parallel with the analysis of objectives, although we will need to have an idea about the tools we are going to use to predict impacts.

## **2.6 Problem identification**

A clearly specified list of problems is the most suitable basis for identifying potential solutions. It thus provides a direct input to the process of developing alternative strategies. Problems can be identified, both now and in the future, as evidence that objectives are not being achieved. However, objectives are often rather abstract, and it may be easier for members of the public to understand a strategy based on clearly identified problems. This problem-oriented approach to strategy formulation is an alternative to starting with objectives, but does still need to be checked against the full list of objectives.

How do we know we have got a problem? Clearly, a current problem exists if some of our objectives are not met. Future problems can be identified by specifying the most probable future scenario, then assessing the performance of a “do minimum” or “business as usual” strategy against the objectives. (A model system will probably be needed for this). The efficiency objective can easily be related to problems of congestion and unreliability; the safety objective to accidents, etc. Again, a future problem is a low level of performance with respect to some of our objectives. The two concepts, objectives and problems, are two sides of the same coin. We can start either with objectives or problems and come to the same conclusions.

To perform such an objective analysis of problems, we need indicators for all objectives and target values or thresholds for the indicators. When a condition is measured or predicted to differ from a threshold, then a problem is said to exist. A

range of thresholds can be set, so that problems may be graded by severity. Thus, for example, noise levels which exceed, say, 65dB(A), 70 dB(A) and 75 dB(A) would be classed as, say, 'slight', 'moderate' and 'severe' noise problems. Inevitably the thresholds set will be somewhat arbitrary, and it will be important to check that problems are not occurring at levels below the threshold. Where thresholds are set for different indicators, this will imply an equivalence between problems of that severity. Thus, for example: if a noise level in excess of 65 dB(A) and a carbon monoxide levels in excess of 8.5 ppm were both to be classed as 'slight' problems, this would imply an equivalent severity.

Problems should be classed by both severity and impact, in terms of the numbers of people affected. What is most important, to solve a severe problem affecting few people or a less severe problem affecting many? Issues of fairness and equity will inevitably be involved when solutions to problems are compared and prioritised. As seen in section 2.4, equity objectives are included in our set of objectives, and in fact we have developed a set of equity indicators. Even if they will not be applicable to all fairness problems, they will certainly be useful in the analysis of problems of unequal accessibility.

Problems may also be identified by consultation or by monitoring. Consultation is a key element of the participation process. If problems are identified through consultation, the city authority is able to determine the areas of concern for citizens and to develop appropriate targets. Problem identification through consultation is however of most use for current problems and may not highlight future problems. Regular monitoring of conditions, using similar indicators to those for objective analysis, is another valuable way of identifying current and emerging problems. As well as enabling problems and their severity to be specified, a regular monitoring programme enables trends to be observed, and those problems which are becoming worse to be singled out for potential remedial action.

Problem identification is treated in somewhat more detail in the Decision-Makers' Guidebook.

## **2.7 Policy instruments**

Policy instruments are the tools which can be used to overcome problems and achieve objectives. They include conventional transport methods such as new infrastructure, traffic management and pricing policies, but increasingly they also involve attitudinal changes and use of information technology. Equally importantly, land use changes can contribute significantly to the reduction of transport problems. Policy instruments can be implemented throughout a city (for example a fares policy), or in a particular area (eg. a light rail line), or at a particular time of day (eg. a parking restriction). In many cases they can be implemented at different levels of intensity (eg. for fares or for service levels).

Appendix I at the back of this Guidebook lists over 60 types of policy instrument. There are several ways in which they can be categorised; we have chosen to do so by type of intervention: land use measures; infrastructure provision; management of the infrastructure; information provision; attitudinal and behavioural measures; and pricing. We have then, as appropriate, considered separately those which influence car use; public transport use; walking and cycling; and freight. Experience with many of these policy instruments is described in our interactive Policy Guidebook. The rest is described more briefly in a PROSPECTS project report (May and Matthews 2001). We intend to expand the Policy Guidebook to full coverage. For each policy instrument, the Policy Guidebook defines it and describes briefly how it works. It then

provides an assessment from first principles of its likely impact on each of the policy objectives and problems highlighted in Sections 2.4 and 2.6. This is followed by a series of case studies and a summary of the contexts in which the instrument is likely to be most effective.

All of these policy instruments will affect the performance of the transport system in one or more of three ways:

- by changing the demand for travel,
- by changing the supply of transport facilities,
- by changing the cost of provision and operation of the transport system.

Initial responses (eg changes in mode) may lead to secondary ones (eg increases in overcrowding). Each of these types of change will in turn affect performance against the objectives in Section 2.4. It is this first principles assessment of the likely impact of a policy instrument which helps to assess its potential contribution, and the Policy Guidebook is structured on this basis.

Most of the time, the planner will find that her choice of policy instruments to test is constrained by tradition and by decisions made at a higher level. That is why the Decision-Makers' Guidebook stresses the value of taking a fresh look at the full range of instruments, including newer ones like awareness campaigns and real time information.

But at times, the planner herself may be in the position to suggest new policy instruments. At any rate, she should keep herself informed about what is known in advance about the instruments that she will be testing. We refer her to the Policy Guidebook and the Decision-Makers' Guidebook for such knowledge. Even more importantly, way too little is still known about the impacts of even the most common instruments, like road building. We therefore invite all planners to contribute their experience to the interactive Policy Guidebook, whether it is experience from modelling tests or from monitoring actual implementation.

## **2.8 Barriers to implementation**

A barrier is an obstacle which prevents a given policy instrument being implemented, or limits the way in which it can be implemented. In the extreme, such barriers may lead to certain policy instruments being overlooked, and the resulting strategies being much less effective. For example, demand management measures are likely to be important in larger cities as ways of controlling the growth of congestion and improving the environment. However, since they are often unpopular, cities may be tempted to reject them simply because of that. If that decision leads in turn to greater congestion and a worse environment, the strategy will be less successful. The emphasis should therefore be on how to overcome these barriers, rather than simply how to avoid them.

We have grouped barriers into four categories.

*Legal and institutional barriers:* These include lack of legal powers to implement a particular instrument, and legal responsibilities which are split between agencies, limiting the ability of the city authority to implement the affected instrument (Section 1.1). Our survey of European cities indicates that land-use, road building and pricing are the policy areas most commonly subject to legal and institutional constraints. Information measures are generally substantially less constrained than other measures.

*Financial barriers:* These include budget restrictions limiting the overall expenditure



on the strategy, financial restrictions on specific instruments, and limitations on the flexibility with which revenues can be used to finance the full range of instruments. Road building and public transport infrastructure are the two policy areas which are most commonly subject to financial constraints, with 80% of European cities stating that finance was a major barrier. Information provision is the least affected.

*Political and cultural barriers:* These involve lack of political or public acceptance of an instrument, restrictions imposed by pressure groups, and cultural attributes, such as attitudes to enforcement, which influence the effectiveness of instruments. Our surveys show that road building and pricing are the two policy areas which are most commonly subject to constraints on political acceptability. Public transport operations and information provision are generally the least affected by acceptability constraints.

*Practical and technological barriers:* While cities view legal, financial and political barriers as the most serious which they face in implementing land use and transport policy instruments, there may also be practical limitations. For land use and infrastructure these may well include land acquisition. For management and pricing, enforcement and administration are key issues. For infrastructure, management and information systems, engineering design and availability of technology may limit progress. Generally, lack of key skills and expertise can be a significant barrier to progress, and is aggravated by the rapid changes in the types of policy being considered.

It is important not to reject a particular policy instrument simply because there are barriers to its introduction. One of the key elements in a successful strategy is the use of groups of policy instrument which help overcome these barriers. This is most easily done with the financial and political and cultural barriers, where one policy instrument can generate revenue to help finance another (as, for example, fares policy and service improvements), or one can make another more publicly acceptable (for example rail investment making road pricing more popular). A second important element is effective participation, which can help reduce the severity of institutional and political barriers, and encourage joint action to overcome them. Finally, effective approaches to implementation can reduce the severity of many barriers, as discussed in Section 2.13.

It is often hard to overcome legal, institutional and technological barriers in the short term. However, strategies should ideally be developed for implementation over a 15-20 year timescale. Many of these barriers will not still apply twenty years hence, and action can be taken to remove others. For example, if new legislation would enable more effective instruments such as pricing to be implemented, it can be provided. If split responsibilities make achieving consensus impossible, new structures can be put in place. If finance for investment in new infrastructure is justified, the financial rules can be adjusted. Barriers should thus be treated as challenges to be overcome, not simply complete impediments to progress.

## 2.9 Strategy formulation

A land use and transport strategy consists of a combination of instruments of the kinds outlined in Section 2.7 and listed in Appendix I. More importantly, it involves the selection of an *integrated* package of instruments that reinforce one another in meeting the objectives and in overcoming barriers. Integration can be thought of at five different levels:

1. operational integration of different services, usually in public transport
2. strategic integration between instruments affecting different modes and

- between those involving infrastructure, management, information and pricing
- 3. policy integration between transport and land use
- 4. policy integration between transport and land use on the one hand and other policy areas such as health, education and society
- 5. organisational integration between those with different responsibilities for transport

Though all of these are important, we are concerned here largely with the second and third of these levels.

All of the objectives can in principle be achieved more effectively by using pairs of instruments which intensify each other's impacts on demand. One difficulty, however, is that individual instruments can have adverse impacts on certain groups of users. A careful choice of other instruments can help compensate the losers. With respect to overcoming barriers, it will be difficult, through the instruments themselves, to overcome either legislative and institutional or technical barriers. However, both financial and political barriers can be reduced by careful choice of pairs of instruments. For all of these reasons, a package of instruments is likely to be more effective than selecting any one measure on its own. In these ways, synergy can be achieved between instruments; that is, the overall benefits are greater than the sum of the parts. The identification of instruments which might achieve synergy is a key element of successful transport planning.

The combination of light rail and road pricing illustrates all of these; road pricing encourages greater use of light rail and generates revenue to pay for the light rail. Conversely the use of revenue to invest in light rail makes road pricing more acceptable and provides an alternative for those no longer able to drive.

Figure 2.2 shows, in matrix form, instruments which are particularly likely to complement one another by reinforcing the benefits of one another, by overcoming financial or political barriers, or by providing compensation to losers. Those in the rows support those in the columns in the ways shown. This table is intended to be used as a broad design guide only.

**Figure 2.2. A policy integration matrix**

These instruments	Contribute to these instruments in the ways shown					
	Land use	Infrastructure	Management	Information	Attitudes	Pricing
Land use		a				a
Infrastructure	ad		b			b
Management	ad	abd			a	abd
Information	a	ab	abd		a	abd
Attitudes	ab	ab	ab			b
Pricing	ad	acd	acd	cb	a	

Key: a Benefits reinforced      c Financial barriers reduced  
 b Political barriers reduced    d Compensation for losers

### 2.9.1 Key elements of a strategy

For cities experiencing congestion and environmental degradation, there are four key elements to any urban transport strategy:

- reducing the current and future need to travel

- reducing the amount of travel by car
- improving the public transport system
- improving the performance of the road network generally

None of these is an objective in its own right, but between them they will help to achieve them. Some success can usually be achieved with the last two of these alone. However, if car use is not reduced, the opportunities for improving the road network will be severely limited, and hence so will the ability to improve bus-based public transport. Moreover, if the growth in need to travel is not curtailed, improvements achieved in the short term will soon be lost. The strategy should thus contain instruments to address all four of these elements, and a key element of an integrated strategy is the determination of the way in which these elements are integrated, and the balance between them determined.

Each type of policy instrument contributes to one or more of the four key strategy elements, as shown in Figure 2.3. Land use measures contribute most to reducing the overall need to travel, but pricing measures are the most effective way of reducing the level of car use. Management instruments offer the most cost-effective way of improving public transport and road network performance, but infrastructure, information provision and pricing policies all have an important role to play. This table reinforces the message that there is no one solution to transport problems; an effective strategy will typically involve measures from many of these types of policy instrument.

**Figure 2.3. Contribution to strategy**

Key strategy element	Reducing the need for travel	Reducing car use	Improving public transport	Improving road network performance
Instruments				
Land use	●●●●	●●	●●	●
Infrastructure		●●	●●●●	●●●
Management	●	●●	●●●●	●●●●●
Information	●●●	●●	●●●	●●●
Attitudes	●●	●●●●		
Pricing	●	●●●●	●●●	●

Key: ● Minor contribution ●●●● Major contribution

Once this highest level strategy is clear, it will be possible to address other issues. In particular, this second stage can establish the strategy on:

- freight
- walking and cycling
- taxis and other minority modes
- provision for disabled users

These issues are no less important, but their treatment will not significantly influence the balance to be sought between the four key elements. For example, the ability to improve freight access will be determined primarily by the extent to which car use can be curtailed and the road system's performance improved. Within that context steps can be taken to allocate more strategic road space to commercial vehicles, and to control their use in sensitive areas. This in turn will improve the performance of the

overall strategy, but it will not affect significantly the overall balance to be struck between restraint and network enhancement. Equally, while walking and cycling are important modes, there is little evidence that steps to improve them will encourage much transfer from car use, and hence reduce the need to control it.

Policy instruments outside the transport field may sometimes be important in supporting transport and land-use instruments. Land use policy is the prime example. The use of pricing instruments may call for compensating or redistributive tax instruments to counteract any adverse impacts on equity. Authorities should liaise between different departments to ensure that policy instruments from all relevant parts of the authority complement each other and form a cohesive, sustainable strategy.

### **2.9.2 Commitment**

The sequence in which instruments are to be implemented needs to be considered carefully. Clearly instruments that need to be implemented to facilitate others are required first. It will also be essential at least to be committed to those instruments which generate income before investing in those which depend on that revenue for finance. Commitments are needed to publicly attractive instruments before embarking on those which on their own are less attractive. However, there is always the risk that the less attractive instruments will still not be implemented, for fear of public criticism. It is preferable if both positive and negative instruments are implemented together. Whichever sequence is adopted, it will be essential to implement all the measures in the strategy if it is to be fully effective.

## **2.10 Predicting impacts**

Having formulated a strategy, consisting of a package of policy instruments and their timing, and having specified the scenarios in which it is supposed to work and the barriers that it will have to respect, our next step is to test how it performs against the objectives we have defined. Individual policy instruments may have a wide range of impacts on demand and supply, some of them immediate and others arising as users change their habits. In the extreme, with land use policies, some effects may take a decade or more to occur. At the same time we need to understand these impacts, not just on demand and supply, but on our seven underlying objectives. Such analyses are often helped by using a model of the land use and transport system.

Models are indeed vital to our approach to planning for sustainability, since they provide the means to compute the future level of the performance indicators for (almost) all the objectives listed in Section 2.4. Without a model it is often very difficult to test and appraise in quantitative terms how a strategy performs in the future. Cities without a model will have to rely on experience drawn from model tests or practical tests elsewhere.

Any model is a simplification of the system being studied. It is not, and should not try to account for, everything. It should instead be a well-made caricature, where the characteristics of the modelled system are brought out with no more brush strokes than necessary. This makes it easier for the modeller to understand the system, and for others to use it. This in turn means that the results are more likely to be trusted. However, simplicity cannot be the main objective. The key to a good model is to drop *unnecessary* detail and complexity.

In Chapter 6 we provide advice on three types of model, in order of increasing complexity:

- policy explorers, which provide a very simplified representation of a hypothetical city, and help users to understand the types of impact which a policy might have;

- sketch planning models which represent the main interactions between demand, supply and land use at a strategic level for the city in question, without giving detailed information on transport networks or land use patterns;
- land use-transport interaction (LUTI) models, which represent transport networks and land use patterns and their interactions in greater detail, while still focusing on strategic issues.

In addition, there are conventional network and transport planning models, which are less complex than full LUTI models, but which typically ignore the impact of transport strategies on land use.

There are dangers both in over-use and under-use of models. The traditional rational, analytical approach to planning can all too easily lead to over-reliance on models, and a failure to realise that other issues are important, and that others may mistrust the experts and their results. Model-based analysis therefore needs to be used as a contribution to strategy formulation, rather than being seen as the whole process. Model assumptions need to be made clear, and results need to be able to be presented in a user-friendly way to decision-makers and to stakeholders as part of the participation process. Ideally models should also be available for non-experts to use, as a tool to support “deciding together”. However, most current models are unfortunately not well designed for this.

In our review of the requirements and capabilities of models we identified the following limitations of current models as of particular importance:

- representation of freight traffic in an urban environment
- objective measurement of journey reliability, quality and information
- subjective responses to journey reliability, quality and information
- estimation of the effects of air pollution upon health
- treatment of distributional and equity impacts
- responses to telecommunications and other information technology applications
- transport supplier responses, e.g. where public transport operation is deregulated

These are all areas for further research and development. Even so, it will be easier to plan a land use and transport strategy for a city with a model, in the knowledge of these imperfections, than to estimate the effects without one. Indeed, there is a need for further research to develop guidance for the prediction of impacts when models are not available.

## **2.11 Appraisal and evaluation**

The terms ‘appraisal’ and ‘evaluation’ are often used interchangeably. However, in this guidebook we use them to refer to two different forms of assessment. Appraisal is the general process of deciding how well a scheme or strategy performs. Evaluation is the specific application of appraisal to the *post hoc* assessment of completed projects. In both cases the question is: “How well does this scheme or strategy meet the objectives which we have set?”

We assume that at the stage of appraisal, the objectives have been discussed among the interested parties and are defined as precisely as possible. But these definitions in themselves will usually not be sufficient to pass judgement on a tested strategy. For each of the objectives or sub-objectives, we need a *performance indicator*. The performance indicators should be computable from the model output or whatever data

about the performance of the strategy that can be produced in the planning process. If this is a problem, either we have to enhance our models or settle for a simpler and more imprecise indicator. And of course they should measure what they purport to measure – the level of achievement of the tested strategy with respect to each and every one of the objectives we have defined.

A large part of the Methodological Guidebook (Chapter 3 and 8-16) is concerned with how to devise and compute these indicators for the objectives that we set out in sections 2.3 and 2.4. When the planner decides on what indicators to use, her major concerns will be that they can be computed from model output or other planning data; that as a whole they cover all the defined objectives; and that the information they contain can be presented in a clear and understandable form to the decision makers and other interested parties.

The single most important thing in appraisal is to judge all strategies against the same standards. Once the objectives are set and their indicators have been devised, the main elements of the appraisal framework are in place. We might choose to present the computed indicator values of each of the tested strategies to the decision makers in a table, for them to decide on which strategy is the best, or we might process the indicator results further before leaving the case to them. One way of doing this is to combine the indicators into an *objective function*, capable of ranking all strategies. Multi-criteria and cost-benefit objective functions are the main types. Another way would be to *set targets* for the indicators and record whether or not the strategies reach the targets. Both methods require normative decisions to be made. What are the weights to be used to sum the indicator values in the objective function? And what targets to use?

We argue (in Chapter 3) that the overall objective of sustainability is well captured by a combination of target setting and the use of an objective function. An objective function consisting of an intergenerational welfare function can be used to rank the strategies that meet minimum requirements with respect to protection of the environment and other objectives where clear targets have been set.

Ex-post evaluation may be carried out using the same appraisal framework as before. But of course, ex-post evaluation also provides an opportunity to reconsider the objectives and the usefulness of the indicators.

## **2.12 Optimisation**

Formal optimisation is a relatively new concept in the analysis of integrated land use and transport strategies. It means to use a transport model or an integrated land use/transport model to maximise an objective function subject to targeted indicators reaching their targets. The variables that may be adjusted to find this maximum value of the objective function are the levels of the policy instruments.

This is a very elegant way of choosing the best strategy. Even if we do not often want to “automate” the decision making process in this way, experience shows that it produces interesting new strategies that would not otherwise have been thought of. Comparing the optimal strategies under different scenario assumptions, different assumptions about barriers and targets, or different assumptions about unit values in the objective function produces new understanding about the trade-offs involved in strategy formulation. Chapters 7 and 18 cover optimisation, which is not covered in any other guidebook.

Traditionally, cities and their consultants have attempted to determine the best strategy through a process of identifying a possible solution, testing it, appraising it and then

seeking improvements. However, this process can be inefficient; time will be wasted on testing inappropriate strategies, and there is no guarantee that the best strategy will be found. Thus the benefits of optimisation are both in developing more effective strategies and in doing so more rapidly. In an early example in Edinburgh, an initial study used some 70 model runs to develop a “best” strategy; a subsequent study using optimisation methods found a combination of policy instruments, after 25 model runs, which increased economic efficiency by a further 20%.

The optimisation is performed assuming a particular scenario (a set of assumptions in the land use/transport model). The optimal strategy can then be tested for robustness against other scenarios. A future possibility might be to use optimisation to find the strategy with the highest expected value of the objective function, given that there is a given probability for each scenario to occur.

Barriers might be treated as upper and lower bounds on the ranges of the policy instruments or as constraints in the optimisation problem. For instance, a lower bound on fares or a constraint on available finance will rule out strategies that exceed these barriers. In either case the optimisation can be repeated without the barrier to demonstrate the benefit of removing it. This can help in making the case for changes in legislation.

A formal optimisation process is most useful in considering a package of strategic instruments which are expected to have a significant impact on the city. They will reflect the key strategy elements in Section 2.9.1. Most strategic instruments have some level which may be varied (e.g. a price). Some, such as discrete road and rail projects, are either included or not. Once an optimal set of strategic instruments has been selected, other second order elements of the strategy may be added in ways which enhance the overall policy.

When a city is assessing a relatively small number of policy instruments, or simply assessing one new proposal within a given strategy, formal optimisation is unlikely to be needed. However, where the number of options is substantial it will often be much quicker and less expensive to use a model in conjunction with an optimisation method than to use the model alone. Where there are several scenarios to consider, or constraints whose impact needs to be assessed, optimisation can prove even more valuable. Of course, in the final decision we might settle for another strategy than the “optimal” one. But in the process we have probably learnt something about how policy instruments can reinforce each other, what the most important elements of a strategy are, or (if the optimisation result looks unconvincing) what the strengths and weaknesses of our appraisal framework and modelling system are.

## **2.13 Implementation and monitoring**

### **2.13.1 Implementation**

Even when a thorough study of the options has been conducted, and stakeholders’ views have been taken into account throughout, implementation of the chosen strategy is rarely easy. Conflicts between stakeholders that seemed to have been resolved, tend to re-emerge at this stage. However, the seriousness of conflicts at the implementation stage depends on what has been done at earlier stages to prevent them. A complete analysis of the barriers to the implementation of the chosen policy instruments (Section 2.8) is a key factor in this respect. It should then be possible to design a strategy which limits their impact. Stakeholder participation is also essential. When those who might be adversely affected (or even fear that they might be) are fully involved in strategy formulation, it should be possible to identify their concerns,

and either redesign the strategy to overcome them, or obtain agreement that, despite them, the strategy should be pursued. In practice those who might be adversely affected are often not identified at the outset, or do not see the need to participate until too late. A distributional analysis at the appraisal stage can help to identify such people. It may be necessary to compensate the losers, either financially or by offering them additional benefits which offset the problems for them. All of this is best done before a strategy has been decided, not at the stage of implementation.

The sequence in which a strategy involving several policy instruments is implemented is extremely important. Some instruments need to be in place before others can be effective; for example, measures which discourage car use may need improvements to public transport to be implemented first. However, there may be a circular argument here; bus service improvements may well be dependent on a reduction in traffic. This suggests that both need to be implemented together. Some instruments can be implemented gradually; for example prices can be raised, or traffic controls intensified, over time. This may well be a way of reducing fear of the unknown and of avoiding undue disruption. It also provides us with a chance to check if the policy instruments work as anticipated. The analysis of a strategy therefore has to consider carefully the costs and benefits of alternative sequences and timescales for implementation. At the same time, it will be important to ensure that the strategy as a whole is implemented; there is always a risk that if the more acceptable elements are introduced first, the less popular ones will never be used.

### **2.13.2 Evaluation and monitoring**

Every new scheme provides an opportunity for learning from experience, and improving our understanding of the performance of the policy instruments used. This can only be done if there is an effective before and after survey which identifies the effects of the strategy on the key performance indicators and against the principal objectives. Preferably, such a study should be agreed together with the rest of the plan.

Before and after studies are particularly challenging for land use/transport plans, since the land use effects are slow to show up in full. If we wait too long to perform the after study, the effects of a strategy tend to get mixed up with other developments, while if we are too quick, the full impacts have not yet materialised. In either case, there is the problem of predicting what would have happened if the strategy had not been implemented (contra-factual analysis).

Large organisations like the World Bank or EU are much better at performing systematic ex-post evaluation than most cities, and much can be learned from them. But even the less than perfect studies may contribute to our knowledge about the impacts of policy instruments and strategies, which is why we encourage planners to report such studies to the interactive Policy Guidebook.

In addition to before and after studies, regular monitoring of conditions will help assess whether problems are being overcome, or whether new problems are emerging. It will thus provide the context for the next review of the strategy. Monitoring should be based on the agreed set of performance indicators, and it is thus essential that they can be readily measured and easily interpreted. Many cities aim to carry out annual monitoring of performance, and five yearly reviews of their strategy.



## **2.14 Summary**

The situation with respect to transport and land use in our cities is unsustainable for two reasons. First, for the sake of those living now, we cannot postpone doing something with the grave problems of congestion, air pollution, noise, traffic accidents, the degradation of some residential areas, unemployment and social exclusion. Second, there are aspects of our present way of doing things that have irreversible negative long run effects, like global warming, increasing dependency on non-renewable forms of energy, building on green area, destruction of cultural heritage sites and some forms of pollution (non-degradable toxic substances etc.). We need to take all of this fully into account when deciding on actions in the short term. Thus a strategy to change the situation needs to combine a long-term and wide-ranging perspective with immediate action.

The nature of planning for a sustainable urban land use/transport system stems from this. On the one hand, we need to know the system-wide short-run and long-run effects of combinations of a wide range of policy instruments. On the other hand, we must make sure that our planning triggers action. This calls for interaction with decision-makers and other stakeholders, and for links to more detailed levels of planning. We do not pretend that our approach is the only possible way of achieving this. However, our approach is designed to be clear, transparent, rational and flexible and, if models are being used, to make the best use of these models. Finally, through combining our analytical methods with public participation, through the application of innovative methods like optimisation and through evaluation and monitoring of the implemented strategies, we will probably all learn more about the challenges facing our cities.



# **Suggested Methods**



## 3 Appraisal

This chapter sets out a consistent and flexible framework of appraisal of urban land use and transport strategies that can be useful to all strategic planning for urban sustainability.

There will be many cities that find themselves in agreement with the general outline of planning for sustainability set out in Chapter 2, but which do not have the modelling capabilities of large scale integrated land use/transport (LUTI) models. Provided they are somehow able to compute or assess the likely level of a sufficient set of indicators for each of their candidate strategies, the proposed appraisal framework should be of use to them too.

It is not our intention to supplant the administrative or legislative appraisal frameworks in use in individual European countries and cities. Rather, the intention is to offer ideas to enhance the methods used within such frameworks to take account of the specific appraisal issues encountered in integrated urban land use and transport planning for sustainability.

### 3.1 The appraisal framework

*An appraisal framework* is typically a matrix, with one row for each impact that is in some way relevant to the appraisal and one column for each alternative that is being considered. In principle, there is no reason why different rows in the framework might not present the same or overlapping information, although if this is done (e.g., to help different stakeholders appreciate an impact in the way they best associate with) then the dangers of explicit or implicit double-counting of impacts must be borne in mind.

In essence, the framework is simply a presentational device. Its main purpose is to overcome man's limited capacity as an intuitive processor of complex and unusual information, by ensuring that all data considered relevant to appraisal is explicitly set down and available. In doing so, it also ensures that all alternatives are assessed against the same set of criteria, something that cannot be guaranteed in the absence of some type of formalisation. At the same time, the very fact that all relevant data is in the open also acts as a deterrent against deliberate or sub-conscious misrepresentation of the impacts of alternatives, since all data is open to challenge. Information may be recorded numerically (on ratio, interval, ordinal or nominal scales) or verbally.

The framework and the choice of performance indicators to be included in the framework are the most critical steps of all in seeking good appraisal practice. To assess each project/strategy explicitly against identical performance indicators for each alternative is the single most important contribution to sound appraisal. Next, choice of performance indicators to serve as the rows of the framework is also very important. Although duplication of information may be acceptable to a limited extent in frameworks, exclusion of significant impacts in general is not. All significant impacts that might realistically make a difference in preference between one alternative and another should be reflected in a row of the framework.

The appraisal framework forms the basis for:

- Communication
- Initial informal understanding and assessment
- Possible revision or screening out of alternatives
- The application of cost-benefit analysis
- The application of multi-criteria analysis
- Possible iterations through the process to examine new or amended strategies

A further use of frameworks, if supported by further disaggregation, is to throw light on distributional questions. For example, it might be useful to understand how impacts are distributed between households, business, government, etc. – the winners and the losers. However, this is not always practicable. Sometimes such information is constrained by data and modelling limitations. There are also challenges in the presentation of such information. Presented in a two-dimensional table, the level of detail could rapidly become unwieldy.

We prefer to present the results disaggregated by group in a table for each of the alternatives under consideration, and to complement these tables by a summary table of the alternatives. Table 3.1 and Table 3.2 provide a simple example of this. In Table 3.1, typical economic efficiency impacts have been included. Thus in this particular appraisal framework, cost-benefit analysis has already been applied to arrive at the relatively aggregate performance indicators used here. Indicators of other impacts are merely hinted at in the last rows, and have not been written down one by one as they would have been in a real case.

Note that one of the indicators, the OF (Objective Function), is supposed to sum up the total effect of all the impacts of the preceding rows. In this appraisal framework, the information in the OF row obviously duplicates information of the preceding rows, which is fine as long as it is made clear that this is a summary row. Italics are used to mark this row as a summary row. The reader has a choice to base his comparison of alternatives on the summary information in the OF row or on the more detailed information of the preceding rows. His choice will depend on whether or not he agrees on the weights that are used to sum the individual impacts. Much the same is true for the column totals row, which sums up the economic efficiency effects.

Thus on the one hand, Table 3.1 gives information about the overall result with the weights that the analyst has used to sum the individual impacts. On the other hand, it also allows the reader to apply his own value judgement to the individual impacts. Table 3.2, then, makes the comparison between the alternatives. The most important distributional impacts from Table 3.1 are incorporated by introducing more rows in Table 3.2.

In listing impacts, it is helpful to try to ensure that particular areas of concern are not represented in detail out of all proportion to others. This is because, irrespective of whether formal aggregation of impacts is later undertaken, there may be a tendency to give more weight to those impact areas that are represented by more rows, irrespective of their intrinsic importance, whether or not formal weighting of impact rows is done. Thus, for example, if impacts associated with sustainability are represented in great detail, whereas those associated with safety are not, there is some danger that the former may be over-weighted and the latter under-weighted.

In essence, the choice of objectives and indicators made in Section 3.3 and 3.5 below determines the appraisal framework that we propose for strategic land use and

transport planning for sustainability. In broad outline, it will be identical to Table 3.1 and Table 3.2, although a lot more needs to be said about the indicators to use and the summary indicators EEF and OF.

### **3.2 The main purpose of appraisal**

The main purpose of appraisal is to provide the participants in the decision making process with the information which they need to rank strategies, to select a single best strategy or a set of preferred strategies, or to retain a set of core strategies to be processed and discussed further by eliminating useless, unacceptable or dominated strategies.

Thus appraisal will usually not be the last word in the decision making process. There will be differing political priorities and differing interests among the participants in the process. Appraisal, as we see it, will provide all of these parties with the information they need to make up their minds, conduct an informed discussion and understand the practical implications of their political differences and their ultimate decisions.

For appraisal to perform this role, it should be *objective-led*. Thus in 2.3 we defined a sustainable urban land use and transport system, and in 2.4 derived from that definition seven objectives (or rather classes of objectives) that form legitimate parts of the overriding sustainability objective. The seven objectives were intergenerational equity, economic efficiency, protection of the environment, liveable streets and neighbourhoods, accidents, equity and social inclusion issues, and growth.

Hopefully, sustainability as we defined it can act as a common objective for all participants in the decision making process. On the other hand, there will inevitably be different opinions with respect to how much the interests of future generations should count compared to the interests of present generations, and with respect to the relative importance of the other six objectives at any point in time. Nevertheless, it is within this framework of objectives that we expect political differences to occur. Consequently, appraisal has to provide information about the level of goal achievement with respect to these objectives.

Where there is the likelihood of differences of opinion among the stakeholders, it is important that the style of appraisal provided offers some opportunity to explore the implications of differing perspectives. While no amount of exploration will change fundamentally opposed views to a consensus, it is true to say that enhanced understanding of how and why opinions on strategies vary can be the basis for re-designing them to accommodate the concerns of stakeholders and perhaps for identifying an agreed alternative strategy derived by amending one of the original ones. Even where complete consensus cannot be achieved, the fact that an open and participative appraisal has been seen to take place can often have a significant influence on stakeholders' willingness to accept the finally proposed option.

**Table 3.1. Example of presentation of economic efficiency results by sector and other indicators**

Strategy no.:										
Euros, present values, year n prices										
	Households	Firms						Government	External	Row totals
		Public transp.	Freight transp.	Pro- perty	Transp. Users	Parking	Toll collection			
Investment costs										
Transport benefits										
Location benefits										
External costs										
<i>Column totals</i>	<i>UB</i>	<i>PS</i>	<i>PS</i>	<i>PS</i>	<i>PS</i>	<i>PS</i>	<i>PS</i>	<i>PVF</i>	<i>EC</i>	<i>EEF</i>
Other OF indicators										
<i>OF</i>										
Indicators with targets										
Other indicators										

UB = user benefits, PS = producer surplus, PVF = present value of finance (financial surplus), EC = external costs, EEF = the Economic Efficiency Function, and OF = the Objective Function, consisting of a linear combination of the EEF and other indicators.



**Table 3.2. Example of appraisal framework**

	Strategy 1	Strategy 2	....	Strategy n
Investment costs				
Other government costs				
Transport benefits, households				
Transport benefits, firms				
Location benefits, households				
Location benefits, firms				
External costs				
Column totals (EEF)				
Other OF indicators				
OF				
Indicators with targets				
Other indicators				

### 3.3 Sustainability objectives and indicators

#### 3.3.1 The hierarchy of objectives

It was described in Section 2.4 how the following six objectives all belong as aspects of the overarching objective of urban sustainability:

- economic efficiency
- protection of the environment
- liveable streets and neighbourhoods
- safety
- equity and social inclusion
- contribution to economic growth

At any point in time, such as for instance the year 2010 or the year 2100, there will presumably be a concern for each of these six objectives. To take account of these objectives in a way that brings about sustainability, however, we need one more objective that does not concern any single year. Rather, it concerns how we trade off the achievements in the various years against each other. So we require

- intergenerational equity.

How to incorporate intergenerational equity into an appraisal framework that also takes care of the first six objectives is considered in Section 3.5.

These objectives won widespread support in the PROSPECTS survey of 54 cities (May et al 2001). There might be a case for including *health concerns* as an additional separate objective. However, health objectives are taken care of by the (traffic) safety objective, by sub-objectives such as air pollution objectives under protection of the environment and by walking and cycling benefits under the economic efficiency objective. If we find a good indicator for liveable streets and neighbourhoods, even that indicator might be related to health.

We have left out from our list an objective that does not concern the outcome from a strategy under a given scenario, but rather the ability of a strategy to perform well under different scenarios. This objective might be called

- robustness.

Since the future is inherently uncertain, the robustness of a strategy is a valuable property. It would be perfectly possible to include this objective in the appraisal framework, but except for a special case, its appraisal requires that strategies be tested in a variety of scenarios.<sup>2</sup> The issue of robustness is discussed further in Section 3.6.

Finally, cities may also have objectives that concern the planning process itself. These can be summed up as

- a democratic planning process.

Since this objective does not concern the outcome of particular strategies, it cannot be fitted into our appraisal framework. Hopefully, our planning approach contributes to achieving this objective. It has to be taken care of by public participation, institutional reform, simple and clear forms of presentation of the results etc. We refer to section 5 of the Decision-Makers' Guidebook on these issues.

The economic efficiency objective is measurable by the tested methods of cost-benefit analysis. None of the other objectives is immediately measurable. In fact, most of them are classes of many objectives, rather than one single objective. We will have to break them down into sub-objectives, each of which can be measured by its own indicator. Table 3.3 shows how we suggest doing this as far as the first six objectives are concerned. Of course it might be adapted to suit the particular circumstances of each city. And although the sub-objectives are a little more precise than the objectives, there will still be many aspects of some of them. This is further discussed in Section 3.3.2.

**Table 3.3. Objectives and sub-objectives**

	<b>Objective</b>	<b>Sub-objectives</b>
1	<b>Economic efficiency</b>	1.1 Economic efficiency in transport and housing markets
2	<b>Protection of the environment</b>	2.1 Reduce energy use and avoid climatic change 2.2 Reduce local and regional pollution 2.3 Protection of valuable areas (green areas, cultural heritage sites) 2.4 Avoid urban sprawl 2.5 Reduce fragmentation (of settlements and habitats) 2.6 Protect (specially defined) vulnerable areas 2.7 Reduce noise
3	<b>Liveable streets and neighbourhoods</b>	3.1 Increase freedom of movement for vulnerable road users 3.2 Achieve positive external effects on social, cultural and recreational activity
4	<b>Safety</b>	4.1 Reduce traffic accidents
5	<b>Equity and social inclusion</b>	5.1 Accessibility for those without a car 5.2 Accessibility for the mobility impaired 5.3 Equity and compensation to losers 5.4 Economise on taxpayers' money
6	<b>Contribution to economic growth</b>	6.1 Create a potential for economic growth

<sup>2</sup> The special case concerns scenarios that only differ with respect to income growth, in which case this objective can be taken care of by carefully choosing a strategy-specific discount rate to be used in the expected growth scenario.

### 3.3.2 Indicators

Our indicators are intended to provide *sufficient* information to pass judgement on the sustainability of urban land use and transport strategies. Each one of them relates to one of the particular sub-objectives identified in Table 3.3. They may be reported by rows in a table with alternative strategies as columns. Since each of them relates to a sub-objective, consistency between appraisal and the hierarchy of objectives can be achieved. Care should however be taken not to overburden the decision-makers and stakeholders with information, which is why in the end we prefer to use a rather short list of comprehensive indicators.

Our indicators are *outcome* indicators, or more specifically, they must measure the level of goal achievement with respect to a sub-objective. As a whole, the list of indicators should be *exhaustive*, that is, it should cover all sub-objectives. As we are not monitoring a system as it evolves in the real world, but are engaged in planning for the future, *only* data that can be derived from the planning process itself can be used to construct the indicators.

We introduce the concept of the *level* at which the indicator is defined. Level 1 indicators are comprehensive measures of all aspects of a sub-objective. They value or weight all the impacts to produce a single measure of goal achievement. Level 2 indicators are quantifiable measures of aspects relating to the achievement of a sub-objective, while level 3 indicators are qualitative assessments of the level of goal achievement. However, in some instances the adoption of a policy will immediately imply that a certain sub-objective is achieved. For instance, if it is decided not to develop existing green areas, a sub-objective regarding green areas may be considered to have been achieved. Such decisions are also used as level 3 indicators.

In Appendix II at the end of the Guidebook we set out a list of indicators at the three levels, and provide short definitions of each of them. This list is intended as a *menu* from which to choose indicators that can be quantified and assessed in each particular city. At some points, several options are indicated. To retain transparency in the appraisal process and avoid double counting, only one of them should be chosen. However, we believe that because of differences in the availability of data and different preferences with respect to multi-criteria analysis, cost benefit analysis etc., it might be useful to present indicators of the same sub-objective at different levels.

Below, we select from the menu the indicators that we think will be the preferred options in most cases. There will still be options, and there will still be problems to be solved with respect to operationalisation. For some major indicators, these issues are discussed further below in Chapters 8 to 16, and proposals for modelling the indicators are set out.

Traditional indicators like mode split and average speed etc. will not be in our lists of indicators. These are process indicators, not outcome indicators, in the terminology of the Decision-Makers' Guidebook. We by no means imply that they should not be used. But in fact there might be a form of double-counting involved in using them together with our indicators of goal achievement. If some of the indicators of goal achievement are sensitive to the traditional indicators and some not, to add the traditional information and let it influence the decision might bias the outcome in the direction of the objectives whose indicators are most sensitive to the traditional indicators. On the other hand, if our indicators of such objectives are incomplete or badly designed, the decision-making process will only gain from adding new information in the form of such traditional indicators.

The following numbered list of 19 indicators will be relevant for *most* planning exercises. The indicators can be computed for each year, and it is such annual values

that we define in the following. For the objective function and some of the targets, the relevant measure is the weighted (discounted) sum of indicator values over a 30 year period.<sup>3</sup>

### **Economic efficiency**

There is only one composite indicator under this heading, **the economic efficiency indicator (1)**. It is treated more fully in Chapters 8-13.

The annual value of this indicator is the sum of user benefits (in transport and housing), producer surpluses (including investment in rolling stock, rents), government surpluses (including investment in infrastructure) and external costs. External costs include the costs of noise, accidents and air pollution.

If for some reason one does not want to use the economic efficiency indicator, a similar picture might be had by collecting accessibility measures for all zones and combining these indicators with data on public expenditure in the strategy. These can be included in MCA, which is described further in Section 3.4.4 below.

### **Environmental indicators**

Five indicators are picked from the full list of Appendix II. Air pollution is covered by the two indicators "CO<sub>2</sub> cost" and "Air pollution cost". Noise is covered by the indicator "Noise cost". The reason why money values and not physical values are used for these three is that it provides the only simple way of aggregating to just a few indicators. Also, it makes the last two of them immediately useful as elements in the economic efficiency indicator. This does not preclude the use of these three indicators in multi-criteria analysis, because if decision-makers think that willingness-to-pay values do not reflect the true values, additional weights can be applied. It will also be possible to present air pollution and noise costs by area if the underlying modelling allows it.

**CO<sub>2</sub> cost (2)** is the annual volume of emitted CO<sub>2</sub> from transport and energy use in the households, multiplied by a value thought to represent the marginal cost to society of a small further reduction at the point where a national target of CO<sub>2</sub> reductions have been reached. The target will be the Kyoto target for 2010 and a stricter target for 2020, say.

**The air pollution cost indicator (3)** is a weighted sum of local and regional air pollutant volumes emitted from transport and energy use in the households. The weights, which might be set differently in different areas of the city, should reflect the damage cost in the particular city or part of the city. See Section 12.2.

**The noise cost indicator (4)** consists of a unit cost per vehicle kilometre by the different classes of vehicle (private car, bus, metro, rail) multiplied by vehicle kilometres of the different classes of vehicle. A broad distinction between the unit costs in urban and rural areas should be made. See Section 12.2.

Land use is covered by the two indicators "Green areas" and "Main land uses".

**The green areas indicator (5)** is the area of land in the urban area taken up by cultural heritage sites, natural habitats, green areas, agricultural land and recreational areas, divided by the total built area.

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<sup>3</sup> With one exception, there are no level 3 indicators on this choice list. It means that if level 3 indicators are preferred to those given here, one will have to go to Appendix II to pick them up. For most of them, this will also mean that one has to design the indicator, perform a survey to get the data etc.

**The main land uses indicator (6)** consists of three numbers: (a) The area of land not in use, (b) the built area and (c) the area of land used for transport, as proportions of the total area of land in the urban region.

*Comment:* It is by no means easy to define these different forms of land use, and one might want to consult the people who actually produce the statistics for definitions.

### **Liveable streets and neighbourhoods**

Streets and neighbourhoods are liveable if they are used for other purposes than transport, such as social life, strolling, playing etc. Two indicators are picked from the full list for this sub-objective, "Vulnerable user accidents" and "Local activity index". While the first might be included in the economic efficiency calculations if the data can be had, the second is strictly for multi-criteria analysis purposes.

**The vulnerable user accident indicator (7)** is the annual number of accidents in the city involving pedestrians/cyclists and a car, multiplied by an average cost.

**The local activity index (8)** is defined for each destination zone as a measure of the attractivity of the zone with respect to shopping and other leisure activities, and is similarly defined for the whole city. It might also be defined for residential zones as a measure of qualities of the environment and services.

The local activity index may be difficult to specify and quantify. It will only be sensitive to our strategies if the destination choice for such trip purposes in the transport model or the residential choice in the land use model is based on variables that we really believe reflect the qualities that make streets and neighbourhoods liveable.

### **Accidents**

Two indicators are included here, "Accidents cost" and "Accidents". The accident cost can be split in three or more types of accident: accidents involving only one mode and accidents involving two modes. We need one of these parts – the cost of accidents involving a pedestrian or cyclist and a car – for our liveable streets indicator. Further disaggregation by zone might also be possible. The same applies to the accidents indicator.

**The accident cost indicator (9)** is a weighted sum of accident costs for different modes and across-modes accidents. The weights are the cost of an accident of mean severity for the types of accident.

**The accident indicator (10)** is a set of numbers giving the annual number of victims of accidents for each mode. It may be sub-divided by severity (fatal, severe injury, slight injury, material damage only).

### **Equity and social inclusion**

Eight indicators are used under this sub-objective (which is really a cluster of sub-objectives). The three first measure aspects of the quality of the public transport system. They are "Accessibility for those without a car", "Public transport performance" and "The quality of public transport with respect to the mobility impaired".

**Accessibility for those without a car (11)** is the user benefits for those in the model without the private car mode in the choice set. It is measured relative to the accessibility of those with a car available by way of a Kolm inequality index<sup>4</sup>. The

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<sup>4</sup> Kolm and Theil indices are defined in Section 14.2.

higher the index, the more disadvantaged are those without cars.

**The public transport performance indicator (12)** is the number of vehicle kilometres per hour by public transport. It might be sub-divided by time of day.

**The quality of public transport with respect to the mobility impaired (13)** is a verbal description of their travel opportunities.

The four next measure inequality. They are: "The income inequality index", which is only available for models with different income groups, both in the transport and the land use model; "Equity impact tables", which describe inequality with respect to household type and household income group in a disaggregate way (and is also only available if there are different groups in the model, of course); "User benefit inequality" as measured by an index, and "Benefits or accessibility by zone", which could be displayed by a map.

**The income inequality index (14)** is a Theil measure of the inequality of the distribution of generalised income. By generalised income we mean household disposable income per consumption unit for an individual, plus the user benefits accruing to this individual. In practice, individuals will have to be grouped by income and the average user benefit of each group added to average income. See Chapter 14 for further details.

**The equity impact tables (15)** are tables of consumer benefits plus compensation displayed by group. Any relevant grouping (household income groups, household types, households by location or combinations of these) may be used.

**The user benefit inequality indicator (16)** is a Kolm inequality index (see Chapter 14) applied to household types, residents at different locations or any other differentiation.

**The indicator of benefits by zone (17)** is a map presentation of the spatial distribution of benefits. Alternatively, the indicator of accessibility by zone may be used. It is a map presentation of the spatial distribution of accessibility.

The principal difference between using a map of the benefits and a map of accessibility is that the first shows the change from the do minimum strategy whereas the latter shows absolute values. Accessibility measures may be chosen from Geurs and Ritsema van Eck (2001).

Finally, the eighth indicator is "Taxpayers' money", which describes the present value of the changes in the net result for government as a percentage of the net present value of all benefits. This indicator really serves two purposes. First, it indicates if the strategy relies on "outside money" – probably financed by taxes that apply nationwide – to be implemented. This is an aspect of equity that tends to be neglected by the city authorities, but not by those living elsewhere in the country. Second, it has an efficiency side to it, since taxes make prices differ from marginal cost and thus create inefficiency in the economy.

**The taxpayers' money indicator (18)** is the net present value of the changes in government budgets (local and national) after compensation to losers as a percentage of the net present value of all benefits.

*Comment:* As given here, it applies to the whole appraisal period and to all government. This is perhaps not always the only relevant definition of the financial constraint. Other definitions may be needed, see Section 5.2.

## **Economic Growth**

The work of SACTRA (1999) – see also Jara-Diaz (1986), Venables and Glasiorek

(1999), Vickerman (2001) – has laid a new foundation for research on growth impacts and regional impacts of transport improvements. If all prices in the economy equal marginal social costs there should be no benefits that have not been accounted for in a careful cost benefit analysis (CBA) of the transport system. This does not mean that there will be no wider economic impacts. But such impacts will be transformed forms of the benefits originally accruing to the agents in the urban transport and land use system. For instance, it may be that in the end parts of the benefits are reaped by agents outside the city. Journey-to-work time savings may give rise to increased competition in the labour market, resulting in lower wages and either higher producer surpluses or lower prices for customers, etc. In this case, it would be double-counting to add an economic growth effect to the net benefits of households, landlords, transport operators and government as calculated by the economic efficiency indicator.

However, if prices do not equal marginal social costs throughout the economy, there might be something to add to or detract from the original CBA. There are tables and formulas in SACTRA (1999) that might be used to judge the size and sign of these additional benefits. Whether they actually they will give rise to economic growth in a particular case, is probably impossible to say, so we prefer to speak of the growth potential rather than promise growth.

**The growth potential (19)** is the sum of user benefits (in transport and housing), producer surpluses (including investment in rolling stock, rents), government surpluses (including investment in infrastructure) as calculated in the economic efficiency indicator. It might be weighted by a factor slightly over or under 1 according to the guidelines in SACTRA (1999).

*Comment:* Even if the indicator can be computed, it will not do to enter it alongside the economic efficiency indicator in the objective function unless a very low weight, reflecting the small adjustment to the transport/land use net benefits that may be needed according to SACTRA (1999), is used. The growth potential will be the user benefits, producer surpluses and government surplus plus this small additional term.

### 3.4 Forms of appraisal

The simplest form of appraisal consists of computing the indicators for each of the tested strategies, and leaving it to the participants in the decision making process to work out their decisions based on this information (and any other information they might have). Since no formal criterion is used to produce a ranking of strategies or to partition the set of strategies into recommended and discarded strategies etc., this form of appraisal might be called informal. However, it is still based on a systematic and comprehensive framework of quantified indicators like the one of the preceding section.

Among the *formal* forms of appraisal, it is useful to make a distinction between those that result in a complete ordering of strategies and those which do not. *Setting targets* is the basis for appraisal that does not produce a complete ordering of strategies (setting targets merely divides the strategies into a those that meet the targets and those that do not). *Forming an objective function* is the basis for appraisal that does produce a complete ordering.

#### 3.4.1 Targets

*Targets* are defined here as the level of the indicators that is deemed necessary to bring

about a sustainable urban land use and transport system.<sup>5</sup>

Note that targets relate to and describe the future state that we wish to attain. If, however, the transition can clearly be divided into stages, it may be relevant to set intermediate targets. In that case, a distinction should be made between long-term targets and intermediate targets.

Note also that a lot of subjective judgement is required to set the targets, and that there are bound to be different opinions about them. Since the farther we look into the future, the less certain our model predictions become, it generally does not make much sense to make detailed model predictions and compute indicators beyond a 20-30 year horizon. That time-scale is generally too short to achieve a fully sustainable urban system. Some judgement must therefore be made as to what targets are the most important and what their levels should be to ensure that the state 20 or 30 years from now could evolve to become fully sustainable.

Planning by targets runs the risk that the targets are set so high that they cannot all be met.<sup>6</sup> One reason for using formal models is to investigate and make sure that this is not the case. If we find that the targets cannot all be met simultaneously, we might reduce some of them, or we might regard all or most of them as indicative rather than absolutely binding. In this case, if we allow targets not to be fully reached, we will refer to them here as *goals* rather than targets.

*Goals* are levels of the indicators that are aimed at, without assuming that they must necessarily be met. *The level of goal achievement* with respect to a goal is 0 in the present state and 1 if the goal is achieved. For intermediate states we define it as the difference between the achieved level and the level of the present state, divided by the difference between the goal and the level of the present state.<sup>7</sup>

Roughly, goals express the ideal or final state that we aim for, while targets express the necessary minimum levels that we do not want to fall below at any cost. Now we might use the defined goals to express targets not directly as levels of the indicators, but indirectly as target levels of goal achievement. (Whether such a common metric for the targets is convenient or confusing might be debated).

Assuming the targets are all achievable by the use of the policy instruments available to us, we have a degree of freedom. This can either be used to set more ambitious targets (until there is no more room for improvement) or to optimise one of the indicators subject to the other indicators reaching their target levels. Thus if we appraise strategies by setting targets that must be met for each of the indicators, we get a set of strategies that pass this test (and may be presented to decision makers for further discussion) and a set of discarded strategies. This is not a complete ordering of strategies, but may nevertheless be what the participants in the decision making process want. If there is also a clear indication of which one of the indicators the decision makers want to see further improved, we might be able to rank the accepted strategies with respect to their goal achievement in this dimension. At this point there would need to be interaction between planners and decision makers about what target to optimise to arrive at a complete ranking of the acceptable strategies.

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<sup>5</sup> Threshold values are forms of target commonly applied to environmental indicators.

<sup>6</sup> The Decision-Makers' Guidebook discusses how to set targets.

<sup>7</sup> Letting  $z$  be the goal,  $y_0$  be the current level of the indicator and  $y_t$  be the predicted level in

year  $t$ , the level of goal achievement is  $\frac{y_t - y_0}{z - y_0}$ .



### **3.4.2 Objective functions**

*An objective function* is a function of a sub-set of the indicators, to be used for (partial or comprehensive) appraisal of strategies or for optimisation.

We will only consider objective functions that are linear in the indicators. Note that if there are targets or goals for the indicators not included in the objective function, appraisal will include both assessment of the objective function (a real number) and assessment of whether the targets on the remaining indicators have been reached (a yes/no or possibly a level of goal achievement). Likewise, optimisation will be constrained optimisation, that is, optimisation of the objective function subject to the condition that the targets of the excluded indicators are met. If all relevant indicators are included in the objective function, we will be able to rank all strategies and to perform unconstrained optimisation.<sup>8</sup>

There are two main forms of objective functions with a pretention to include all or most indicators, and thus to produce a comprehensive appraisal and a complete ranking of the tested strategies. They are cost benefit objective functions and multi-criteria objective functions. We consider the pros and cons of each in the appraisal of urban sustainability.

### **3.4.3 Cost benefit analysis (CBA)**

A basic principle of CBA is to use the individuals' own valuations to measure the parts of the impacts of a strategy that they experience themselves. We seek the changes in their welfare expressed in money. So the question that must be asked and answered is what each individual herself would be willing to pay to get the benefits or avoid the costs of a strategy.

Next, we must somehow sum over all individuals in society to arrive at the value to *society* of implementing a strategy. In principle, society might attach a higher value to the welfare of some individuals than others, and this might be reflected in the ensuing social welfare function. In practice, this is seldom used in CBA. Instead, every individual's willingness-to-pay is counted the same. That way, if by some government intervention the winners could be made to pay compensation to the losers, so that losers are as well off with the strategy as without it and the winners still have some gain, the strategy is seen as an improvement to society as a whole (the Kaldor-Hicks criterion). The big problem with this point of view is that such compensations will not be made. Nevertheless, underlying CBA is the concept that government has the power to redistribute wealth so that any targeted wealth distribution could be reached. Efficiency and equity issues can be dealt with separately. If this is the case, any strategy with a potential to leave some individuals better off after compensation has been paid is an improvement in economic efficiency. Summing over all individuals, we arrive at the monetary value of this improvement.

CBA is well established in transport as a means of aggregating the impacts of competing transport proposals so as to get an overall ranking in terms of contribution to net social well-being. There are numerous texts and manuals outlining both its theory and practice, see, for example, Pearce and Nash (1981), Sugden and Williams (1978).

As part of the recent EUNET project, an in-depth assessment of CBA in application at the trans-European network level of thinking has been undertaken. In particular,

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<sup>8</sup> Unless, that is, there are constraints of other kinds, like financial barriers.

Deliverable 9 of EUNET (Nellthorp *et al.*, 1998) not only thoroughly assesses current appraisal practice and general appraisal issues, but also explores the specifics of appraisal not only of all the major direct impacts of transport projects that would typically be incorporated in a CBA, but also all environmental and indirect socio-economic impacts. See also Grant-Muller *et al.* (2001). These last two references, together with the references that they in turn include, provide up-to-date guidance on the state of the art in cost-benefit application within transport. In particular, they give guidance and sources on methods for appraising individual types of impact, such as noise, safety, etc.

Closely linked to CBA is the use of discounting procedures to allow costs and benefits that occur at different points in time to be aggregated into a single measure. This has a strong foundation in individual behaviour – individuals will prefer to consume now rather than later, and would require compensation in the form of interest to postpone consumption. Also, financial markets set the price of obtaining money now rather than later. However, when we appraise strategies with respect to sustainability, the issue is not just how individuals value benefits now compared to later. Sustainability involves very long term considerations, reaching well beyond single individual lives, and there is an important equity issue (intergenerational equity) involved. This may call for other approaches to discounting. In fact, faced with irreversible long-term impacts of strategies, CBA in its traditional form will be inadequate and needs to be modified.

Since CBA concentrates solely on efficiency, it goes without saying that the distribution of impacts, socially and spatially, is not covered by CBA appraisal. It might be possible to derive the distribution of impacts from a CBA, but distributional aspects are certainly not *appraised* by the CBA. Thus in the context of the seven sub-objectives to sustainability identified in Section 3.3.1, CBA can be used to compute an overall indicator of economic efficiency, but the equity objectives must be tackled by other means.

Furthermore, CBA has difficulty in establishing money values for a number of crucial environmental and social impacts, either because the impacts are difficult to quantify or because the value per quantity varies considerably according to circumstances and across individuals. Even if accidents, air pollution and noise seem to be amenable to monetary valuation, the loss of natural habitats and cultural sites, the level of security and freedom of movement, liveable streets and neighbourhoods etc. pose much greater problems. For the impacts that can be quantified but not valued, separate non-monetised indicators need to be established. Since these indicators (and the indicators relating to equity) cannot be included in the CBA objective function, the CBA objective function will not perform a complete ranking of strategies. It may however perform a complete ranking of strategies that meet targets with respect to these indicators. This provides a way of incorporating environmental and social sustainability issues in a CBA setting, or conversely of taking care of economic efficiency issues in an Environmental Impact Assessment setting. Barbier *et al* (1990) is an example of how environmental sustainability can be incorporated in cost benefit analysis.<sup>9</sup> Another alternative is to use multi-criteria analysis, which is the subject of Section 3.4.4.

#### **3.4.4 Multi-criteria analysis (MCA)**

There are many distinct multi-criteria approaches, responding to a number of different types of potential application in terms of, e.g.:

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<sup>9</sup> Technicalities of that paper have been criticised by Pires (1998).

- The time available to undertake the analysis;
- The amount or nature of data available to support the analysis;
- The analytical skills of those supporting the decision;
- The administrative culture and requirements of the organisations involved.

This section concentrates on some types of MCA that offer a good combination of: internal consistency and logical soundness; transparency; ease of use; data requirements consistent with the importance of the issue being considered; realistic time and manpower resource requirements for the analysis process; ability to provide an audit trail; and software availability, where needed. For a wider overview, see Dodgson et al (2000).

One style of MCA that is not explored here relates to those models that focus on argumentation and seek to support a process of dialogue with decision-makers to help establish both suitable alternatives and their appraisal (see Viegas and Macario 2000, Toman et al 1998). Although such methods can be very effective in a small group of local stakeholders, they are not readily embedded into any wider appraisal framework, and are hence less supportive of formal assessment of alternatives.

To the extent that monetary methods fail to capture all key features of a decision, multi-criteria methods offer an alternative:

- That is open and explicit;
- Where the choice of objectives and criteria is open to analysis and to change if they are felt to be inappropriate;
- Where scores and weights, when used, are also explicit, are developed according to established techniques and can be cross-referenced to other sources of information on relative values, if necessary;
- Where performance measurement can be left to experts, so need not necessarily be left in the hands of the decision-making body itself;
- That can provide a means of communication, within the decision-making body and between that body and the wider community;
- That enables sensitivity and robustness tests;
- That provides an audit trail.

Central to achieve this is the appraisal framework. Performance assessment in the framework may be numerical, but can also be qualitative. In the latter case, it is then possible to move ahead to a more formal, numerically based analysis, in which all performance assessments, including those initially made in qualitative terms, are converted to 0 – 100 scales. Subsequently, the performance on individual scales is aggregated, using weights, to create aggregate performance scores that may then be used to support the final decision process.

There is no single approach to multi-criteria analysis that is without critics. However, a central reference is the work of Keeney and Raiffa (1976) who developed a set of procedures, consistent with normative foundations, which would allow decision makers to appraise multi-criteria options in practice. Keeney and Raiffa formally take uncertainty into account and allow attributes to interact with each other in other than a simple, additive fashion. These contribute to complexities in application and are best implemented by specialists. In certain circumstances, it can be important to build into the analysis one or both of these factors, but often in practice it may be better to ignore them in order to allow a simpler decision process. Such a model is a simple linear one, created by multiplying the value score on each criterion by the weight of that

criterion, and then adding all those weighted scores together.

Models of this type have a well-established record of providing robust and effective support to decision-makers working on a range of problems and in various environments. They have an adequate theoretical foundation and an ability to diminish the cognitive limitations of unaided decision makers. They are often referred to as MADA (Multi Attribute Decision Analysis) models. Most importantly, they are sufficiently simple and transparent for use as part of a process of consultation with stakeholders. These stakeholders may be internal to the organisation, or external. MADA models are often employed as the analytical base for decision conferences or for the types of stakeholder dialogues that may benefit from having a capability to estimate the aggregate performance of alternatives in terms of the stated objectives of stakeholders.

A full description of how to implement a MADA process is given in Dodgson *et al.* (2000) and is beyond the scope of this Guidebook. However, the principal steps in a MADA application typically follow a sequence something like the following:

- Establish the decision context. What are the aims of the analysis? Who are the decision makers and the other key stakeholders?
- Identify the alternatives (strategies, in our case).
- Identify the objectives and criteria that reflect the value associated with the consequences of each alternative.
- Describe the expected performance of each strategy against the criteria, that is, create the performance matrix.
- Assign weights to each of the criteria to reflect their relative importance to the decision.
- Combine the weights and scores for each of the alternatives to derive an overall value.
- Examine the results.
- Conduct a sensitivity analysis of the results to changes in scores and/or weights.

The process is not a simple linear one to be worked through once, sequentially, with an “answer” emerging at the conclusion. Rather, a good MADA process is likely to involve substantial iteration, with feedbacks to earlier steps. For example, after the initial estimation of the performance matrix, it may well be desirable to re-visit the initial list of alternatives to fine-tune existing alternatives or to create new ones in the light of the insights gained from the initial performance assessment. (This is also discussed in Section 11 of the Decision-Makers’ Guidebook).

Elements of the MADA process do have some technical content and need to be undertaken with care, according to properly laid down procedures. This is particularly true of the weight assessment step. However, most practical experience with MADA indicates that the main value added to decision making comes through its influence on the process of identifying, characterising and understanding the full range of implications of the available alternatives, rather than as a consequence of its more formal aspects.

### **3.4.5 The choice of an approach**

The core elements in any approach to the appraisal of transport projects are the appraisal framework and the setting of targets and/or specification of an objective function through CBA or MCA. These elements are complementary, not competing.

All seek to impose a level of formality on the appraisal process which is strict enough to ensure defensible and genuinely informative appraisal practice, but which is nonetheless sensitive to the realities of appraisal in practice.

Different cities are likely to want to use the elements in different ways. The framework is a requirement for all. Thereafter, occasionally it may be appropriate to move directly to a choice based on the contents of the framework alone (“informal appraisal” in the terminology adopted at the start of Section 3.4). More commonly, one would like to set targets and/or proceed to aggregate the indicators by forming an objective function. This could be either CBA or MCA, or a mixture of the two. The European countries have different traditions with respect to which one of the two they are accustomed to use. Also, different users have different needs. Where there are a multiplicity of users and different emphases, flexibility within a formal structure is an important feature. Arguably, the combination of framework, targets, CBA and MCA offers precisely that.

It will be necessary for each group applying the guidebook to check its own understanding of sustainability against that set out in Section 2.3, to adjust the set of objectives and indicators accordingly and then to undertake forecasting, appraisal and evaluation. In this process, one will also have to take into account the national requirements on the planning process and the models available and the data that can be had from them at each stage of the planning process. This inevitably entails compromises and is one of the reasons why a flexible approach is needed.

The fact that we have seven objectives, some of which can and some of which can *not* be appraised by CBA, clearly points to a form of appraisal where CBA is supplemented by other information. This can either be done by forming an objective function that is a mix of CBA and MCA terms, or by a combination of CBA and setting targets for the indicators that fall outside CBA. Cities can choose whichever of these two approaches they prefer. However, in Section 3.5 we will be able to derive a more specific proposal from the very definition of sustainability.

### **3.5 Measuring sustainability**

In Sections 3.1-3.4 we outlined the appraisal framework consisting of objectives and indicators, and the key elements of formal appraisal: an objective function (MCA or CBA) and targets for the indicators not included in the objective function. In Section 3.3 the indicators were defined. We are now ready to put these components together in a more specific approach to appraisal with respect to sustainability.

#### **3.5.1 Background to the sustainability objective function**

We repeat our definition of sustainable urban transport and land use:

*A sustainable urban transport and land use system*

- *provides access to goods and services in an efficient way for all inhabitants of the urban area,*
- *protects the environment, cultural heritage and ecosystems for the present generation,*
- *does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.*

This definition requires us to improve the land use/transport system for those living now, while remembering that future generations should be given at least the same opportunities (intergenerational equity). The other outstanding feature is the requirement to protect the natural environment and cultural heritage, now and in the future. Natural resources should be valued not only as something that may be consumed (in production or consumption), but also as stocks that benefit us even when not being consumed. The fundamental reason for this is that we are dependent on some basic qualities of our surrounding ecosystems for our quality of life and indeed to continue to exist.

The concerns about sustainability arise precisely because our actions now may constrain the opportunities of future generations and diminish their maximum attainable welfare. The aspects of our actions that are most likely to do so, are energy consumption, CO<sub>2</sub>-emissions, emissions of other pollutants with long term or irreversible effects, and the running down of non-renewable resources like various kinds of green areas and cultural sites inherited from the past. On the other hand, long term investments may produce benefits far into the future.

There is also an implicit reference to intragenerational equity in the use of the phrase “all inhabitants” in the first bullet point of the definition.

All of this suggests that to measure sustainability, we must somehow combine four elements:

1. Welfare improvements for present generations (which can of course be measured by CBA, using a standard discount rate approach).
2. Welfare improvements for future generations (which should not be allowed to disappear through discounting).
3. Target values for environmental indicators (for non-renewable resources, they should apply as far into the future as possible).
4. Target values for intragenerational equity indicators applying at all times.

Intergenerational equity concerns the balance between the first two elements. How to combine these two elements is exactly the issue at stake in the heated discussions about the appropriate discount rate to be used to appraise measures to stop global warming (see IPCC 1996, Portney and Weyant 1999, IPCC 2001 for introductions). Let us give the objective function consisting only of the terms going into a cost-benefit analysis the name EEF (Economic Efficiency Function). Suppose we form a linear combination of an ordinary CBA – the EEF – and an *undiscounted* term representing the annual benefits in a year as far into the future as we can realistically predict transport and land use at all. Obviously, the weights we apply to each of the two terms will reflect our concern for intergenerational equity. A weight of 1 for the first term, 0 for the second would imply that we do not care at all. Nevertheless, this might be appropriate for projects that do not affect the options of future generations, so generally, we could not say that ordinary discounting is wrong. Conversely, a weight of 0 on the first element and 1 on the second would imply that any sacrifice now should be made if it would benefit future generations. This is an extreme position.

In analyses with a finite time horizon, such a combination would roughly follow a rule that says that the discount rate should be declining over time. Interestingly, it seems that more and more environmental economists agree that such a rule must be applied to the appraisal of policies that affect sustainability (IPCC 2001).<sup>10</sup>

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<sup>10</sup> "...there is still no consensus on appropriate long-term rates, although the literature shows

Now we consider the third element. If we can make sure that the long-term environmental targets are satisfied in the one, undiscounted year, we may be reasonably confident that what we are weighing together by our combination of EEF and the undiscounted year is the welfare of present generations and the *long-term* achievable welfare level. In an axiomatic framework, Chichilnisky (1996) shows that if the stock of natural resources matter for welfare, and if at least *some* weight is given both to the welfare of present generations and to welfare in the long run, then an (infinite horizon) intergenerational welfare function will *have to be* exactly such a linear combination of an EEF and the undiscounted annual welfare in a future situation that can be carried on indefinitely.<sup>11</sup> This is a very compelling reason for adopting such a function as a measure of sustainability.

In analyses with finite time horizons, like ours is bound to be, experience shows that a high weight on the undiscounted future year means a preference for strategies with benefit profiles that increase with time. Thus strategies which make the world a better place for our children are preferred to strategies that solve problems in the current situation but tend to get worse with time.

The combination of an ordinary CBA and the undiscounted benefits of a future year in which environmental sustainability has been reached, is our *Sustainability Objective Function, OF*. Since it weighs the welfare of current generations against the welfare of a future generation, it is an intergenerational welfare function.

Broadly, there are two ways of ensuring that the environmental targets are met. Either we could include them in the Sustainability Objective Function as a set of terms that penalises any strategy that does not meet the targets, or we could keep the environmental indicators apart, but make sure that we will not consider further any strategy that does not meet them. In our general formulation we should keep both options open. The mathematical formulation is set out in Section 3.5.2.

We will not try to include the fourth element, the indicator on intragenerational equity, into the Sustainability Objective Function. The reason is that as outlined here, the OF is rather firmly in a CBA tradition. The first element is an ordinary CBA and the second element is a "one year" CBA. The only unusual thing about it from a CBA perspective is the way this particular year is weighted. The introduction of environmental targets is not new in a CBA setting – as we saw, it was done already in Barbier et al (1990), and Toman (1994, 1998) advocates a similar approach. If one wishes, our objective function might be called a "CBA" sustainability function, although it must be remembered that it performs radically different from an ordinary CBA with respect to discounting. So (intragenerational) equity will have to be assessed separately.<sup>12</sup>

However, there is only a short step from this to an MCA formulation. If we choose the option to include the environmental targets as penalty terms in the function, we have the option to weight these terms in an MCA way. Then possibly we might include a term with the equity indicator as well. Pursuing MCA options still further, we might introduce other ways of weighting the welfare measures of the individual years. This will not be pursued here.

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increasing attention to rates that decline over time and hence give more weight to benefits that occur in the long term". (IPCC WGIII Third Assessment Report, Summary for policy-makers) Also for example Weitzman (1998), Heal (2000).

<sup>11</sup> The discount factor of the EEF needs however not be a constant.

<sup>12</sup> Welfare functions combining economic efficiency and equity have been devised (by Atkinson 1970 and others, see Myles 1995), but for transparency, we have decided to keep efficiency and equity apart.

A slightly less general version of the Sustainability Objective Function than the one we set out here was used in the OPTIMA project. See OPTIMA (1998), Minken (1999) and May et al (2000) for details. An in-depth treatment of the properties of Chichilnisky's function can be found in Heal (2000).

We are not of the opinion that the final word about the sustainability of a strategy has been said once the sustainability objective function has been calculated. Rather, the most important purpose of such formalisation is to allow us to explore trade-offs and to allow optimisation (as described in Chapter 7). Formal planning methods are not the decision-making process itself.

### 3.5.2 Definition of the sustainability objective function

The general mathematical form of the Sustainability Objective Function OF is:

$$(3.1) \quad OF = \sum_t \alpha_t (b_t - c_t - I_t - \gamma_t g_t) + \sum_{it} \mu_{it} y_{it}$$

where

$\alpha_t = \alpha \frac{1}{(1+r)^t}$  for all years between 0 and 30 except year  $t^*$ , the last modelled year;

$r$  is a discount rate and  $\alpha$ , the intergenerational equity constant, is a constant between 0 and 1, reflecting the relative importance of welfare at present as opposed to the welfare of future generations,

$$\alpha_{t^*} = \alpha \frac{1}{(1+r)^{t^*}} + (1-\alpha)$$

$b_t$  and  $c_t$  are benefits and costs in year  $t$ , including user benefits, producer surpluses, benefits to the government, and external costs. Investment  $I_t$  has been singled out as a special type of cost.

$\gamma_t$  is the shadow cost of CO<sub>2</sub> emission, reflecting national CO<sub>2</sub> targets for year  $t$ ,

$g_t$  is the amount of CO<sub>2</sub> emissions in year  $t$ ,

$\mu_{it}$  is the shadow cost of reaching the year  $t$  target for sub-objective  $i$ , or possibly a more subjectively set weight,

$y_{it}$  is the level of indicator  $i$  in the year  $t$ .

Many of these variables are of course specific for a particular strategy – a subscript denoting strategies is however omitted here.

The Sustainability Objective Function  $OF$  is in accordance with the definition of sustainability, because it involves the weighted sum of a CBA and the welfare of an undiscounted year (this is the first summed terms) plus penalties to assume that this last year stays within environmentally sustainable limits (this is the CO<sub>2</sub> term and the last summed terms).

### 3.5.3 The relation between the Sustainability Objective Function (OF) and targets

Not all indicators need to be included in the objective function, but the indicators that are needed for the calculation of the welfare of present and future generations will of course be included. They are the economic efficiency indicators for the whole range of



modelled years, or in other words, the  $b_t - c_t - I_t$  elements of the formula. In our interpretation,  $b_t - c_t - I_t$  also includes the costs of local air pollution, noise and accidents. As explicitly stated in the formula, the CO<sub>2</sub> costs  $\gamma g_t$  are also included. Together, these elements make up what we might call the core of the objective function – the first sum of terms. The unit cost of CO<sub>2</sub> emissions is of course not peculiar to the city under study, so we have assumed that it was derived from national emission targets (see Chapter 16 for details).

In an MCA interpretation of the objective function, all remaining indicators are included in the other sum of terms, the  $\mu_{it}y_{it}$  's. Here,  $\mu_{it}$  is the MCA weight and  $y_{it}$  is the level of the indicator recorded for that year. But the MCA interpretation is not the only one. Suppose a target has been set for indicator  $i$ . The weight  $\mu_{it}$  might then be understood as a penalty term, chosen so carefully that in the best of our strategies as measured by the core of the *OF*, the target is just reached. This is what we mean when we say that  $\mu_{it}$  is the shadow cost of reaching the year  $t$  target for sub-objective  $i$ .

How do we find such shadow costs? In fact, we could find them if we first maximised the *OF* over all feasible strategies, using any weights  $\mu_{it}$  that we thought were sensible, then maximised again using other weights until we found the weights that produced the least possible maximal *OF* value. Any textbook in optimisation could be used if the reader wants to verify this and make it more precise. But this is a very cumbersome procedure, so in practice we will not know if the weights we are using are real shadow costs. It is perhaps more realistic to think of them just as penalty terms which experience has shown us to ensure that the best of our strategies also fulfils the targets. (If experience shows the opposite, we should increase the penalty term next time!).

We can now sum up the possibilities with respect to indicators that are not included in the core part of the objective function. If no target is set for indicator  $i$  in year  $t$ , but we still want to include this indicator in the objective function, then we are performing MCA. If a target has been set, we might or might not include the corresponding indicator in the objective function. If we do, we should choose a weight that is as close to a real shadow cost as you can come. If we do not, appraisal consists in first discarding all strategies that do not meet this target, then choosing among the rest according to the level of the objective function. The latter procedure can be done most elegantly and systematically by performing constrained optimisation – see Chapter 7.

We do not necessarily need to set targets for all indicators that we choose to leave out from the objective function, but they should anyhow be monitored (see Section 3.5.5). It is also possible to set targets for indicators that are part of the core of the objective function, or to include the shadow costs of such targets in the non-core part of *OF* – see Section 3.5.4.

So within the general framework of our objective function, there is really a great deal of flexibility and scope for judgement. The only really hard requirement is contained in Section 3.5.6.

### 3.5.4 The core of the objective function

The core of the objective function consists of the terms that could not be interpreted as involving shadow costs. Here it includes the "CBA" and the CO<sub>2</sub> cost. The air pollution, noise and accident indicators are included in this. This does not prevent us from setting local targets for these indicators. But if instead of setting targets we want to include CO<sub>2</sub>, air pollution, noise and accident indicators in the non-core part of the objective function, we will have to take account of the fact that they are already

included in the core part. The extra terms will only constitute a modification of the weights attached to them in the core part. Also, the indicators of liveable streets, economic growth, accessibility to those without a car and taxpayers' money might already be elements of the "CBA", in whole or in part, and this should be acknowledged when setting separate weights for the additional terms.

### **3.5.5 Indicators which need not be included as targets**

A strategy is implemented in the model by making certain changes in the network or in the exogenous variables. In certain instances, the degree of fulfilment of some of the goals is not influenced by subsequent behavioural changes in the model, and can be ascertained directly. In such instances the most convenient thing to do is to make sure that the goal is taken care of when implementing *all* strategies in the model. There will then be no need to include terms that measure goal achievement with respect to such sub-objectives in the evaluation function. However, if we must incur investment costs or operating costs to achieve the goal, just for the record, these could be included in the CBA part of the evaluation function.

An obvious candidate for such treatment is the indicator "Accessibility for the mobility impaired". This is because the mobility impaired will not be identifiable as a group of travellers in any of the models. Another candidate for such treatment is the green areas indicator, although if it is possible to infer changes in green areas from the model output, it would be better to treat it explicitly.

In conclusion, we do not need to include all indicators as parts of the objective function or as targets in the optimisation problem. Some targets will be taken care of right at the outset. Others may be expected to be reached automatically in the solution (non-binding constraints could be removed). Still other indicators may be assigned a secondary role. Their levels will be reported as part of the analysis, but unless they turn out to be unacceptably low, they will not form a part of the optimisation problem.

### **3.5.6 Keep the same objective function throughout appraisal**

As pointed out in Section 3.1, a basic requirement of appraisal is to use the same evaluation criteria to appraise all strategies. Once a particular objective function has been chosen, it will not do to make changes to it as targets or other constraints are varied.

## **3.6 Taking uncertainty into account**

The future is uncertain, and the simplest way to take that into account is to define a small number of scenarios which, taken together, span most of the range of uncertainty. To the extent that we have to decide on a strategy before actually knowing which one of the scenarios is going to materialise, we will be interested to know how a strategy performs in a number of scenarios. If all strategies were immediately reversible at no cost, there would be only a theoretical interest in testing and appraising them in different scenarios. But in fact, the strategies that interest us will always have irreversible elements and will take time to implement, and so there is a case for testing them in a number of scenarios and appraising them with respect to how they perform across the scenarios.

There will also be other forms of uncertainty, and they have to be tackled by other means. We might feel uncertain about whether our methods capture the key elements

and relations of the system we are studying – the urban land use and transport system. Furthermore, there will be uncertainty about values – effectively what weights should go into an MCA model or how should a CBA be parameterised – and uncertainty in related areas – whether, for example, European Commission decisions about emissions taxes may influence the appropriateness of any city’s transport choices.

The initial response to all of these inevitable uncertainties is to use *sensitivity analysis* and a later search for *robustness*. Sensitivity analysis seeks to assess the extent to which the overall attractiveness and hence ranking of strategies changes as plausible changes are made to key input assumptions, reflecting the degree of uncertainty that might surround them. To test how a strategy performs in different scenarios is just one example of sensitivity analysis. Such testing may be simple, one input at a time, or more sophisticated, for example using Monte Carlo analysis. In practice, the output from such investigations of sensitivity would be a deeper understanding of quite how vulnerable any particular package of measures might be to changes in key input assumptions. A response to high levels of sensitivity might involve search for fuller information, to diminish the uncertainty surrounding a particular input, or re-design of the alternative to seek to make it less susceptible.

*Robustness* is a characteristic of strategies that reflects lack of sensitivity. It is particularly appropriate to long-term strategic planning, where strategies are often implemented in stages. For an example of a practical application of robustness analysis using different scenarios, see Allport *et al.* (1986, 1987).

Going beyond sensitivity tests, there are a number of other approaches to uncertainty. In a transport planning context, we will regard them as experimental, but they at least deserve to be mentioned.

*Expected utility theory* might be used to define an objective function over many scenarios. The degree of risk aversion of the decision maker will then be part of the information on decision makers’ preferences that need to be extracted. We would also need to assign probabilities to scenarios. Apart from the difficulty of doing this, the approach is perhaps difficult to communicate to stakeholders. This approach is left for future research.

If a strategy consists of policy instruments that can be applied at different levels over time, an approach could be used that combines explicit recognition of the fact that some policies are irreversible with recognition that there is uncertainty about the future scenario, but that information about it will gradually emerge. This is the *real options approach* (Dixit and Pindyck 1994), which also requires probabilities of the scenarios.

The simplest improvement on the pure sensitivity approach in a CBA setting would be to recognise that the benefits to society of a land use/transport strategy are only a part of the total return on regional or national capital. A strategy that produces high benefits in a low-income scenario will contribute to reduce the overall uncertainty of national capital, while a strategy that performs well in high growth scenarios and poorly in low-growth scenarios will increase overall uncertainty. Thus *the relevant risk to society* of adopting a strategy is not tied to the uncertainty of the strategy as seen in isolation, but to the overall uncertainty of the stream of returns on national capital. It might be comparatively simple to produce such estimates of relevant risk of the strategies, and if uncertainty is about growth rates or economic conditions, this concept will be more useful than the concept of robustness.

To implement the concept of relevant risk, start by testing the strategies in high-growth, medium growth and low growth scenarios like in ordinary sensitivity analysis, and compute the annual net benefits. Before computing the net present values in the

medium growth scenario by way of a discount rate, adjust the discount rate somewhat upward for strategies that are more than average sensitive to the growth rate and somewhat downward for strategies that are less than averagely sensitive. The strategy with the highest net present value in the medium growth scenario will then be the best from a social efficiency point of view, taking into account the relevant risk to society. An adjustment of one percentage point will probably be right, but even an adjustment of 3% down might be used if the annual net benefit of a strategy is virtually constant when the annual income of this year is assumed to increase or decrease by one per cent. If on the other hand the annual net benefit of the strategy in a certain year is increased by 2% if income in that year is assumed to be 1% higher (which is rather unlikely), a 3% upward adjustment of the discount rate might be used.

An approach very similar to this is part of official guidance in Norway, and might be adopted if income growth is uncertain and strategies turn out to be ranked differently under different income assumptions. If not, stick to sensitivity analysis and subjective assessment of robustness.

## **4 Presentation**

This chapter concerns presentation of results from the strategic planning process to professionals, decision makers and the public. The appraisal framework of Chapter 3 provides us with a solid basis for presentation of results. However, at this point we will probably have to communicate with different audiences (professionals, decision-makers and the public), each with their own requirements on the kind of information they want.

Even more importantly, presentation of results may take place at various stages of the planning process, from early results of the first exploratory tests to assist strategy formulation, to a final report, structured to comply with national rules and regulations. In terms of the logical structure set out in Section 2.2 (Figure 2.1), presentation of results in one form or another may inform the decisions about objectives, indicators and problems; strategy formulation; appraisal and comparison of solutions; as well as ex post assessment of performance. Each presentation may have its own purposes, including of course the purpose of providing the decision-makers with the information they need to rank or choose among the strategies, but also maybe the purpose of inviting ideas for further tests or the purpose of raising awareness of the issues at stake.

### **4.1 Presentation to decision-makers and the public**

The planner needs to interact with the decision-makers at many stages of the planning process, such as determining objectives, assessing problems, identifying possible solutions and appraising strategies. In Chapter 3 in particular, we made it clear that there are normative decisions to be made concerning the appraisal criteria. Which of the objectives are the most important? How much should the welfare of future generations count compared to present generations? What targets should apply for the indicators? These are not decisions to be made by the planner. Results from early exploratory tests may inform such decisions.

When it comes to presenting results to decision-makers at a later stage, these earlier decisions should first be summed up and be presented as assumptions underlying the analysis. It may however be that the results throw a new light on these decisions, and that the decision-makers would want to reconsider earlier decisions or try out new options in the light of results. This possibility should have been taken into account when the planning process was planned. If it was, and there is still time, the presentation of results should also be influenced by this possibility. It might stress sensitivity tests showing the effect of changing the assumptions, pointing out the assumptions that were vital for the results, or even – if possible – letting the decision-makers test their new ideas with the model, as was suggested in Section 2.10.

It will also be important at all stages where results are presented to try to explain how the tests were performed and how the model works. By knowing something about how the results depend on the assumptions and the tools used, the decision-makers get a clearer understanding of their options and the issues involved.

Much the same goes for presenting results to the public. It might well be that public interest is only aroused at a rather late stage, when some results have emerged. But if

public involvement, feedback and consensus is sought, there must still be time at this stage to make changes to the assumptions and test new options before the final report is delivered. And it will not do to present *only* the results. To draw conclusions from the results with respect to what options exist and what normative and positive assumptions drive the results would be even more important. This should all be presented in a short, clear and understandable way.

Thus presentation serves many purposes and needs to be carefully planned and executed. Presentations to each group will have to be different, both with respect to content and presentation techniques. Each presentation technique will also have technical points of its own. With respect to visualisation, this is covered in some detail in Chapter 17, while other sources will have to be consulted with respect to good practice in other forms of presentation.

We are concerned here with strategic planning, leading to strategic decisions and decisions to proceed with more detailed planning of particular options. While the professionals will want to know what we have done, the decision makers and the public will want to know if what we have done is acceptable and what to do next. Thus even if some aspects of our analysis and results lend themselves perfectly to popular presentations by way of visualisation, maps and even animation, we should not be tempted to present these aspects only and suppress the overall picture. The main thing must be to communicate the problems that require a strategic decision, the options for tackling them and the overall lessons from the planning exercise. It is these major issues that need to be communicated efficiently – by way of maps and animation if needed, but possibly only by simple text and tables.

There is mounting evidence that the decision makers are not very happy with the information they traditionally get from planners and the administration for their decisions on strategic transport/land use issues. Only time will tell if this situation can be improved by the approach to planning for sustainability that we advocate in this Guidebook.

A useful account of how public consultation and participation work in practice is given in Taylor and Tight (1996), which includes case studies of the public participation in the development of traffic calming schemes in various urban locations in the UK. Other useful references are Booth and Richardson (2001) and Wilcox (1994).

## **4.2 Presentation to professionals**

The strategic analysis should be presented to professionals in a report consisting of text and summary tables. The text should describe the background and purpose of the analysis, what methods and tools have been applied, and the assumptions made. The tables with results must be commented upon. The uncertainty surrounding the finding must be assessed, and conclusions drawn.

The presentation should be detailed and disaggregated enough for those who might disagree with the values and normative assumptions made to be able to adjust for that and draw their own conclusions. Similarly, those who disagree with the assumptions should be able to adjust for that. Data sources and other documentation used should be reported. Ideally, our analysis should be so clear and detailed that it is possible for other professionals to replicate it.

To assist implementation and perhaps to devise compensation to losers, the distributional effects of the strategies need to be reported. There will also be other requirements and regulations that need to be adhered to in reporting, for instance

stemming from national legislation or rules set for the particular planning exercise of which our work is a part.

There will always be individual politicians or members of the public that want to go into details of the analysis, and the report must be written so that it will be useful for them too.

### **4.3 Presenting the individual indicators**

This section suggests how the indicators described above in Chapter 3 might be presented. It will have to be remembered that presentation of individual indicators constitutes only a part of presentation of the whole picture, and will have to be supplemented by a summary consistent with the whole evaluation framework, presentation of the principles underlying the models, main findings and conclusions etc. This overall picture must be tailored to the preferences of the audience (what do they need to make up their minds?) and the background knowledge they have. Our evaluation framework provides the flexibility needed for that.

#### **4.3.1 Economic efficiency**

Economic impacts of a transport scheme are often crystallised into one figure, like the cost-benefit-ratio. In order to do this, several components have to be monetised and evaluated. This *background* information should be shown in a transparent way for credibility to all stakeholders.

Suitable methods are tables, probably backed up with bar charts. For each strategy presented, we propose to present the results in a table with columns for each category of affected sectors (households, firms, government and external) as shown in Tables 3.1 and 3.2. The columns might be further divided into sub-sectors if the data allows and if it is found necessary. For instance, firms may be divided into transport operators, property developers etc. The rows will indicate the type of impact, such as travel time benefits, monetary benefits etc. For analyses where more than one year is modelled, rows might also show the benefits by year. One of the purposes of such tables is to show broadly who wins and who loses by the strategy.

Elements of economic efficiency, notably the user benefits, may also be presented by zone in a map. This is in effect one of our equity indicators.

It has to be remembered that several issues covered in the economic calculus are also part of other impact descriptions (accessibility, accident costs, environmental costs, even land-use impacts). Implicit double counting through presenting the same impacts in different ways is a real risk here, maybe not so much with planners, but with decision makers and the public. Therefore, it needs to be pointed out very clearly how the data presented comes together in the overall evaluation of sustainability.

#### **4.3.2 Protection of the environment**

All environmental impacts cannot be presented in the same way, as their spatial properties differ significantly. Some are local (like noise and particulates), some regional (like NO<sub>x</sub>) and some global (like CO<sub>2</sub>). Also, their temporal frames are different, immediate like noise, or cumulative like Pb.

In addition to presenting the levels of emissions or noise, or the positive or negative changes, there is the need to quantify the number of people exposed to the improved

or worsened air quality or noise at different locations.

Unless the environmental impacts are added together by way of monetary unit values, the group “environmental impacts” means many tables, bar charts and maps, which may bias the relative weights of individual items inside the group, as well as between environmental and other impacts. To keep things simple, we will often want to opt for monetisation of the impacts.

For some of the local effects, like local pollutants and noise, presentation by zone or for instance road class might be possible, but for the others aggregated figures of the levels of the effects are sufficient.

Indicators related to the protection of valuable areas, urban sprawl and fragmentation are perfectly suitable for thematic maps and much less suited for monetary evaluation.

From the above, it is clear that several types of presentation are needed to cover the various environmental aspects, and careful consideration must be used in selecting representative items for different presentation purposes. The intention is not to flood decision-makers or public with detail, but to show the importance and relevance of the impacts.

### **4.3.3 Liveable streets and neighbourhoods**

Indicators of liveable streets and neighbourhoods may be a subgroup of the accident indicator, namely accidents involving pedestrians and cyclists. Consequently the same presentation methods as for the accident indicators (see 4.3.4) apply here. If data allows, the spatial distribution of accidents involving pedestrians and cyclists should be used to show where in the city the improvements occur.

An indicator related to social, cultural and recreational activities or the quality of neighbourhoods may also be used if the destination choice has been affected by the quality of the zone. For these indicators thematic maps visualise the differences between the zones best, perhaps even with subdivision according to activity. In modelling, some suitable intrazonal accessibility indicators might be used and also utilised for presentation purposes.

### **4.3.4 Accidents**

For the visual presentation of accidents our first thought is a detailed map with accident data on it. However, regarding evaluation of future plans there are no empirical data on accidents to present. Even so, there might be some spatial indicators of estimated accident rates or costs.

Regarding accidents, both the absolute levels and relative changes are usually of importance for the authorities involved as well as for the decision makers and the public. In many countries fatal accidents are of special interest. Therefore, representing the predicted development of these accidents by severity levels on zone level, by road type or even aggregated over the whole area may be an advantage.

Possible presentation methods for accident indicators are maps, tables and charts on zone level, by road class and zone or aggregated zones, and by severity level. An example of basic presentation would be a thematic map of relative changes of accidents by zone with absolute numbers of accident as a bar chart on each zone. Since unit costs of accidents of different degrees of severity are accepted in many countries and allow for aggregation of accident of different degrees of severity, presenting accident costs is clearly an alternative to presenting accidents by number.



### **4.3.5 Equity and social inclusion**

Equity and social inclusion indicators address accessibility for different groups such as those without a car or the mobility impaired, losses and gains by socio-economic groups and by residential locations, and the issue of how much of the benefits are kept inside the urban area.

Appropriate presentation methods vary from thematic maps at zone level to charts and tables both at zone level and for the whole area. Information on relative values in comparison with the average in the city, or on relative changes from the base scenario, are at least as important as the absolute figures.

For various reasons, presentation of results with respect to equity is perhaps the most difficult of all. Distributional impacts have many aspects, and focusing on one of them may mean to neglect other, equally important aspects. Moreover, the aspects that appear to be the most important before the study started may not turn out to be all that important in the end. There is a danger of neglecting inequality that affects less vocal groups and concentrate on issues that are high on the political agenda at the time. On the other hand, there is obviously a need to concentrate on one or a few indicators.

There is little actual experience with presenting inequality indicators in a systematic way. We even have too little experience with computing them, choosing parameters and understanding the normative content of such choices.

The visual impression of inequality that can be had from a map will be very dependent on the chosen level of aggregation, scale and colouring – see Chapter 17. Consciously or unconsciously, issues can be downplayed or exaggerated by the technical choices we make in presentation. This, by the way, is not only true for maps but also for charts and tables.

For all of these reasons, presentation of equity results must be very carefully planned.

### **4.3.6 Economic growth**

The economic growth indicator proposed in Chapter 3 is a global indicator derived from user benefits, producer surpluses and government surpluses. Thus similar methods of presentation to those for the economic efficiency indicator can be adopted.

The economic growth indicator might also be used as a regional indicator reflecting differences with respect to growth potential within the city area. Only user benefits admit of such zonal representation. However, it is not even probable that the user benefits within transport and land use will be retained within the origin zones. If anything, it would be better for this purpose to aggregate user benefits by destination zone, since they will probably translate into lower wages for the firms at the work trip destination zones, profit for shops and higher rents for property owners.

### **4.3.7 Summary principles**

Two main principles for the presentation of PROSPECTS indicators can be drawn:

- *The level of all major indicators in all tested strategies should be presented in a table.* The tables guarantee the transparency of the evaluation. The tables then can provide the data for comparison of selected strategies through bar charts, pies or other chart types suitable for that particular indicator.
- *Visualisation using thematic or ordinary maps and GIS should be used wherever possible.* This assists a layman (decision maker and public) to quickly grasp the main points of the presentation.

# 5 Strategy formulation

## 5.1 Analysis of synergies

Chapter 2 has discussed a number of issues with respect to strategy formulation, concerning the creation of packages of land-use and transport instruments. A list of instruments is given in Appendix I. Chapter 7, concerned with optimisation, describe methods for creating optimal packages, i.e. those packages that lead to optimal values of the objective function. This chapter outlines methods which can be used by the transport/land-use planner to create *initial* sets of packages for their specific cities. If formal optimisation methods are to be used, these initial sets provide the starting point for such a process. However, even if formal optimisation methods are not to be used, the methods outlined in this chapter provide a useful tool for the planner to think about issues such as complementarity and conflict between instruments.

The methods described below have not been adequately tested in real-life applications and thus are only provided in summary form. However, it is planned that formal testing will take place in the SPECTRUM project. For current usage, though, it is feasible for planners to adapt the basic concepts in this chapter to their own needs and, in effect, create their own practical methods.

The methods involve the creation of different types of *instrument matrices*, which indicate the likely contribution of pairs of instruments if implemented together in the specific city of interest. A full range of instruments is given in the Policy Guidebook, <http://www.transportconnect.net/konsult/index.html>, where instruments are discussed with respect to their contributions towards objectives. It is recommended that only those instruments of likely interest to a particular city are included in any instrument matrix, thus making the matrices relatively more manageable. All the matrices take the form given in Table 5.1, for which it is assumed that N instruments are being considered for possible implementation by the planner.

**Table 5.1. Template for an instrument matrix**

Impact of instrument in row on instrument in column	Instrument 1	Instrument 2	.....	Instrument N
Instrument 1			.....	
Instrument 2			.....	
Instrument 3			.....	
.	.	.		
.	.	.		
Instrument N				

Five different types of matrix are considered, and are described further in the sub-sections below:

1. Reinforcement of benefits
2. Reducing acceptability barriers (financial)
3. Reducing acceptability barriers (political)
4. Institutional responsibilities
5. Integration

In general, any uncertainty when filling in a box (in any of the tables) should be indicated with a “?”, which will provide a useful impetus for further thought and analysis.

### **Reinforcement of benefits**

This matrix shows whether particular instruments are likely to reinforce the benefits of one another, or whether instruments mutually undermine each other. Due to this definition, the matrix is *symmetric*.

As an additional attribute, the matrix could also indicate whether the implementation of a particular instrument might be viewed as an *alternative* to the implementation of another instrument. The implication here is that it would be strange to implement both instruments at the same time and that a choice needs to be made as to which instrument better fulfils the needs of the city.

### **Financial barriers matrix**

This matrix indicates whether an instrument can overcome a financial barrier associated with another instrument. By this definition the matrix is *asymmetric*. For example, the cost of building new public transport infrastructure can be raised through road pricing.

### **Political barriers matrix**

This matrix indicates whether an instrument can overcome problems of political acceptability associated with another instrument. By this definition the matrix is *asymmetric*. For example, the acceptance of road pricing can be greatly increased by improvements in public transport. In analysing public acceptability, it is important to recognise that different social groups, with potentially different perspectives, are affected by instruments in different ways.

### **Compensation matrix**

This matrix indicates whether an instrument will provide compensation to groups adversely affected by another instrument. By this definition the matrix is *asymmetric*. For example, the traffic congestion arising immediately outside a road pricing cordon could be reduced by appropriate traffic management measures. Hence, the residents living immediately outside the cordon would be compensated for the nuisance caused to them by the road pricing scheme. More information about gainers and losers from particular instruments is given in the Policy Guidebook.

### **Institutional responsibilities matrix**

As is discussed in the Decision Makers’ Guidebook (Chapters 3 and 10), there can be difficulties with introducing packages of instruments if individual instruments in the package are controlled by different authorities. This is particularly the case if the private sector controls certain instruments under a regime of deregulation. The

Institutional Responsibilities Matrix shows, for each pair of instruments, whether the same institution is responsible for both instruments, and, if not, the specific institutional differences involved. The following cases, in rising order of awkwardness, should be distinguished:

- One public authority (or agency) is responsible for both instruments;
- Two different public authorities/agencies are responsible (one for each instrument);
- A public authority (or agency) is responsible for one instrument and the private sector is responsible for the other instrument;
- The private sector is responsible for both instruments.

### **Integration matrix**

For various purposes, such as presentations to decision-makers, it is useful to combine information in a single matrix. The Integration Matrix aggregates the results of the other four matrices. In many cases, it would be extremely crowded if the four matrices were simply added together. If so, there is a need in the Integration Matrix to report only those factors that are seen as being most important. However, imaginative use of colour can greatly enhance the amount of detail that can be incorporated in such a matrix.

An alternative approach, especially appropriate if the other matrices are scored, would be to combine the matrices in a numerical way. This could be achieved either by adding or multiplying them together.

## **5.2 Financial barriers**

A strategy will probably have to respect financial constraints. To the extent that such constraints are removable in principle, they are called financial barriers. The potential types of financial barrier appear to be:

1. limits on capital expenditure in the first year or in any subsequent year,
2. limits on operating expenditure in any year,
3. constraints of type 1 specific to particular types of measure (e.g. dedicated budgets for public transport infrastructure which cannot be used for other purposes),
4. constraints of type 2 specific to particular types of measure,
5. limits on the ways in which revenues from different sources can be used (and the converse of hypothecation for specified purposes),
6. limits on the ability of the city to borrow to tackle barriers of types 1- 4,
7. limit on the present value of finance over the appraisal period.

The first six of these barriers arise from the accounting practice and institutional setting in each particular city. For instance, there may be limited possibilities of transferring money between transport investment and operation, or limited opportunities of transferring money from one use (such as road maintenance) to another (such as housing construction). Or there may be restrictions on the use of road pricing revenue, or restrictions on the use of public transport subsidies.

Most of these restrictions can perhaps be softened or lifted in the long run if there is a compelling reason to do so. Our planning exercise itself may help lift unnecessary restrictions if it can be shown that the optimal result without the restriction is much

better than the optimal result with the restriction in place. The seventh barrier is a little different in this respect. To lift this barrier must either mean that the city need not repay its loans in the appraisal period (which is clearly an unsustainable practice if the appraisal period is long), or it means that money keeps flowing into the system from outside sources at whatever rate is required. Thus the issue concerning this barrier is whether we can expect taxpayers nationwide or in the city to provide unrestricted amounts of finance to the transport and land use system in the city.

As a rule, either we should retain an overall financial barrier or assume that taxpayers' money is costly. If we retain the barrier, we could either pre-screen all our strategies to ensure that they stay within the available finance, whatever that may be, or we could use the present value of finance as one of the indicators in the appraisal framework. If we assume that taxpayers' money is costly, it means to use a positive shadow price of public funds to value the present value of finance. For instance, if a shadow price of public funds of 0.2 euro is used, it means that every euro from public funds or coffers is counted as 1.2 euro in appraisal. See Chapter 8.

# 6 Predicting impacts

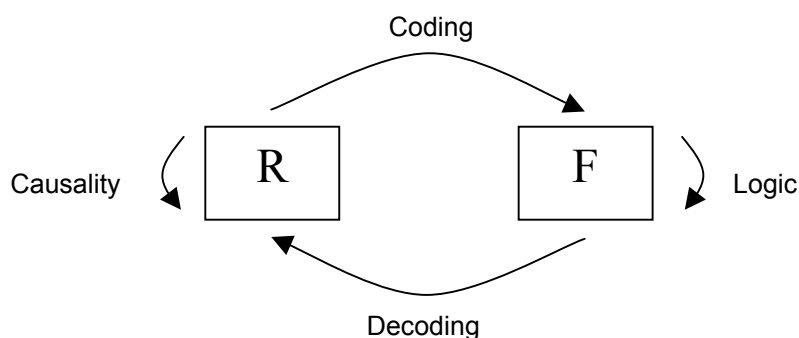
## 6.1 Introduction

In the process of planning for sustainability we want to use models to predict what happens to the urban land use and transport system if we change the conditions in some way, by introducing some policy instrument or other. Our approach, where we appraise how well objectives are met in years far into the future, will by its nature require modelling in some form.

The concepts model and modelling can vary quite considerably, both in terms of abstraction and complexity. In a very wide sense, any systematisation of patterns made to better understand sensory or other data could be regarded as a model. In this sense, parts of the appraisal framework set out in previous chapters are also models. Usually by model we mean a formal mathematical description of a system. Somewhat confusingly, a computer program implementing a package of mathematical models is also often referred to as a model. In this guidebook we use the term in both meanings. This confusion is not as serious as it might seem at first, we will come back to that in a moment.

Let us start with a very general description of what modelling is, from a systems analysis point of view<sup>13</sup>. We want to represent a real world system, R, with a formal system, F, either because we want to gain understanding of R, or because we want to know what might happen if we introduce some changes. In order to do this, the characteristics of R, in terms of e.g. important quantities or dynamic responses to changes, must be determined. We can call this process *coding*. This includes specifying functional relationships between variables, as well as defining initial and boundary conditions.

Figure 6.1. Process coding



The coding can be straightforward in some systems, like in physics and parts of chemistry, where exact measurements of model quantities are available. In other systems, e.g. in biology or economics the coding itself is a major part of the modelling craft. We will come back to this in Sections 6.5 and 6.8.

<sup>13</sup> See e.g. Miser and Quade (1985), for a more general overview of systems analysis.

With the coding done it is up to the model's logic to work out what the implications are. This is the model's counterpart to the real system's causality. The fundamental assumption of modelling is that we can decode, or interpret, the results we get in F, and draw conclusions about the behaviour of R.

If the system in question is complex it might be useful to look at it as made up of different sub-systems, each treated with its own sub-model. Often, there are no theories capable of explaining the system fully. Instead models of different sub-systems can be based on different theoretical foundations. To come back to the confusion around the term model, it is the logic in the box F above that is the model. It does not really matter if that logic is implemented in a computer program or exists only as mathematical formulas.

## 6.2 The need for models

We have seen that the appraisal framework suggested in previous chapters calls for quantitative models that should generally be applied within computer-based modelling systems. But why use mathematical formalism and computers? Meadows and Robinson (1984) list five reasons:

- *Rigour*: When specifying a mathematical model it is necessary to be exact. There is no room for ambiguities. This can actually help in building the understanding of the problem by providing structure.
- *Comprehensiveness*: Computers can handle vast amounts of data, much more than any human mind. They can also incorporate theories from different fields of research into one model system.
- *Logic*: The logical implications of input data are drawn. The model's logic is the counterpart of real world causality.
- *Accessibility*: A formal system - mathematical or other, can be examined by others. Expert judgement, or mental models, are much more difficult to assess and, if necessary, audit.
- *Flexibility*: A range of strategies can be tested with a model, while it can be too expensive or dangerous, or otherwise impossible to test them in the real system.

The flexibility we get from being able to test a range of strategies also extends to the possibility to test strategies in different scenarios. We can illustrate how robust a strategy is with respect to forms of uncertainty in our assumptions.

Related to the first and fourth points above, the mathematical formalism also helps in identifying gaps in our knowledge of the system, or in our data material. By forcing ourselves to specify everything, we can tell exactly what theory and data we have based our forecasts and decisions on. It is also very useful for gaining understanding of the characteristics of a system.

To be really useful as decision support, a model should be able to produce results in a form that is easy to grasp by the decision maker. Mathematical, computer based models, are very versatile in this respect. The output from models can be processed and presented in e.g. tables, maps or animated movies (Chapter 4). How easily this can be done depends on the modelling package.

In Chapter 3 we argued that it is crucial that the same framework is used to appraise all the alternatives. The same argument holds for the modelling package itself. If we want to use a model as the base for appraisal that ranks our alternatives, we have to use the same model in all of them.

## 6.3 What is a good model?

A good model should:

- be theoretically sound and reflect the causal processes
- be based on good data
- use statistically efficient parameter estimation
- reproduce estimation data reasonably well
- reproduce other data reasonably well
- have reasonable elasticities

All these issues should be handled as a part of a validation procedure, discussed below.

Furthermore a good model should:

- provide the required output,
- be easy to use,
- be accepted by the user, and
- be well documented.

Finally, a good model definitely needs to illustrate the desired problem, both in terms of representing the necessary causal relationships and in providing the appropriate output for further analysis.

In our context we focus on using models as forecast and decision support tools. To be useful for decision support it is of paramount importance that the results are trusted. Otherwise it is a futile exercise from the start.

Of course, a certain degree of distrust is prudent. There is no such thing as telling what will really happen. We can either use a model to make a forecast or wait and see what happens. Therefore it is not to be expected that it is possible to represent every detail of the real world system within a model. It should instead be a well-made caricature, where the characteristics of the modelled system are brought out with no more brush strokes than necessary.

The same applies to the whole modelling process. For instance Still et al. (1999) find that the confidence in transport and land use forecasts is dependent on understanding of the theoretical structure of the model and on the transparency of the modelling process. It may be worth pointing out, however, that simplicity cannot be the main objective when constructing a model. The key to a good model is to drop *unnecessary* detail and complexity.

This is where modelling becomes an art.

It is up to the modeller to determine where the optimal trade-off is between detail and simplicity. A less complex model is easier to use as a mental model, and it is easier to follow what it actually does. Thus we might gain important understanding of the problem. On the other hand, with less complexity we might have to sacrifice important causalities and relationships. This might prove disastrous in some cases, e.g. when the objective is to study how different policies interact.

### 6.3.1 Validation

It is a dilemma that complex models used in computer-based model packages are distrusted, even though they may have better forecasting abilities. A step towards lessening this distrust might be to invest more effort in validating the models. People



trust aeroplanes without understanding aerodynamics, and this is largely because flying works, which is a very powerful validation of the theory. Lundqvist and Mattsson (2002) discuss the issue of validating models in the context of national transport model packages. They suggest a kind of checklist, covering most of the points above:

- *Practical validation.* Checking that the model package is well designed at system level, and well applied to the problem: Are the right things exogenous/endogenous in the models? Is the package transparent and easy to use? Are assumptions well documented?
- *Theoretical validation.* Checking that the models have an appropriate theoretical foundation. Is it equilibrium or dynamics based, and is it used appropriately with respect to this? Are the variable relations and causalities reasonably modelled?
- *Internal validation.* Can it reproduce estimation data? Are estimated parameters significant? Sensitivity analysis.
- *External validation.* Can it reproduce other than estimation data (e.g. traffic counts)? Are elasticities reasonable? Can forecasts reproduce time series data?

## **6.4 A quilt of theories**

The focus of this guidebook is on sustainability, often considered to have three aspects; economic sustainability, social sustainability and environmental sustainability. There is no single theory that can both predict the system's responses to strategies and the economic, social and environmental impacts these responses might have. Instead there are several bodies of theory from different scientific traditions, each covering some aspect and each with its own strengths and weaknesses.

The following is not intended to cover all relevant theory used to explain the behaviour of the urban land use and transport system, but rather to briefly review some specifics of the theoretical background of the most commonly used types of models. State-of-the-art urban models are often influenced by several research fields. Other reviews of the theoretical background can be found in Fujita, Krugman and Venables (1999), de la Barra (1989) and Anas (1982).

### **6.4.1 Urban economics**

Urban economics can trace its roots back to von Thünen's (1826) models of location of crops and farms around market towns. In short each farmer faced a trade-off between land prices and transport costs. But if the crops are allowed to differ in how much they yield per area unit and in transport costs, the competition will lead to a pattern where high value crops are grown closer to the market. The land price, determined by what is called 'bid-rents' or willingness-to-pay, will be declining with distance from a maximum at the centre of the area.

In the 1960's the von Thünen model was reinterpreted by Alonso (1964) to explain commuting to a central business district in a monocentric city. The central concept is that of land prices being set by a bid-rent mechanism, in a partial equilibrium fashion.

### **6.4.2 Gravity models**

From the 1950's onwards transport engineers have been using gravity models to predict balanced origin-destination matrices in transport networks. Wilson (1967)

showed that it was possible to give the gravity models a theoretical foundation, with an approach analogous to entropy maximisation in statistical mechanics.

A gravity model in this context can be thought of as finding the most probable state of a system fulfilling a set of constraints. Examples of constraints are known numbers of trips originating in each zone, or a known total number of trips by mode. It is also possible to derive the gravity model from information minimisation assumptions (see e.g. Snickars and Weibull, 1977).

### **6.4.3 Random Utility Models**

A third strand of theory started out from theories of individual choice. McFadden (1973) derived a tool for analysing individual choice behaviour, first applied in a transport-planning context. The starting point was the behavioural assumption that an individual would choose the alternative with the greatest utility, in the tradition of microeconomics.

By introducing a stochastic error term with some specific properties, McFadden derived the multinomial logit model. It has turned out to be a very powerful tool in analysing choice behaviour in econometrics. In contrast to the gravity approach, where models were estimated using aggregate data, the random utility models used data of choice behaviour at the level of individuals.

An interesting point is that the multinomial logit (MNL) model is derivable from both random utility maximisation and information minimisation/entropy maximisation, as shown by Anas (1983). This does not mean the two approaches are equivalent, because either approach can lead to other models than the MNL, depending on how the specification is made. But it shows that a properly specified MNL model estimated on aggregate data still is consistent with utility maximisation. This is important when carrying out welfare analysis (see Chapter 9).

### **6.4.4 Urban Simulation**

Lowry (1964) introduced the notion of linking models of different sectors of the urban system together, in his case basic employment, residential location and service employment. An iterative procedure was used where the output from each sub-model was fed into the next until the process converged. Many models of land use and transport today are using this approach.

## **6.5 Land use-transport interaction (LUTI) models**

In order to find good combinations of policies to address issues of sustainability we argue that it is necessary to look at the urban system as an interaction between transport patterns and location patterns. The reason, of course, is that there seem to be strong dependencies between the two. An obvious example is that car use is very high in the sprawling cities of the United States, while in other cities, both in the U.S. and elsewhere, more public transport and more dense location patterns seems to go hand in hand.

This simple observation on its own will not help us achieve sustainability. To be able to provide predictions of the kind of indicators the appraisal framework requires we need more sophistication, though it is of course impossible for a model to incorporate all the possible causalities involved.

### **6.5.1 Dynamics**

There are a lot of decisions going on in an urban area at any given time. Since there is no single theory to explain all of them it is customary to split the urban system into several sub-systems. Wegener (1986, 1998) identifies the following eight, ordered by the speed with which they change:

*Very slow:* Networks, land use

*Slow:* Workplaces, housing

*Fast:* Employment, population

*Very fast:* Goods transport, travel

He also identifies a ninth sub-system, *urban environment*, difficult to include in the time scale view above. Different aspects of the environment react on very different time-scales.

Arguably, the political decision-making system could be included as well. In the planning process we envisage in this Guidebook, we generally leave this factor outside the modelled system, and the judgement on how political processes and public reaction will turn out is left solely to the decision maker. On the other hand, in the long time frame necessary to analyse sustainability issues, political conditions might change and affect the system. (Section 6.7 describes a modelling approach, used in a *policy explorer*, which represents such factors explicitly).

### **6.5.2 Ways of representing dynamic change**

In present day computer-based modelling systems there are typically two generic methods for representing dynamics:

*Time-marching approaches* (which are a particular type of *system dynamic* approach and can be considered as “naturally dynamic”) where many connected sub-periods are modelled throughout the period under consideration. Time-marching models can represent policy instruments with different levels for each modelled sub-period with respect to instrument attributes such as time of day and location. In theory a time-marching model could model steps of one year though in practice each model has different assumptions for the time steps used.

*Equilibrium approaches*, where one or more target years are used to represent short and long term effects, and it is assumed that an equilibrium exists in each of these target years. The model does not try to explain implicitly how demand and supply change between target years: these changes are estimated by exogenous assumptions or models.

In the research community there is currently much discussion about the relative benefits of systems dynamics and equilibrium approaches. In general, the arguments can be summarised by the statements in Table 6.1.

**Table 6.1. Systems Dynamics versus Equilibrium models**

	<b>Systems Dynamics Models</b>	<b>Equilibrium models</b>
<b>FOR</b>	Life can be observed to be a dynamic process. At times, certain cities can go through fundamental changes which might be predicted by a system dynamic model.	For any one snapshot in time, an equilibrium model provides a representation which has a certain internal consistency. Powerful tools for parameter estimation and model calibration are available.
<b>AGAINST</b>	A system dynamics model is overly dependent upon the accuracy of the parameters it uses: if these are inaccurate the model can “go off” in strange directions and produce unbelievable or wrong results.	Equilibria do not actually exist but are a purely theoretical concept for representing systems. Their main disadvantage is that they can hide the potential for large change and are hence innately conservative.

## 6.6 Sketch planning models

The LUTI models described above typically have a long run time when implemented in a computer-based model system and in many circumstances it might not be feasible on resource grounds either to build or run such a model system. An alternative is to use a *Sketch Planning Model* which makes model predictions on a more strategic level than a standard LUTI model, and hence is much simpler to build and faster to implement in a computer-based model system.

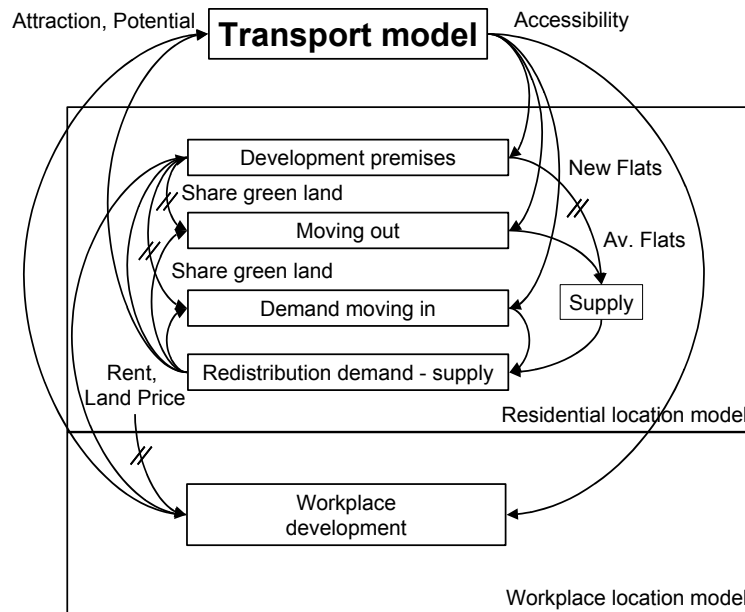
Compared to a large-scale LUTI model, a Sketch Planning Model may mean a simplification with respect to:

- *The network.* An abstract network is substituted for the real network of the LUTI. This means that there is no route choice, and that interaction between traffic to different destinations is not accounted for.
- *The agents (households and firms).* Instead of different socio-economic groups, each with their own preferences, a single average group is formed.
- *The trip purposes.* Possibly only one, two or at most three purposes.
- *The markets.* Supply and demand in all markets is not explicitly modeled. While trips and the housing market are probably explicitly modelled, adjoining markets such as the labour market and other markets for inputs to production are not.
- *The choice set.* Dimensions of choice such as time of day or size of house may be left out.

Experience in PROSPECTS shows that the sketch planning model applied there (PROSPECTS SPM, Pfaffenbichler et al 2003) can achieve very fast run times and is modest with respect to data requirements and therefore can be set up and calibrated fairly quickly. However, the art of making a SPM is not only to make a fast model, but also to make a model that actually addresses the broad and important long run strategic issues. This may mean fairly much detail with respect to other aspects, such as the behaviour of developers, environmental effects and car ownership and technology choices (not all of these are addressed in the PROSPECTS SPM). The PROSPECTS SPM is a “time-marching” model in the terminology of Section 6.5.2, which means that it is thought important to represent some of the different time-scales referred to in Section 6.5.1. A good representation of walking and cycling is thought to be very important for the strategic decisions.

Some of the basic interactions of the PROSPECTS SPM are shown in Figure 6.1.

**Figure 6.2. Link between the transport and the land use sub-model of the SPM**



## 6.7 Policy explorers

Policy Explorers are computer based simulation models of the land use and transport system in a hypothetical urban area which are not intended to represent any actual city. They are designed to help explore the generic interaction of transport planning policies and to clarify the issues involved in the formulation, execution and appraisal of such policies. By avoiding the need to consider the peculiarities that exist in a particular city (and which distinguish it from other cities), they are particularly useful as learning tools.

One such policy explorer is PLUTO, Planning Land Use and Transport Options (Page 2000) described below as an example. Another model with many similar features, used to study for instance effects of toll rings and ring roads, can be found in Eliasson and Mattsson (2001), and Mattsson and Sjölin (2002)

In PLUTO, users take on the role of transport and land use planners for a hypothetical city ('Plutopia'). After studying the conditions and trends in the city, they are encouraged to set objectives and specify criteria by which their achievement might be measured. They then formulate a range of strategies designed to secure these objectives over a period of five years. Having commissioned model forecasts to test the likely performance of these strategies, they then select the most promising strategy (or combination of strategies).

The chosen strategy is then implemented in five annual stages. At each yearend the user will receive feedback on the evolving state of the city (including voters' and business confidence!) and may use this information to fine-tune or further revise the strategy. At the end of the five year period the user should determine the extent to

which their policy objectives have been met.

The forecasting model at the heart of PLUTO represents all the most important mechanisms which affect the evolution of the land use and transport system of real-world cities. Indeed it has several features, such as its treatment of the evolution of land uses in response to changing economic conditions and its representation of the commercial behaviour of bus operators, which are not normally found in the most widely used transport models. This level of sophistication allows users to be fairly confident that policy effects that might be expected in the real world will also occur in Plutopia. For the purposes of the exercise users can therefore assume that Plutopia *is* a real city and behave accordingly.

However, in the interests of reducing computer run time to a manageable level, and in order to reduce the amount of time needed for users to become familiar with the city, a number of important simplifications have been made. The most significant of these simplifications are in the structure of the city (it has perfect radial symmetry and exists as an 'island' without connections to any external networks) and in the simplification of its travel patterns (freight traffic and all non home-based trips are ignored and the only modes available are car, bus and walk). Given these simplifications it would be quite wrong to assume that the performance of particular policies in Plutopia is an accurate indication of their likely performance in any given real world city.

Various policy instruments are available to the user within PLUTO as follows:

- Major construction projects
- Bus lanes
- Sponsoring changes in bus fares or frequencies
- Traffic management and restraint
- Development control
- Road maintenance
- Financial Planning

## **6.8 Desired capabilities**

So far we have discussed modelling from a general systems analysis point of view and briefly described some examples of modelling tools, from large-scale integrated land use/transport models to simple pedagogic devices. We touched upon the modelling of dynamics in general, which is a part of coding the real world system into a formal one. Let us now go into more detail on what we consider to be the important features of a land use and transport model and point out some shortcomings.

Ideally, we would use the indicators from Chapter 3 as a checklist of output from the model. Similarly a list of available policy instruments could be used as a wish list of input variables. But indicators and instruments are represented in different ways in different models. Instead we define two general categories of model capability:

The representation of the *supply effects* which result from the implementation of transport instruments. These effects are of two types. Firstly there are those effects which result automatically from the implementation of an instrument (without any behavioural response occurring). Secondly, there are those changes in supply that occur once such behavioural responses have taken place. Both types of effect can be subdivided into *system internal supply effects* (such as changes in capacity and direct user costs) and *social and environmental effects* (such as accidents and pollution). The latter may also be called system external effects.

The implementation of transport or land use instruments lead to supply effects which in turn trigger *behavioural responses* by the various actors in the transport / land use system. These can be further subdivided into: *responses by system users* (either individuals or organisations); *responses by suppliers*; and *public opinion responses*.

### 6.8.1 System internal supply effects

System internal supply effects can be defined as those supply effects that lead directly to user responses in the land use / transport system.<sup>14</sup> Five basic classes of internal supply effects are considered:

- Capacity/congestion
- Direct user costs
- Reliability of journey time
- Quality of journey
- Information provision

*Capacity* concerns the capacity of the whole transport system and results from the aggregation of the capacities of individual elements of the system, such as the capacity of a road. *Congestion* concerns the interaction between capacity and demand, and in particular how the level of system service deteriorates as demand increases.

*Direct user costs* are those costs which the land use/transport system user experiences subjectively. Typically, such costs include expected journey time and money costs and are aggregated to form a generalised cost function. It is usually argued that these costs are the most important to take into account when modelling behavioural responses. However, other user costs (for example those considered immediately below) can also be considered.

*Reliability, quality and information provision* are here understood to be objective characteristics of the land use/transport system which might be automatically altered by the implementation of an instrument. In order to represent such a change, it is firstly necessary to be able to measure (in some quantitative way) the overall level of reliability, quality or information in the system. It is important not to confuse such objective measures with the contribution that reliability, quality and information provision might make towards a user's subjectively experienced direct costs. Although it is likely that there would be a correlation between objective characteristics and subjective costs, they are essentially different elements of the land use / transport system.

Congestion and other user costs are always modelled in land use and transport models, whereas reliability, quality provision and information provision are often not. This is obviously a shortcoming. In particular, one might wish to incorporate the effects of intelligent transport systems (ITS), e-commerce and other new technology developments, which will currently have to be assessed as part of the description of the scenario (Section 2.5).

### 6.8.2 Social and environmental effects

*Social and environmental effects* are defined as those effects which occur outside the land use and transport systems being studied, and such effects are not assumed to

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<sup>14</sup> In some models, social and environmental effects may also trigger behavioural responses (as they will in the real world). This is ignored for the purpose of a simple classification of effects.

change the behaviour or affect the choices of the users of the system. A broad range of effects may be considered under this heading, including environmental effects, accidents, implications for government budgets, and wider economic and social impacts. Some of these effects (especially global and regional environmental effects and some of the wider economic impacts) will be felt by residents living outside the studied area and even living far into the future.

Effects that are experienced by residents in the studied land use/transport system will also be classified here provided they do not affect them in their capacity as travellers or influence their location choices. Thus a policy might affect them as taxpayers, but since their response to tax increases is not a part of the land use/transport system as we define it in most cases, this will be an external supply effect in most cases. Also, travellers in the transport system are currently not assumed to change their decisions based on, say, the changes in the accident rates of different modes or the levels of local pollution experienced on a trip. This is why we can regard such effects as lying outside the studied system.

The concept of social and environmental (system external) effects must therefore be defined relative to the studied system and the purpose of the study (strategic, tactical) being made. In an integrated land use/transport context, local pollution will perhaps be a borderline case. For the travellers in the transport system, local pollution is an external effect, since the level of local pollution does not affect their trip behaviour. But the same individuals are also residents in the location system. If changes in local pollution levels in the zones affect their location choices, and if the link between traffic volumes and zonal levels of pollution is established in our model of the system, local pollution can clearly not be seen as a wholly external effect any longer. In fact, in the DELTA modelling system used in PROSPECTS local air pollution (along with noise pollution) from transport is considered to be a factor in the residential location choice model<sup>15</sup>. Hence, in the DELTA system, local pollution (both air and noise) from transport is a system internal effect. Unfortunately, though, this approach is not common in land use modelling systems, and so local pollution is treated as a system external effect here.<sup>16</sup>

We consider the following system external effects, which can be seen to tie in closely with the indicators defined in Section 3.3:

- Environmental effects
- Traffic accidents
- Health effects

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<sup>15</sup> However, a distinction needs to be made here between *zonal levels of pollution* (the subject of this discussion) and the *amount of emissions from traffic generated in each zone*. The latter does not take account of pollution from non-transport sources or the dispersion effects of pollution due to, for example, weather conditions, and hence it is the former concept that more closely fits with standard perceptions of air quality. In the DELTA modelling package there is a link between traffic emissions generated in a zone and location choice. However, this link should be seen as a proxy for the link between zonal levels of pollution and location choice and is clearly a modelling simplification.

<sup>16</sup> Even if agents in the model do respond to a supply effect, they might not respond properly from an economic efficiency point of view, that is, there might still be uninternalised external costs in the sense of economics. Thus the concepts of system external and system internal effects do not coincide with externalities and the internalisation of externalities in economics. The only difference between a system internal and a system external effect in our terminology is that the latter does not influence the behaviour of the users of the system as we conceive or model it.



- Liveable streets and neighbourhoods
- Implications for government budgets
- Equity and social inclusion
- Economic growth

Per definition of these effects, they can be modelled by models *appended* to the modelling system. Data to compute these effects comes from either the land use/transport model input or from its output. More or less sophisticated processing of the data might be required to establish the effects. Examples of such post-modelling include equity analysis, accident analysis and air pollution modelling. Usually, current models apply very crude post-models of these types, and there is scope for large improvements.

### **6.8.3 User responses**

Demand/behavioural responses by system users can be separated into four categories:

- Location responses
- Strategic transport responses
- Responses to expected daily traffic conditions
- Responses to unexpected conditions

The meaning of *location responses* is probably clear without further explanation, except that users in this case need not be equivalent to a person. It can also be companies or other organisations.

However, it is useful to explain further the categories of transport response, and such discussion will hopefully help to distinguish between them. Two types of *strategic transport responses* are considered. On the one hand, there are discrete long-term decisions which are likely to have a heavy consequential influence on transport behaviour. For example, buying a car, motorcycle or public transport season ticket are such events. The other type of strategic transport response simply concerns the overall quantity of travel carried out, without disaggregating between purpose, mode or other factors.

The responses to expected daily traffic conditions include the choices of destination, mode, time-of-day and route, and ways in which daily activities are combined and trips are chained. Destination, mode and route choice are included in most models, whereas time-of-day and trip chaining are still considered “advanced” by many.

Responses to unexpected conditions include reconsideration of the usual or habitual choices in the light of information about unexpected events, or in the light of other information issued or traffic control measures taken on that particular day. Such responses are usually modelled by microsimulation models, which are not a part of the ordinary modelling system. But even so, events are frequent enough and the information and traffic control measures are important enough to be able to influence ordinary behaviour.

Modelling of user responses are at the core of current models, but even so, there are considerable challenges in taking more aspects of behaviour into account and in combining the long-term and short-term responses in a single consistent modelling system.

#### **6.8.4 Supplier responses**

The assumption underlying much of the planning approach described in this Guidebook is that there is a responsible “transport/land use authority” who is the main initiator of the instruments given in the rows of the tables. The reality that there might be splits in responsibility between a number of organisations was addressed at the start of this guidebook (in Section 1.1). This split in responsibility leads to the issue of supplier responses.

Where organisations different from the main transport authority have supplier responsibilities, they are termed *third party suppliers*. They may be private firms (public transport operators, property developers, other businesses), neighbouring local government or others. The actions of third party suppliers, except developers and landlords, are rarely modelled. Such actions may include:

- Developing unused land (greenfield, whitefield, brownfield) and deciding on its use (housing, business etc.) and density of use.
- Building of houses, office buildings and other facilities on the available land. (Some such decisions are included in most LUTI models).
- Determining rents (included in most models).
- Operating or stopping to operate public transport services, reorganisations of public transport.
- Changing rail/bus frequency.
- Changing size of trains/buses.
- Changing rail/bus fares.
- Changing public transport quality.
- Changing total car parking capacity.
- Reallocating car parking space between “long term” and “short term”.
- Changing car park charges.

Furthermore, other land/transport authorities (such as neighbouring authorities or authorities on a higher/lower level) could make supplier responses by implementing any of the land use / transport instruments considered throughout this Guidebook.

Because of the difficulties of predicting these responses they are often modelled as changes in the input assumptions. In the light of the current trend of liberalisation of transport markets and the continuing lack of coordination of land use and transport responsibilities in many cities, this is a shortcoming of current model systems.

#### **6.8.5 Public opinion responses**

The term *public opinion responses* encompasses both the impacts on public opinion of implementing particular instruments as well as the action taken by the public in response to these impacts. In general, the term *public opinion* includes both the majority opinion of society (as expressed through democratic processes) and the opinion of special interest groups who have the power to affect transport policy. Examples of the latter are business organisations, the media, the police and environmental organisations.

Current land use/transportation models do not generally represent public opinion responses and it is legitimate to question why they should. On one hand, it could be

argued that if planners are attempting to make predictions about the future development of the land use/transport system, they need to take into account all the actions of participants in this system that are liable to change it. These actors include users, suppliers and the public. If actors are missing from the representation of the system, predictions about it are liable to be wrong. On the other hand, no such models exist (except for a similar feature of PLUTO, see section 6.7), and it might be argued that to present the public and decision-makers with a model of how they are likely to act in the future is inappropriate.

### 6.8.6 Capabilities of already-existing software packages

Our survey of modelling capabilities has identified the following weaknesses and shortcomings of most model systems in use at present:

- Reliability, quality provision and information provision is not modelled (Section 6.8.1).
- Most models usually apply very crude post-models of the social and environmental effects, and there is scope for large improvements (Section 6.8.2).
- There are considerable challenges in taking more aspects of user behaviour into account and in combining the long-term and short-term responses in a single consistent modelling system (Section 6.8.3).
- In the light of the current trend of liberalisation of transport markets and the continuing lack of coordination of land use and transport responsibilities in many cities, there is a need for modelling the responses of at least some of the major categories of suppliers (Section 6.8.4).

Some modelling systems are definitely better than the average in some of these respects, and we may expect more to happen in the future. But even if these shortcomings are serious, the question must be asked if they are so serious as to invalidate any long-term predictions using the average, state-of-the-art model. We believe that provided the long-term (“strategic”) decisions about car ownership and location have been adequately incorporated in the current state-of-the-art modelling system, it may be regarded as a “well-made caricature” of the real world system (Section 6.3), capable of telling us important things about the future development of the city.

Timms and Minken (2002) carried out a review of the computer model packages used in PROSPECTS with regard to whether they include the above-described capabilities. The results are summarised in Table 6.2, where the number of  $\sqrt{s}$  represents the relative degree of model package capability, and where X represents no capability. Three points must be made when interpreting this table:

There is clearly a great deal of variety between different large-scale models. Table 6.2 can only provide a rough overview.

There is no indication in the table as to *how well* any particular model package represents an effect or response. The table is simply concerned as to whether the model packages try to make the relevant representation.

The different types of model are all intentionally pitched at different levels of aggregation (and in fact the Policy Explorers do not even represent specific cities). Thus a simplistic comparison (without trying to understand the needs of the model-users) should not be inferred from the table.

**Table 6.2. Capabilities of different types of model package.**

	<b>Large-scale models</b>	<b>Sketch Planning Models</b>	<b>Policy explorers</b>
<b>System internal supply effects</b>	√√√	√√	√
<b>System external effects</b>	√√√	√√	√
<b>User responses</b>	√√√	√√	√√
<b>Supplier responses</b>	√	√	√
<b>Public opinion responses</b>	X	X	√

# 7 Optimisation

## 7.1 Background

Formal optimisation is a relatively new concept in the analysis of integrated land use and transport strategies. Early contributions include Wilson et al (1981) and Lundqvist and Mattsson (1983). Optimisation with respect to land use policies was built into the IMREL model system (Anderstig and Mattsson 1991, Boyce and Mattsson 2000). A number of papers, including Fowkes et al (1998), May et al (2000) and Timms et al (2002), have described a method for finding optimal urban transport policies using any kind of transport model.

Optimisation involves maximising a quantified objective function within a given scenario, and subject to a given set of constraints, by using a given range of land use and transport policy instruments. At the heart of this optimisation process lies the definition of objective functions which encapsulate policy-maker objectives, as described in Section 3.5. By use of a suitable transport model, sets of transport policies (instruments and their levels of implementation) are found that maximise the value of the objective function.

Normally, planning consists in testing and appraising predefined strategies. Optimisation is different in this respect. The policy instruments to use are specified only within certain ranges, and the particular levels of the instruments are determined as the levels which together produces the highest value of the objective function. This is particularly useful for strategic studies, because it provides knowledge on how instruments interact when they are used in the best possible way, and it produces optimal strategies that were perhaps never even thought of in advance.

Optimisation may also be of help in selecting the policy instruments to use, since an instrument which is optimally used at the “zero” level is obviously not contributing anything that the other instruments could not do better.

Traditionally, cities and their consultants have attempted to determine the best strategy through a process of identifying a possible solution, testing it, appraising it and then seeking improvements. These improvements could either be straightforwardly to increase performance, or to overcome barriers such as lack of finance or limited public support. However, this process can be inefficient; time will be wasted on testing inappropriate strategies, and there is no guarantee that the best strategy will be found. Thus the benefits of optimisation are both in developing more effective strategies and in doing so more rapidly. In an early example in Edinburgh, an initial study used some 70 model runs to develop a “best” strategy; a subsequent study using optimisation methods found a combination of policy instruments, after 25 model runs, which increased economic efficiency by a further 20%.

The instruments identified in Appendix I cover a wide range of possibilities. The formal optimisation process will lend itself well to optimisation of *strategic* instruments which form the basis of an overall package or plan. Strategic instruments can be considered as those instruments which are expected to have a significant impact upon indicators and objectives, or which impact upon a significant area of the city or a particular corridor. Furthermore most strategic instruments have some parameter (e.g. price) that can be varied and hence optimised.

All other instruments are considered as local and relatively inexpensive. The local instruments are to be appraised within the overall framework against the common set of indicators (as covered in Chapter 3). It is envisaged that once a preferred set of strategic instruments has been selected then these local instruments may be added to the overall plan and that this can only enhance the overall policy.

Barriers to implementation of certain instruments were discussed in Section 2.8, and can be dealt with in two ways. Firstly, the barrier can act as a constraint on the range within which the instruments may be considered. Alternatively, the instrument can be considered without constraints within the optimisation process and the benefit of removing the barrier can be presented to the decision maker.

Targets for some of the indicators may also be modelled as constraints in the optimisation problem.

In the following sections we

- describe the general optimisation problem,
- develop categories for the policy instruments (continuous and discrete),
- introduce the time dimension and the concept of policy profiles,
- identify model types (time-marching and equilibrium based),
- describe three optimisation approaches,
- and discuss how to deal with different types of constraints.

## **7.2 The general optimisation problem**

### **7.2.1 Statement of the problem**

The general problem relates to maximising a quantified objective function (either some form of CBA or quantified MCA) within a given exogenous scenario using a given range of land use and transport policy instruments. The appraisal period is taken to be 30 years though the sustainability issues relate to an even longer term. Chapter 3 has defined the overall objective in terms of sustainability and its seven sub-objectives:

- economic efficiency
- protection of the environment
- liveable streets and neighbourhoods
- safety
- equity and social inclusion
- contribution to economic growth

The seventh objective of intergenerational equity will also have to be addressed.

The first sub-objective is dealt with by standard cost-benefit analysis. For the next five sub-objectives, indicators have been defined. There is no one-to-one relationship between indicators and sub-objectives, though, since some of the sub-objectives are of a composite nature. Intergenerational equity is dealt with by weighting the annual benefits in the objective function.

Let  $M$  be the set of indicators that we want to apply in a particular study. In principle, we should be able to compute them for any of the years in the appraisal period. For all or a sub-set of the indicators, their annual levels are included linearly in the objective function. For some of the years, there will be targets on some of the indicators, or

there will be other constraints on their levels. We do not assume that the indicators that go into the constraints cannot be used in the objective function, neither do we assume that all indicators need to be included in the objective function. Some may be used only as constraints or be kept out from the optimisation altogether. But to appraise all strategies against the same objective function, we do require the objective function to be the same throughout a particular study.

Let  $\mathbf{X}_t = (X_{1t}, \dots, X_{nt})$  be the vector of the levels of the  $n$  policy instruments in the year  $t$ , and  $\mathbf{X} = (\mathbf{X}_1, \dots, \mathbf{X}_{30})$  be the vector of policy instrument vectors from the first to the last year of the appraisal period (here, from year 1 to year 30). Any specific  $\mathbf{X}$  is what we have previously called a strategy. We have seen that it is important to recognise that there may be barriers to the use of the policy instruments. This is represented by the requirement that the strategies we consider belong to a set  $K$ .

Thus the general form of the optimisation problem can be written as follows:

(7.1)

$$\text{Maximise } OF(\mathbf{X}) = \sum_{\mathbf{X} \in K} \sum_{t=0}^{30} \alpha_t (b_t(\mathbf{X}) - c_t(\mathbf{X}) - I_t(\mathbf{X}) - \gamma_t g_t(X)) + \sum_{i \in M} \sum_{t=0}^{30} \mu_{it} y_{it}(X)$$

s.t.

$$\sum_{t=0}^{30} \omega_{it} y_{it} \leq C_i \quad \forall i \in M$$

$$y_{it} \leq C_{it} \quad \forall i \in M, \forall t \in (0, 1, \dots, 30)$$

Let us explain (7.1).  $OF$  is the objective function, the same as was defined in equation (3.1) of Section 3.5. As can be seen, all of its elements are functions of the whole strategy  $\mathbf{X}$ , and not necessarily only of the policies in place in any particular year,  $\mathbf{X}_t$ . For the benefit of the reader, the meaning of the symbols is repeated below. The first term represents economic efficiency where

$b_t$  is the sum of all benefits in year  $t$

$c_t$  is the sum of all costs in year  $t$

$I_t$  is the sum of capital investments in year  $t$

$\gamma_t$  is the shadow cost of  $\text{CO}_2$  emission, reflecting national  $\text{CO}_2$  targets for year  $t$ ,

$g_t$  is the amount of  $\text{CO}_2$  emissions in year  $t$ ,

The annual cost and benefit terms are weighted by  $\alpha_t$ . We use

$$\alpha_t = \alpha \frac{1}{(1+r)^t}$$

for all years between 0 and 29. Here,  $r$  is a (country specific) discount rate and  $\alpha$ , the intergenerational equity constant, is a constant between 0 and 1, reflecting the relative importance of welfare at present as opposed to the welfare of future generations. So for these years,  $\alpha_t$  is an ordinary discount factor. For year 30,

$$\alpha_{30} = \alpha \frac{1}{(1+r)^{30}} + (1-\alpha).$$

In case not all 30 years are modelled, we may use the last modelled year instead of year 30 as the year with the exceptional term.

Furthermore,

$i$  represents the remaining indicators ( $i \in M$ )

$y_{it}$  is the level of indicator  $i$  in year  $t$

$\mu_{it}$  is the weight in year  $t$  for indicator  $i$

$C_{it}$  is the constraint/target for indicator  $i$  in year  $t$

$C_i$  is the overall constraint/target for indicator  $i$  (for instance, a financial constraint)

$w_{it}$  is a weight, possibly but not necessarily a discount factor.

Note that there are two kinds of constraints in the optimization problem (7.1). The first says that a weighted sum of the annual values of indicator  $i$  should keep within a certain bound  $C_i$ , while the second is a constraint on the indicator value at particular points in time. Not all of these constraints will actually be used in a particular case – if there is no constraint,  $C_i$  or  $C_{it}$  can be set to a high number. (The first type of constraint can be used if we require the annual average of some indicator to reach a certain level, or if we are interested in the cumulative effects. The second type will often be used to set environmental goals for the end of the appraisal period).

Note that the constraints and weights for the indicators are taken as inputs from the appraisal framework. Both are included in the specification of the general problem, though some indicators will be incorporated by constraints or targets alone while others may be incorporated by weights alone. The specification of a target implies a certain shadow price may be output; while specification of a shadow price as an input weight implies a target (though this may not be known in advance).

It is possible that targets and shadow prices, where more than one indicator is involved, may be inconsistent (The targets are set by decision-makers without full knowledge of the modelling process which will derive these indicators, and the shadow prices are dependent upon the models used and upon the combinations of instruments adopted in any particular optimisation – output shadow prices may then differ from other estimates from literature if we use methods which provide the implied shadow prices to meet the targets). Note that most targets will be specified for around 10 years in the future and that targets for years 20 and 30 years in the future will have to be set with some “expert judgement”.

We may also wish to add specific financial constraints within the objective function other than that implied by the inclusion of the present value of finance which is naturally included within the economic efficiency terms. It may be that financial constraints can be dealt with prior to any optimisation process as part of the initial screening of available instruments.

We assume that the policy instruments can in the most general case be applied at any level in any one year ( $t = 0, \dots, 30$ ). Thus, for a single instrument there could in theory be 30 different levels in the optimal solution. In practice we do not intend to solve this theoretical problem for a number of reasons:

- The optimal policy should be easily understood and easy to present to the public and other decision makers.
- Optimisation processes become harder to solve as the number of variables is increased with increased likelihood of finding local optima rather than a global optimum.



- Furthermore, each optimisation requires more computing time as the number of variables is increased.
- Some software packages used cannot represent instruments varying over time to such a fine degree or many more runs would be required which would be computer resource intensive.

With this in mind the following sections discuss the general problem and simplify the approach where appropriate.

### 7.2.2 Types of policy instrument

The vector  $\mathbf{X}_t$  may consist of differing types of *strategic* policy instruments as suggested below:

- *Continuous overall policy variables* are policy variables that are used to change the relative overall level of an instrument applied to the whole of the study area or a significant part thereof. Examples would include changes in the relative level of the fuel tax, changing parking charges in different zones by the same percentage, changes in uniform tolls around a cordon, uniform changes in public transport fares and frequencies.
- *Discrete policy variables* are binary (0,1) variables which describe an instrument as either used or not used (on/off). Whether to implement a large road investment project is one example of a discrete instrument, i.e. the investment project is either implemented or not implemented. Some discrete instruments introduce an associated continuous variable and the dimension of the problem increases, e.g. different cordon locations may be considered as discrete options within the optimisation process with the charge as an associated variable.
- *Other dimensions.* These basic continuous and discrete variables can be given other dimensions in space, by time of day and by other instrument specific attributes. For example pricing instruments can be given different levels in the peak and off-peak as suggested by marginal cost pricing. Parking charges can vary by time of day, duration of stay and by zone within a city. Property taxes may vary according to zone and use of floor-space.

Thus the general problem is to maximise  $OF$  given a set of policy instruments  $\mathbf{X}_t$  which are made up from say

- c continuous overall policy instruments
- d discrete policy instruments
- with many more dimensions possible but specific to each instrument.

If we suppose that the discrete policy instruments can be applied in any year, and that the year of implementation is to be optimised for discrete variables, this gives us a total of  $30*(c+d)$  optimisation variables assuming no “other” dimensions were to be optimised. Thus it is important to acknowledge the dimensions of each policy instrument early in the decision process and concentrate upon the most significant attributes/dimensions for each instrument.

Given the nature of the objective function i.e. a very complex *black-box* function, the fact that it is a constrained optimisation would suggest that the maximum number of variables should be limited as much as possible. Previous experience in SAMI (2000) suggests a limit of around 30 variables would be reasonable before the problem should be broken down further and a decentralised approach utilised. Experience in OPTIMA (May et al, 2000) and FATIMA (2000) would suggest that around 10-15

variables is a very complex problem to solve using one of our optimisation algorithms, the regression approach. It is desirable to limit the number of variables for optimisation to be less than 15 for the regression based approach. More variables can be used with automated procedures.

Whilst some policy options such as discrete measures being considered in only one year can help cut down the problem, the most efficient and practical method for trimming the problem down is to limit the variation of all the instruments over the evaluation period.

Our approach is to specify a piece-wise linear policy profile where policy instrument levels are optimised for two points in time,  $t_A$  *the implementation year* and  $t_L$  *the long run year*. Thus we need only specify the year of implementation  $t_A$  and the number of years until a long run value is to be expected.

As we will see, the assumptions regarding choice of implementation year and long run year plays a crucial role in developing the modelling approach.

### **7.2.3 The time dimension**

Economic theory suggests that if there is investment, there should be a short run and a long run optimal value associated with each policy instrument. Limiting each policy instrument to be optimised in only two periods (specific years) would reduce the number of optimisation variables to  $2*(c+d)$  (still assuming no “other” dimensions), and would produce an “instrument profile” over time which varies according to the interpolation and extrapolation assumptions for each type of instrument. In theory, then, it is feasible to use two points in time to specify an optimal short run and long run instrument profile. However, practicalities such as phased implementation of certain instruments and possible choices as to when to implement instruments may not always coincide with our (cities’) judgement of when short run and long run effects should be optimised. Indeed, in a package of measures, some measures will be implemented immediately, having immediate effect, others will be implemented immediately but have lagged effects. Still others may not be implemented until later on in the evaluation period. These practical issues also affect the choice of the modelling approach to be used.

The assumptions that can be applied vary with the type of model being used. As stated in Section 6.5, we have identified two generic model types with respect to dynamics:

- Time-marching approaches, where many connected sub-periods are modelled throughout the evaluation period.
- Equilibrium approaches (where two/three target years are used to represent short and long term effects).

So from a modelling point of view we have to consider two different approaches to represent the same general problem, though both model types will adopt the same basic assumptions regarding policy profiles and benefit profiles where possible.

### **7.2.4 Time-marching models**

Our experience with time-marching models (within the PROSPECTS study) includes use of the sketch-planning model (SPM), the policy explorer PLUTO and DELTA-START. The time-marching models can implement policy instruments with different levels for each modelled sub-period, with other instrument attributes such as time of day and spatial differences as appropriate. In theory, a time-marching model could

model steps of one year, though in practice each model has different assumptions for the time steps used. The following discussion is based on one year time steps.

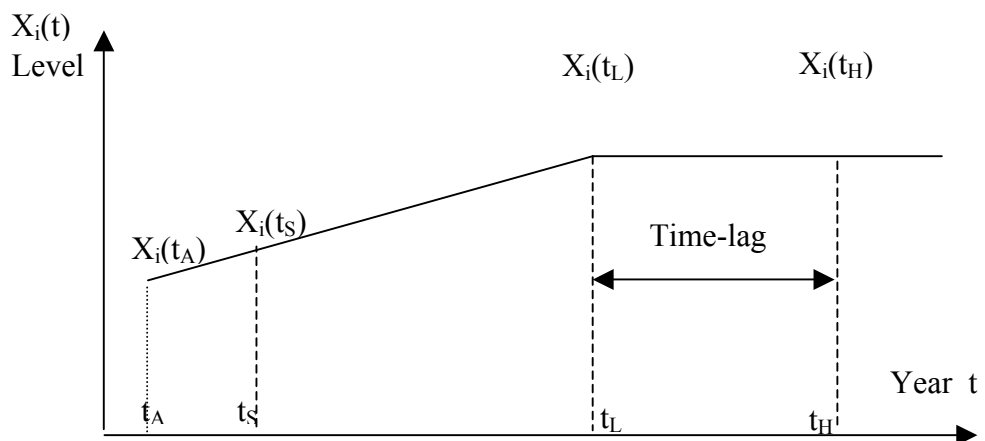
Each modelled sub-period produces outputs that can be used to form  $b_t$ ,  $c_t$ , and  $y_{it}$  directly for use in the objective function OF as defined in equation (7.1). Where time-steps are greater than one year, some form of interpolation will be required.

For both the time marching models and the equilibrium models, both discrete and continuous instruments are optimised in a short-term year  $t_A$  (implementation year) and a long-term year  $t_L$ . The vector of levels on instruments in the short-term year are denoted  $\mathbf{X}_A$  and levels on instruments in the long-term year are denoted  $\mathbf{X}_L$ . The levels of instruments in intermediate years can be determined by interpolating between the instrument levels in years  $t_A$  and  $t_L$ . We then assume the level to be constant for any year after the long run year as depicted in Figure 7.1.

The long run year is chosen such that any time-lagged responses in the model have taken full effect by the year  $t_H$  which is taken to be the final horizon year of the appraisal period (e.g. year 30). The year  $t_S$  is included to be consistent with the discussions on equilibrium models and represents a typical “short” term year.

Thus a continuous policy instrument can be implemented in any year  $t_A$  (where  $t_A \leq t_L$ ) and the optimisation variables are the levels at years  $t_A$  and  $t_L$ .

Figure 7.1. Instrument profile for the continuous instrument  $X_i(t)$ .



Thus we need only specify the year of implementation  $t_A$  and the number of years until a long run value is to be expected. The issue of what is a typical short run year is not a problem for time-marching models as instruments may be implemented in different years.

One may wish to consider the implementation year of certain instruments as a variable to be optimised. In theory this would be feasible, but it adds another dimension to the problem, and the merits of such an investigation should be viewed in light of the whole set of instruments to be appraised (i.e. some judgement is needed to decide if the implementation year would affect the objective function significantly). In practice it is thought that instruments will be implemented according to practical and financial considerations and the modeller should discuss these issues with the city planners.

Note that the linear interpolation assumption for the instrument profile between  $t_A$  and

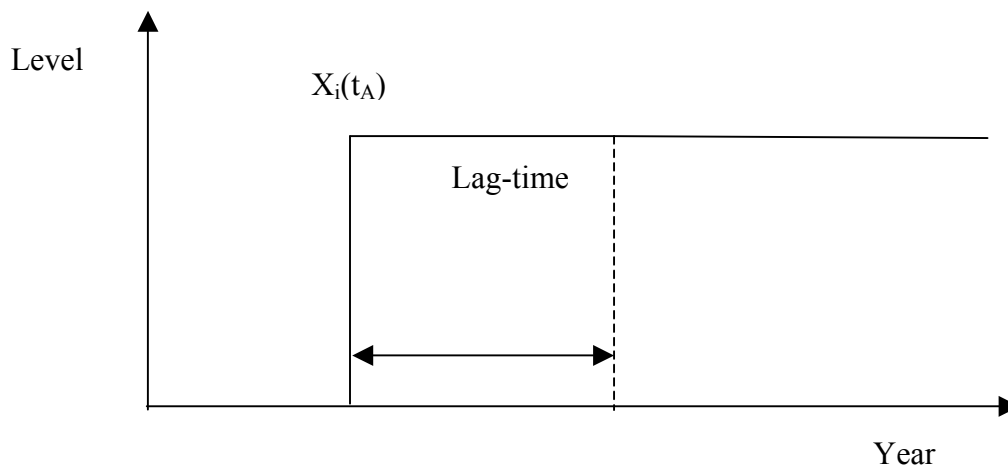
$t_L$  is not necessarily an optimal profile path, but it is the most complicated feasible path defined by only two parameters. If a non-linear path were to be assumed, another parameter would be required to fully specify the path.

Discrete policy options can be considered to be implemented in any year within the evaluation period subject to the restriction that all long term responses will be in effect before the end of the evaluation period. Thus  $t_A + \text{lag-time}$  should be less than 30 years in our case. Again, the implementation year  $t_A$  could be optimised if it were thought to be of interest.

However, in practice the user may wish to suggest only one year to be considered for some discrete options, as this would simplify the optimisation process. This would be advisable whenever the discrete option had an associated level or price such as the charge for a given toll location, as it is expected that the optimum price would also vary with the implementation year.

In this way the time marching models present a very flexible approach for representing policy instruments and can output benefits, costs and indicator values directly in the form required for equation (7.1). Profile for discrete policy instruments is depicted in Figure 7.2.

Figure 7.2. Instrument profile for the discrete policy instrument  $X_i(t)$ .



### 7.2.5 Equilibrium based models

Our experience with equilibrium models (within the PROSPECTS study) includes use of SAMPERS/IMREL and RETRO. When a strategy is applied in an equilibrium model, it computes the new equilibrium within and between the transport, housing and employment markets. Equilibrium models do not explicitly model the adjustment process leading to the equilibrium; instead they focus on predicting the end result, at a certain point in time.

Whereas time marching models can calculate net benefits at each time step, it only makes sense to apply the equilibrium model in years where we may assume that an equilibrium situation is achieved. But the sustainability objective function (OF, equation 3.1) is a weighted sum of impacts in all years in the planning period. The usual way of treating this when doing a CBA with an equilibrium model is to assume a linear interpolation of benefits and costs between the base year and the modelled year. This works fine with the OF as well, if the final (horizon) year is the one modelled. Otherwise it becomes necessary to make some assumption on what happens between the modelled year and the horizon year. We can of course devise some more elaborate

representations where we model more years, and use forms of interpolation other than linear.

The general optimisation problem set out in equation (7.1) allows the introduction or change in the level of a policy instrument at any year in the planning period. We have already discussed how to reduce the problem to only two years in which policy changes are allowed to occur. Having decided on these two years ( $t_A$  and  $t_L$ ), we next have to decide on which years to model. To do that we must take into account what effects we model and the time scale on which they adjust. If we introduce a change we can expect travel demand to react quickly, while workplace and household location takes much longer to adjust. In essence it is the slowest adjusting effect that will decide. We might also expect that the larger the change, the longer it will take to reach a new equilibrium.

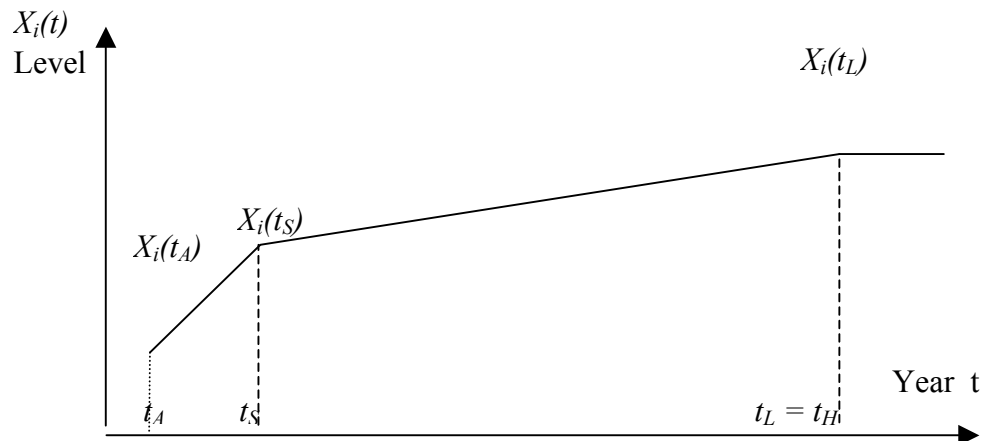
Let us say we think that it takes 5 to 10 years from the introduction of a strategy package until the full effects in both the land use market and transport market have shown up, and that we implement the strategy in year  $t_A = 5$ . In that situation it would be meaningless to apply a model in year 7 that assumes that everything is in equilibrium. Referring to Figure 7.1, we have to let  $t_S$  be sufficiently many years after  $t_A$  for a new equilibrium to form. What is sufficient will ultimately depend on what effects are modelled.

In Figure 7.1 we also allow a gradual change in instrument level between  $t_A$  and  $t_L$ . This does not necessarily break the equilibrium assumption. If the change is slow enough we can assume that the system reacts on a scale much quicker and thus be near equilibrium the whole time. The reasoning is the same as in classical thermodynamics.

However, the levels of the policy instruments in the years not modelled do not affect the objective function OF, so the only point in making assumptions on policies in un-modelled years is to be able to defend the equilibrium assumption for the modelled years.

Still referring to Figure 7.1 with its gradual policy change, there is no need for the lag time between  $t_L$  and  $t_H$ , because if we can assume that the system is in equilibrium in  $t_L$  then it is the full effect of the instruments we are seeing. In the case where we have reduced the optimisation problem down to two points in time, it is perhaps more natural in the context of equilibrium models to let  $X_i(t_S)$  and  $X_i(t_L)$  be the optimisation variables, let  $X_i(t_A)$  be the level just before the instrument is introduced, and let  $t_H = t_L$ . Then we need only apply the model at  $t_S$  and  $t_L$  to calculate costs and benefits. This is shown in Figure 7.3.

**Figure 7.3. Instrument profile for the continuous instrument  $X_i(t)$ . Suggested model runs at  $t_S$  and  $t_L$ .**



Discrete instruments are handled no different from the continuous ones, with the exception that the system probably has to be considered not to be in equilibrium for a while after the introduction, since there is no way to introduce discrete instruments gradually.

For the case where policies change only once (at  $t_A$ ), it will sometimes be of interest to record impacts in both the short term equilibrium (equilibrium in the transport markets only) and long run equilibrium (after land use changes). Figure 7.3 can be interpreted to cover this case too, if we take it to show the *benefit* profile, not the *policy* profile. The transport model is run for year  $t_S$ , and the whole model system is run for the year  $t_L$ . The calculation of the objective function is based on the results from both years and interpolation of benefits as shown.

To summarise: For an *instrument* profile like the one in Figure 7.1 we can make useful predictions for any points in time between  $t_S$  and  $t_H$  given that  $t_S$  is sufficiently long after  $t_A$  and that the gradual change is slow enough. In practice each modeller must decide what is long enough and slow enough with respect to their model system. It is also probable that other concerns such as long run times and available scenario data will have a large impact on the decision of which years to model. Costs and benefits are interpolated between the modelled points in time. We have no information on how they evolve over time, so a linear interpolation is the best we can do. Provided the equilibrium assumption is not violated, we can get a better approximation by adding more modelled points.

An alternative assumption to the very gradual policy change that keeps the system at long term equilibrium all the time, might be to assume sudden policy changes at long time intervals and record its short term and long term equilibrium effects.

## **7.3 Optimisation approaches**

### **7.3.1 Overview**

We have defined the general problem faced by land-use and transport planners in terms of an optimisation problem. The problem can be categorised as follows:

It is a constrained global optimisation problem with either continuous, discrete or mixed continuous and discrete variables; the constraints may be input and/or output related and the objective function must be considered non-linear and black-box in nature. Even more importantly, there is no guarantee that the objective function is concave and the constraints are convex, so there might be local optima. The approach must be one that does not easily get “stuck” in a local solution if there are better local optima elsewhere.

The problem can be considered in three distinct cases distinguished by the variable types to be optimised:-

- (i) Continuous variables only
- (ii) Discrete variables only
- (iii) Mixed continuous and discrete variables

It is thought that many cases will involve continuous variables only. Few strategic studies will be interested in combinations of discrete options only (it may be that certain discrete alternatives may be of interest, but this does not involve optimisation of combinations). Finally many studies will involve mixed continuous and discrete options. If the number of discrete options is small, the approach could be to solve the

continuous only problem for each discrete option. Alternatively some approaches such as a regression based one can deal with a limited number of discrete variables.<sup>17</sup>

This section presents an overview of various optimisation approaches. A non-linear optimisation algorithm is needed in order to obtain a solution to the maximisation problem (7.1). Non-linear optimisation algorithms are based on differing principles. An important difference is that some algorithms require the gradient,  $d(OF)/dx$ , whereas so-called DUD algorithms (Doesn't Use Derivatives) do not. In general the former have higher order rates of convergence, whereas the latter are more robust and easy to apply.

It is not our intention to give a literature review of all possible optimisation approaches within this guidebook. We do however look at how to select an optimisation approach and discuss some general approaches to dealing with constraints. Technical details are left for Chapter 18.

The choice of optimisation algorithm for maximisation of a given objective function depends on certain qualities of the objective function and then upon practicalities of modelling procedures. The practicalities include the required number of model runs and the computer time needed per model run. Some optimisation algorithms require the value of the derivative of the objective function for arbitrary values of function arguments. The derivatives of simple functions can often be expressed as analytical functions. For other functions, finite differences can be used to approximate the derivatives. Although algorithms that use values of the derivative are often efficient in terms of function evaluations, it is sometimes cumbersome to establish the routine that calculates the values of the derivatives. One also need to be aware that algorithms of this kind can be sensitive to round-off error, which means that there can be situations where convergence to the optimal solution is not achieved if there are round-off errors in function values. Algorithms of this kind can also be sensitive to approximation errors, which means that the distance between function values that are used in finite differences may not exceed a certain level.

We have experience in applying three optimisation approaches to both time-marching and equilibrium based models within the PROSPECTS case studies. The first two approaches treat the model as a “black-box” and merely require the model to output the value of the objective function and of the indicators that appear in the constraints at each model run, whereas the third approach additionally requires that the model output the value of the derivatives of the objective function.

### 7.3.2 Downhill Simplex approach (AMOEBA)

The Downhill Simplex method due to Nelder and Mead (1965) was applied via the AMOEBA routine (Press et al, 1990) in projects SAMI, AFFORD and PROSPECTS. It is a robust and easy to use DUD method in multi-dimensions. It can deal with a set of continuous policy variables and can be applied with “hard” and “soft” constraints within the objective function. The details of the method are described in Chapter 18.

The Simplex method is well suited for optimisation of OF both with and without constraints on independent variables (policy instruments) and on performance indicators (target constraints). However, the objective functions must be modified

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<sup>17</sup> A larger, but still limited number of discrete variables can be handled by solving the so-called Network Design Problem. On the other hand, this method requires a simplified network in most instances. It is not considered further here.

according to the penalty method (Section 7.3.6) if target constraints are introduced.

The AMOEBA routine provides a robust automated routine and is easy to link to models where the input of policy instruments and output of the objective function can be easily automated. It is most suitable for fast running models. Generally some programming of input and output procedures will be required to link to the AMOEBA algorithm.

### **7.3.3 A Regression Based approach**

Another approach to optimisation is based on a regression analysis (Fowkes et al, 1998). The basis of the technique is to perform an initial set of orthogonal (in terms of policy instruments) model runs, calculating the objective function OF for each run. Next the user has to create a regression analysis of the outputs and simple calculus is used to predict where the optimum should lie. The user then adds a few more model runs based on this prediction and their own judgement and updates the regression analysis. The process is repeated until the regression model predicts the optimum reasonably well. This method has the advantage of being able to cope with continuous variables and a limited number of discrete variables. The method is not automated and requires the user to create regression models after adding more model runs to the data set. Previous experience shows that the number of variables should be limited to around 12-15. The method does not require any interface to the transport models and can allow the user to input their own preferred strategies as part of the process, thus accounting for prior belief.

The regression based approach is well suited to slow models or for those where it would be difficult to automate input and output procedures. No programming is required to implement the regression based approach. It, too, is described in more detail in Chapter 18.

### **7.3.4 Dealing with Constraints**

There are two types of constraint which affect the optimisation approach. The first one relates to the ranges of the policy instruments, which will have to be decided prior to the simulations, and the second one is related to targets that reflect the objectives of the decision-makers, or other constraints that have been imposed.

Input ranges for policy instruments will be given by the user partly to address acceptability issues (for example by restricting increases in parking charges to say +300%), partly to avoid unrealistic negative values on policy instruments (e.g. road pricing charges) and partly to restrict the modelled range of instruments as the error in predictions increases as large changes are made for most incremental models.

The second type of constraint is based on outputs from a model run rather than inputs. Such constraints may be expressed as targets in a particular year for a given indicator, as rates of change in certain indicators towards the end of the appraisal period (to reflect concerns about the sustainability of the end state), or as other functions of the indicator levels at more than one year. We are not concerned within the optimisation process with how the constraints are derived (though some may require further model runs, which increases computing time). Indicator values are taken as given and are used to say whether or not a constraint or target has been met.

In the following discussion we are not concerned with the actual constraints but with constraints in general and how to deal with them in terms of constrained optimisation.



### 7.3.5 Dealing with input ranges for policy instruments

The input ranges will be specified as upper and lower bounds and can be dealt with in various ways depending on the optimisation approach:

- Restricting the input to a model manually (testing only strategies were the policy instruments stay within their bounds)
- Implementing constraints as penalties within the objective function
- Re-parameterisation of the input variables (see Chapter 18)

The first approach can be used with the regression approach, where each model run is input manually between regression forecasts. Basically, the regression model is used to find the maximum within a bounded policy space (see Chapter 18).

Methodological approaches for implementing constraints within the objective function include unconstrained optimisation with penalties (Section 7.3.6) and constrained optimisation (Section 7.3.7). Unconstrained optimisation with penalties was used in the SAMI project in conjunction with the AMOEBA optimisation process. Basically a large penalty is incurred if the prediction was out of the allowed range for any instrument. The method of re-parameterisation of the input variables was applied in conjunction with the AMOEBA routine for the Oslo case study in AFFORD (Vold, Minken and Fridstrøm 1999). It uses a logarithmic transformation of the input variables which allows the problem to be recast as an unconstrained optimisation problem (Section 18.1.4).

### 7.3.6 Dealing with targets for indicators

The simplest way to deal with this type of constraint is to build it into the objective function itself in the form of penalties. Previous implementation of the penalty approach (SAMI, FATIMA) have used two types of penalty functions:

- Soft penalties
- Hard penalties

The *soft* penalties are of the form:

$$\text{Penalty} = -\beta(y - y^*)$$

where  $\beta$  is a positive input coefficient (and could be the shadow price) and the penalty<sup>18</sup> is positive if the output value of the indicator  $y$  is less than the target value  $y^*$  and negative otherwise. The coefficient  $\beta$  could be set at the best available estimate of the shadow price of  $y$ .

Other variations of the soft penalty can be used. For example the form of the penalty could be quadratic or one-sided whereby there are no benefits for going beyond the required target value. These types of penalty are algorithmic and have no economic meaning i.e. the objective function value is only valid when the penalty is zero in this case.

The extreme case of a *hard* penalty is where the penalty is a very large number for any value of  $y$  that is not equal to the target value  $y^*$ . Such a penalty was used to represent the profit requirements of the private sector in FATIMA (required profit was assumed

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<sup>18</sup> Note that a penalty is to be subtracted from the objective function OF which is maximised so that a positive value should result if the target is not met.

to be 15%). It is more likely that the penalty relates to a threshold value. The hard penalty could be used as follows:

$$\begin{aligned} \text{Penalty} &= \text{Large Number} && \text{If } y < y^* \\ &= 0 && \text{If } y \geq y^* \end{aligned}$$

Experience in FATIMA and SAMI showed that if hard penalties are used alone, the optimisation procedure can cope with only a few constraints of this type, due to an increasing number of discontinuities. A better approach was to combine the hard and soft approach producing some sort of penalty surface based on a quadratic but backed up by the hard penalty beyond certain values, e.g.:

$$\begin{aligned} \text{Penalty} &= \gamma(y - y^*)^2 && \text{if } y \text{ is within } x\% \text{ of } y^* \\ &= \text{large number} && \text{otherwise} \end{aligned}$$

Obviously the form of the penalty will depend upon the type of indicator and the meaning of the target. Some threshold values may be considered critical and so a hard penalty should be used to ensure the condition is met, others may be some desired values which can however be traded with other constraints (so if  $y$  is close to  $y^*$ , that may suffice). Obviously these approaches tend to be more algorithmic than say the use of optimal Lagrange multipliers (i.e. shadow prices), but they have the advantage that the number of constraints met can be varied within the optimisation process and the method can “flag” which constraints have not been met for certain indicators/targets. The user can then view the results and make a decision about the trade-off between similar strategies.

### 7.3.7 Constrained optimization algorithms

A constrained optimisation algorithm that does not require the user to specify penalties was used in the Oslo case study in PROSPECTS. Such algorithms are available for very general constrained optimisation problems, where the constraints can be linear or non-linear equalities or inequalities, or a combination of both. It may be applied equally well to constraints on the ranges of policy instruments or constraints on the indicators (i.e. both model input and model output). Associated with each constraint is a Lagrangian multiplier that can be interpreted as a shadow price. The multipliers are automatically computed by the algorithm.

Such algorithms all apply the gradient of the objective function, either as analytical expressions or in terms of finite differences. Though analytical derivatives of the objective function  $OF$  are usually not available, there is the option to approximate the derivatives in terms of finite differences. Implementations of constrained optimisation algorithms are available as part of many commercial software packages and as free FORTRAN and C library routines, available on the Internet, which can be linked into conventional programs.

Approximations of the derivatives by finite differences can however cause some problems if we apply programming software like EMME/2 to compute the  $OF$ . EMME/2 has relatively low precision in its input parameters, with the consequence that the finite differences either include round-off errors or truncation errors or both.

Another problem related to optimisation of this kind is the long computation time per function evaluation. This may cause one optimisation to take several days to complete. Moreover, a completely new optimisation must be run if we for instance decide to alter the constraints.

A way to circumvent such problems is to generate a grid for the instruments that are

available for optimisation, making sure that the optimal value of the *OF* is likely to be found somewhere within the range of the grid. Polynomial interpolation or regression is then applied to the grid values to approximate the *OF* and the indicator responses. Polynomials are well-defined functions that are easily represented directly in any library routine or software package for constrained optimisation. We may then apply any other constrained optimisation algorithm to the polynomials instead of the true objective function. With polynomial representation, constraints are easily altered so that new optimisations can quickly be run.

Section 18.3 provides references for such methods.



# **Some Specific Issues**



## 8 Basics of CBA

### 8.1 Introduction

One conclusion from the chapters above is that our evaluation of strategies should include an economic efficiency indicator and additional indicators for the environment, safety, equity and liveable streets. The elements of the economic efficiency indicator is the topic of Chapters 8-13, and the other indicators are treated in Chapters 14-16.

### 8.2 The elements of the economic efficiency indicator

The economic efficiency indicator consists of the following elements:

1. User benefits for the households, defined by "rule of a half" or logsum formulas and including the benefits from land use.
2. Producer surpluses, defined by annual revenue minus cost including taxes for all firms, operators and landlords and developers.
3. Value of finance, defined as annual government tax revenue minus outlays for local and national government taken together.
4. External costs, defined as accident cost plus noise and air pollution cost and given by these indicators.

All four elements are measured as differences from a do minimum or base case strategy. As a rule, our models do not permit us to record any secondary impacts outside the transport and land use system, so for instance, changes in the tax revenue or external costs stem from changes in transport and land use demand and supply.

Investments are entered either under producer surpluses or value of finance, as the case may be. A distinction is made between:

- Infrastructure and house building costs
- Rolling stock costs (annuity of infinite chain of investments)<sup>19</sup>

The first of these is entered at the points in time where it occurs, whereas investment in rolling stock is treated as the annuity of an infinite chain of investments.

For the calculation and presentation of the economic efficiency indicator, four broad *sectors* are defined: Households, firms, government and nature (or system external costs). In a table of net present values with the benefit and cost elements as rows, each of these sectors will have its own column, possibly subdivided (by type of firm, sector

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<sup>19</sup> Since as far as we can see into the future, there is a need for public transport, the rolling stock must be renewed at regular intervals from now to eternity. The annual cost of doing this

is  $a = c \frac{r}{1 - (1 + r)^{-n}}$ , where a is the perpetual annuity, c is the cost of buying new rolling

stock, r is the discount rate and n is the lifetime of a generation of rolling stock. If at point in time t,  $K_t$  vehicles are needed, the cost is  $K_t a$ .

of government etc.). This makes it possible to enter the benefits and costs of each sector without having first to eliminate transfers. Such a disaggregated presentation of the indicator facilitates informal evaluation of the distributional aspects of a strategy – who gets what, and what is their net gain.

Transfers cannot be ignored or too hastily be eliminated in the calculation of economic efficiency. The reason is that it is the perceived costs, including transfers to the public transport companies (fares) and taxes and charges to the government, that determine demand and the user benefits. In the end, transfers will implicitly be eliminated by summing over sectors.

Financial benefits to the government will be treated in the following way: The main principle is that when a strategy uses taxed resources that are drawn from consumption and use elsewhere in the economy, there is no change in government revenue, as the only difference is where in the economy the resources are used. On the other hand, when a strategy uses resources newly produced or imported (and this will be the main case, except for labour), there will be an increase in tax revenue to the government. Applying this principle, we get the real social costs of the resources used or produced in the strategy by using the perceived costs including taxes to compute elements (a) and (b) of Table. The government revenue changes (c) and the external cost changes (d) will in fact constitute the correction from perceived to real social costs.

The government column might be multiplied by a *shadow cost of public funds* to reflect the fact that taxation creates inefficiency in the economy. The rationale for assigning extra value to each euro of government revenue brought about by the strategy is that this revenue allows the government to cut taxes or to use more money on efficiency-improving public projects. Taxes – for instance the income tax and the value-added tax – distort the price signals of the economy by making the perceived cost of hiring labour or buying goods higher than the marginal social cost. In such a case the total output of goods and services become smaller than it could have been if all individuals had been facing the true marginal social cost. The same reasoning applies if the strategy causes new public expenditure. The extra cost to each euro of public expenditure is that this must be covered by higher taxes or by cutting back on efficiency-improving public projects.

Some countries have national guidance on what shadow price of public funds to use. For instance, Norwegian guidance sets it to 0.2, meaning each taxpayers' euro costs 1.2 euro to society, or the government column must be multiplied by 1.2. Alternatively, we can apply a financial constraint when appraising the strategies – see Section 5.2. We should also take into account that transport and land use taxes and charges may be part of our strategies, and this raises the issue if it really is an efficiency improvement to substitute ordinary taxes with transport and land use taxes.

In the external cost column of Table 8.1 we include accident costs, local air pollution and noise costs, as well as CO<sub>2</sub> costs. National guidance on what to include differs among countries, so it might be debated if all of this is to be included in the EEF or kept as separate indicators. If it is included, one has to remember that a part (possibly all) of the external costs have already been accounted for in the EEF when presenting or attaching a weight to the individual environmental and accident indicators.

Adding over the columns and rows of Table 8.1 for a single year gives us the annual net benefit of the strategy. Discounting (next section) will then produce the net present value of the strategy. Denoting the net present value by EEF, net benefits to households by UB, net benefits to firms by PS, the present value of finance by PVF and the external costs by EC, we have shown in this section that

$$(8.1) \quad \text{EEF} = \text{UB} + \text{PS} + (1+\lambda)\text{PVF} - \text{EC}$$



where  $\lambda$  is the shadow price of public funds (which might be set to zero or to a small positive value such as 0.1, 0.2 or 0.3).

User benefits are treated in Chapter 9. Chapter 10 discusses how to enter taxes and charges in the economic efficiency indicator EEF, and the government surplus PVF in Section 11.3 depends on that. Producer surplus is treated in Chapter 11, while external cost is the topic of Chapter 12. Investments (point 5 above) will partly be included in government expenditure and partly as costs to the producers.

Our framework for computing and presenting the economic efficiency indicator owes much to MVA et al (1994). It was adapted and applied in the OPTIMA, FATIMA and AFFORD projects. Examples of detailed specifications can be found in the reports from these projects.<sup>20</sup>

**Table 8.1. Simplified example of presentation of economic efficiency results by sector**

Strategy no.:		Euros, present values, year n prices					
	Household s (a)	Firms (b)			Government (c)	External (d)	Row totals
		Public transp.	Pro- perty	Other			
Investment costs							
Transport benefits							
Location benefits							
External costs							
Column totals							

### 8.3 Discounting

Annual net benefits are really only the raw material for the calculation of economic efficiency. To be comparable and be summed (like in Table 8.1), the different annual net benefits at year  $t_1, t_2$  etc. need to be transformed to *present values* – the amounts *now* that are equivalent to getting the net benefits at time  $t_1, t_2$  etc. The “now” is conventionally taken to be the year before any of the impacts have begun to show. Call this year  $t_0$  or year zero. There might be some initial costs in year zero (investment costs), but other benefits and costs will be zero, since benefits and costs are relative to a do minimum strategy, and no change from the do minimum has yet occurred.

We will assume that all costs and benefits at any time are real and not nominal values. That is, we do not take account of inflation when we compute benefits and costs, or if we did, we need to deflate the nominal values by a price index before entering them in the economic efficiency calculation.

The present value of a cost or benefit at year  $t$  is the annual value at  $t$  multiplied by the *discount factor*  $\delta = 1/(1+r)^t$ , where  $r$  is the constant *discount rate*. Since we did not consider inflation when computing the annual benefits and costs, the discount rate must also be a real rate.

<sup>20</sup> Note that the approach taken in this section is different from the method traditionally employed by road authorities in cost benefit analysis of highway projects. Our method requires data on taxes and costs split by sectors, whereas this is usually not required in the road authority manuals.

One reason why discounting is necessary is that individuals prefer to have one euro now rather than later. The other reason is that there actually exist financial markets that are willing to compensate you for not using your euro this year by giving you  $(1+R)$  euros next year,  $R$  being the market interest rate. If you could save and borrow as much as you liked at the same rate, you could borrow or save up to the point where your own valuation of saving (borrowing) another euro equals the price the financial institution is willing to pay you (must charge you) for the extra euro. So in perfect financial markets, the two approaches to measuring what a euro next year is worth today (individual time preference and the market rate) will coincide, or  $r = R$ . In practice, for most of us they do not. Therefore, finding the right discount rate to use in a cost-benefit analysis is not straightforward. There is also the added complication that the strategies we are evaluating involve risk and uncertainty. We would want a higher compensation to commit to a strategy with highly risky future net benefits.

For some countries, the discount rate to be used in CBA is set by national authorities.<sup>21</sup> For other countries, we recommend to use a discount rate in the range of 5-8%. If strategies are tested in low-growth and high-growth scenarios (Section 3.6), one might want to apply a discount rate consisting of two elements, a risk free rate and a risk premium. The risk premium should be high for strategies that perform well only in high-growth scenarios, and low for strategies that perform well also in low-growth scenarios. The latter strategies contribute to reduced overall risk in society, while the former do not. It is the overall risk in society that matters, thus the risk premium should reflect the covariance between the annual benefits of land use and transport strategies in the urban area and total national income. For instance, official guidance in Norway (Finansdepartementet 2000) is to use a risk-free rate of 3.5% and add a risk premium depending on the covariance. If the covariance is 1 (annual benefits and national income seems to move closely together), the risk premium is set to 4.5%, giving a discount rate of 8%. For strategies that produce the same benefits regardless of the economic conditions, the risk premium is 0.

As described in Section 3.5, the discount rate has to be modified to take account of sustainability.

## **8.4 A multi-modal analysis**

Obviously, a cost benefit analysis of strategies like the ones we are considering, in cities with congestion and public transport services, must be multi-modal in nature. This is implied in the sections above. A multi-modal cost benefit analysis must be based on output from transport demand models with mode choice as one of the choices open to the travellers. In a city, there will also be a lot of possible destinations, so destination choice is vital. Route choice is important to get to grips with the congestion impacts. These are minimum requirements on the model that provides the input to the multi-modal analysis.

In some countries, national guidance on multi-modal studies exist, and the reader might for instance want to consult the British GOMMMS (DETR 2000c) for comparison with this guidebook or other guidance, and for additional details.

Of course, as we need to take land use impacts and location choices into account in our calculation of economic efficiency, there will be even more agents and choice options to consider in our analysis than in the ordinary multi-modal analysis. The main difference concerns the user benefits (Chapter 9), but there will also be impacts

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<sup>21</sup> See Appendix 2 of Mackie et al (2001) for official national discount rates in Europe.

for a wider range of firms. This is reflected in the Tables 3.1 and 8.1 and is briefly described in Chapter 11.

The Glossary provides additional explanation of key cost benefit terms (cost benefit analysis, benefit cost ratio, irreversibility, discounting and other entries).

## 9 User benefits in LUTI models

### 9.1 Introduction

This chapter covers the calculation of user benefits in integrated land use and transport (LUTI) models. User benefits are defined as the part of the social benefits of a strategy that is reaped by individuals or households in their capacity of travellers, car owners and owners of houses or tenants.

As a rule, it will generally be possible to compute user benefits in an integrated land use/transport model as the sum of three parts. The three parts are:

- elements of benefit calculated from changes in transport generalised cost,
- elements of benefit calculated from changes in trip attractions,
- elements of benefit calculated from changes in the characteristics of residential zones, housing prices and other housing characteristics.

Whenever there are land use changes, there will be elements of user benefit that cannot be captured by the traditional rule-of-half formula as applied to transport. In Section 9.2, we explain why. Section 9.4 provides formulas that capture all elements of user benefit. But since these formulas really only apply to a particular type of model, we have to exercise caution and use judgement if we want to apply them to other types of model. The rest of Chapter 9 discusses this problem.

Many will find this chapter difficult. Since user benefits are so important for the whole appraisal, we have chosen to be as precise as possible on how to compute them, even if this creates problems. At the end of Section 9.4, there is a box that provides the main result of the section – the formulas for computing the three parts of user benefits indicated above. The reader is then encouraged to read on to check if these formulas are applicable in her situation. If she finds it difficult, she might also want to discuss the issues with outside experts or with the providers of the modelling software that she uses.

### 9.2 Need for alternative to the traditional rule-of-a-half formula

By a *transport market*, we mean trips between a start zone  $i$  and a destination zone  $j$  for a trip purpose  $p$  with a mode  $m$  at a time  $t$  of the day. We differentiate according to trip purposes because they might imply different values of travel time and may be subject to different tax rates. We differentiate according to time-of-day because congestion might make a difference to travel times.

Let  $W$  be the set of all transport markets in an urban transport system, and index  $W$  by  $w$ . So  $w = (i, j, p, m, t)$ . The number of trips in market  $w$  in a situation without a strategy (the “do minimum” situation) is called  $T_w^0$ , and the corresponding number in the situation with a strategy implemented is called  $T_w^1$ . The corresponding generalised costs are  $G_w^0$  and  $G_w^1$ .

The traditional “rule-of-a-half” user benefit measure is

$$(9.1) \quad \Delta S = \frac{1}{2} \sum_{w \in W} (G_w^0 - G_w^1) (T_w^0 + T_w^1)$$

Simmonds (2001) notes that if strategies influence the elements of generalised cost and nothing else,  $\Delta S$  is a workable measure of user benefits. However, “as soon as we introduce changes that are not represented in generalised costs, the conventional method becomes less reliable, and may give wholly misleading results”. This is evident from the formula: if no change in  $G_w$  occurs, no benefit is registered in this market. But in reality there might be benefits, for instance in the form of more opportunities at the destinations or environmental improvements and cheaper housing in the residential areas. Broadly, we might identify the improvements that do not show up in generalised costs as land use benefits.

Evidently, land use benefits, if they occur, cannot be captured by the traditional “rule-of-a-half” user benefit measure. Such benefits will inevitably appear in a LUTI model, and some forms of them will even appear in ordinary transport models, namely benefits from improvements at the destination (such as more workplaces) in a model where the origins are given, and benefits from improvements at the origins (such as lower rents) if destinations are given. This is the reason why we need something else than (9.1).

### 9.3 Consistent benefit calculation in some types of model

It has long been known that for singly and doubly constrained gravity models and nested logit models, alternatives to (9.1) are available. There *are* ways of including land use benefits in the overall benefit measure *for these forms of model*. The resulting user benefit measure will either be exact or a good approximation, depending on the kind of model (Neuberger 1971, Williams 1976, 1977).

To use exact benefit measures (logsum formulas like (9,2) below) with logit models would require the whole land use/transport modelling system to be of the nested logit type. If only the transport model, but not the whole model system is nested logit, it means that the land use model does not use the total benefit that can be reaped in the transport system by locating in zone  $i$  as a determining factor in the choice of residential zone. Perhaps it uses only a part of the total transport benefits, such as the benefits from trips with a particular trip purpose. We might nevertheless capture the benefits of more opportunities at the *destination* zones by *logsums from the transport model* (one for each  $(i,p,t)$ ). But we would never be able to capture benefits of improvements in the *origin* zones by calculations based exclusively on transport model output.

Consider a model where households are assumed to change residential location as a consequence of transport system changes, but based on transport cost variables that are something else or less than the entire benefits that can be reaped in the transport system when locating in a zone. Thus residential choice is not a part of the nested logit structure.

If only the transport model logsums are used, one part of the benefits will inevitably be missing. The missing part will be the benefit associated with activities that are performed at home, in the residential zone. These residential benefits will inevitably be influenced by a transport strategy through relocation and the changes in equilibrium rents and housing congestion costs that it entails. This is why we need an assessment of the benefits that goes beyond the benefits that can be measured in the

transport system (including benefits at the destination of trips).

If, on the other hand, we use the benefits from the land use model in this case, there will be another part missing, namely the benefits in the transport system that were not included in the land use model. So in any case (except if the whole integrated LUTI model is a nested logit model) there will be something to add.

The IMREL model is a case in point. In IMREL, work trip destinations are decided in the employment location sub-model. The workers of these workplace zones choose their residential zone based on the cost of the work trip. This might be a composite cost (a logsum) at the mode choice level, but it cannot include the work trip destination choice of the transport model, since work trip destinations are already given from the employment location model. Neither could it include benefits of non-work trips. Since the model assumes that non-work trip benefits play no part in location choice, it seems the thing to do is to add the benefit from non-work trips and the benefits from the residential location model. But we would never be able to capture benefits of improvements in the *destination* zones (such as higher wages). This is consistent with IMREL's simple employment location model, where employers attract workers only by choosing attractive locations. Wages are not an issue.

#### 9.4 User benefit formulas in a logit residential choice model

With minor changes, the following can be seen as a summary of Section 3 of appendix B of Simmonds (2001). Conventionally, an asterisk denotes aggregation over the missing indices, so if  $H_i$  is the number of households residing in zone  $i$ ,  $H_*$  will be the sum of households in all zones, and if  $T_{ijmp}$  is the number of trips from zone  $i$  to  $j$  by mode  $m$  for the purpose  $p$  at the time-of-day  $t$ ,  $T_{ij*}$  will be the total number of trips from  $i$  to  $j$ , regardless of mode, purpose and time-of-day. In these cases, the form of aggregation is simply summation. However, with respect to costs and benefits, we will make use of aggregation by way of "composite costs" or logsums, so for instance

$$(9.2) \quad V_* = \frac{1}{\lambda_L} \ln \sum_i \exp(\lambda_L V_i)$$

where  $V_i$  is the utility of residing in zone  $i$ ,  $\lambda_L$  is a distribution coefficient associated with the residential choice and  $V_*$  is the expected utility from the residential choice. This particular mathematical form of aggregation is known to be the exact measure of user benefit in a simple multinomial logit model. Note in particular that if (9.2) is to be used as a way of summarising the user benefits in the transport/land use system, possible income effects are ignored.

Assume the residential choice model is

$$(9.3) \quad H_i = H_* \cdot \frac{F_i \exp[\lambda_L (A_i + \alpha^u U_i + \alpha^r R_i + k_i)]}{\sum_s F_s \exp[\lambda_L (A_s + \alpha^u U_s + \alpha^r R_s + k_s)]}$$

where  $i$  and  $s$  are indices of zones and

$F_i$  is an index of the size of the zone  $i$  as a residential zone

$A_i$  is the utility that can be achieved in transport if you are located in zone  $i$  (measured in money)

$U_i$  is the utility of occupying a house in zone  $i$  (probably an increasing function of the size of the house and a decreasing function of the density of housing)

and the rent or housing cost)

$R_i$  is an index of the amenities and environmental qualities of zone i. ( $R_i$  may well be influenced by the transport system).

$H_i$  expected demand for housing in zone i

$\alpha^u, \alpha^r$  are coefficients

$k_i$  is a constant

$\lambda_L$  distribution parameter

If we define  $f_i$  by  $f_i \equiv \frac{\ln F_i}{\lambda_L}$ , we have  $F_i = \exp(\lambda_L f_i)$ . Consequently, we can write  $H_i$  in terms of  $f_i$  instead of  $F_i$ :

$$(9.4) \quad H_i = H_* \cdot \frac{\exp[\lambda_L (A_i + \alpha^u U_i + \alpha^r R_i + k_i + f_i)]}{\sum_s \exp[\lambda_L (A_s + \alpha^u U_s + \alpha^r R_s + k_s + f_s)]}$$

Now define  $V_i$  by

$$(9.5) \quad V_i = A_i + \alpha^u U_i + \alpha^r R_i + k_i + f_i$$

Then the individual utility from the residential choice in this model is given by  $V_*$  of (9.2), and the total user benefit is given by  $H_* V_*$ . Or rather, if we use the superscript 0 to denote the base case situation and 1 to denote the situation after some strategy has been implemented, the total user benefit UB of moving from situation 0 to 1 is

$$(9.6) \quad UB = H_* \cdot (V_*^1 - V_*^0)$$

At this point, our argument departs somewhat from Simmonds. By (9.2), (9.4) and (9.5),

$$\frac{\partial V_*}{\partial A_i} = \frac{\partial V_*}{\partial V_i} \frac{\partial V_i}{\partial A_i} = \frac{H_i}{H_*} \text{ and similarly } \frac{\partial V_*}{\partial U_i} = \alpha^u \frac{H_i}{H_*}, \quad \frac{\partial V_*}{\partial R_i} = \alpha^r \frac{H_i}{H_*}, \quad \frac{\partial V_*}{\partial f_i} = \frac{H_i}{H_*}$$

We can make use of these partial derivatives of  $V_*$  to compute a first-order Taylor expansion of  $V_*$  around the point of the 0 situation. The result of the Taylor expansion is:

$$(9.7) \quad V_*^1 \approx V_*^0 + \sum_i \frac{H_i^0}{H_*} ((A_i^1 - A_i^0) + \alpha^u (U_i^1 - U_i^0) + \alpha^r (R_i^1 - R_i^0) + (f_i^1 - f_i^0))$$

Before we use (9.7) in (9.6) to arrive at our user benefit formula, we note that if we evaluate the  $H_i$ 's not at the 0 point as on the right hand side of (9.7), but at a certain point between the 0 and 1 situation, the equality in (9.7) would be exact. This is the Taylor expansion formula with a remainder term in the case where the remainder is of order 1. To use this, we form a vector  $\mathbf{X}$  consisting of the vectors of A's, U's, R's and f's:  $\mathbf{X} = (\mathbf{A}, \mathbf{U}, \mathbf{R}, \mathbf{f})$ . Then the point where the formula is exact is  $\mathbf{X}^0 + \theta(\mathbf{X}^1 - \mathbf{X}^0)$  for some  $\theta$  between 0 and 1. With this notation, a shorthand description of (9.4) would be

$H_i = H_i(\mathbf{X})$ . We introduce the notation  $H_i(\theta) = H_i(\mathbf{X}^0 + \theta(\mathbf{X}^1 - \mathbf{X}^0))$ . Now,

$$(9.8) \quad UB = \sum_i H_i(\theta) \left( (A_i^1 - A_i^0) + \alpha^u (U_i^1 - U_i^0) + \alpha^r (R_i^1 - R_i^0) + (f_i^1 - f_i^0) \right)$$

In formula (9.8), the total user benefit from a change that affects transport as well as land use is decomposed in terms that relate to transport and the attractivity of destinations (the ‘‘A’’ terms) and terms that relate to land use changes in the residential zones (the ‘‘U’’, ‘‘R’’ and ‘‘F’’ terms). The ‘‘A’’ terms can be computed from a transport model, whereas the other terms need a land use model of the form (9.4).<sup>22</sup>

Now since  $\theta$  is an unknown, we need an approximation. This is conventionally done by using  $\frac{1}{2}(H_i^0 + H_i^1)$  instead of  $H_i(\theta)$  in (9.8) – that is, to apply the rule-of-half at the level of land use.<sup>23</sup> The rule-of-half formula applied at the level of land use becomes:

$$(9.9) \quad UB = \sum_i \frac{1}{2} (H_i^0 + H_i^1) \left( (A_i^1 - A_i^0) + \alpha^u (U_i^1 - U_i^0) + \alpha^r (R_i^1 - R_i^0) + (f_i^1 - f_i^0) \right)$$

As an alternative to the rule-of-half formula, we could recognise that  $V^*$  is a differentiable function of  $\theta$  on  $[0,1]$  and that in (9.6),

$$V^*_1 - V^*_0 = \int_0^1 \frac{\partial V^*}{\partial \theta} d\theta = \sum_i \int_0^1 \left( \frac{\partial V^*}{\partial A_i} \frac{\partial A_i}{\partial \theta} + \frac{\partial V^*}{\partial U_i} \frac{\partial U_i}{\partial \theta} + \frac{\partial V^*}{\partial R_i} \frac{\partial R_i}{\partial \theta} + \frac{\partial V^*}{\partial f_i} \frac{\partial f_i}{\partial \theta} \right) d\theta$$

Some simple calculation would then give us

$$(9.10) \quad UB = \sum_i \int_0^1 H_i(\theta) d\theta \cdot \left( (A_i^1 - A_i^0) + \alpha^u (U_i^1 - U_i^0) + \alpha^r (R_i^1 - R_i^0) + (f_i^1 - f_i^0) \right)$$

The integral of this formula could for instance be evaluated by Newton approximation. Apart from any approximation involved in the numerical evaluation, (9.10) like (9.6) is an exact and valid user benefit measure for models like (9.3).

Finally, if the transport model is a logit model, each of the ‘‘A’’ terms can be decomposed further by exactly the same reasoning as we used to decompose UB. This will provide us with decomposed measures of user benefits in transport for each of the residential zones. For instance, the  $A_i$  might be the transport user benefits of residents in zone  $i$  computed at the level of destination choice in a model such as this:

$$(9.11) \quad T_{ij^*pt} = T_{i^{**}pt} \cdot \frac{W_{jpt} \exp(-\lambda_D \tilde{c}_{ij^*pt})}{\sum_k W_{kpt} \exp(-\lambda_D \tilde{c}_{ik^*pt})}$$

where

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<sup>22</sup> It is worth noting that  $(f_i^1 - f_i^0) = \ln \left( \frac{F_i^1}{F_i^0} \right)$ .

<sup>23</sup> By the Intermediate Value Property of continuous functions on a closed domain, the existence of a  $\theta \in [0,1]$  that makes  $H_i(\theta) = \frac{1}{2}(H_i^0 + H_i^1)$  is guaranteed.



- $T_{ij^*pt}$  is the number of trips to zone  $j$  from zone  $i$  for the purpose of  $p$  at time-of-day  $t$ , regardless of mode,
- $\mathcal{C}_{ij^*pt}$  is the composite cost of such trips, given by the logsums at the level of mode choice,
- $T_{i^{**}pt}$  is the total number of trips from zone  $i$  for the purpose of  $p$  at time-of-day  $t$ , regardless of mode and destination<sup>24</sup>,
- $W_{jpt}$  is an index of the attractiveness of destination  $j$  for carrying out activities of type  $p$  at time-of-day  $t$ , as measured by for instance the number of workplaces, square metres of shopping floor etc.
- $\lambda_D$  is the distribution parameter at the level of destination choice.

Just as before, we might transform the attractiveness index  $W_{jpt}$  to some form of benefit  $w_{jpt}$  at the destination by  $W_{jpt} = \exp(\lambda_D w_{jpt})$  and define the indirect utility of such trips to  $j$  by  $A_{ij^*pt} = w_{jpt} - \mathcal{C}_{ij^*pt}$ . (Alternatively, we might have constructed a money metric index of the utility at  $j$  directly). The user benefit of  $(p,t)$  trips for residents at  $i$  would then be

$$(9.12) \quad A_{i^{**}pt} = \frac{1}{\lambda_D} \ln \sum_i \exp(\lambda_D A_{ij^*pt})$$

The  $A_i$  of the land use model might consist of a sum of such  $A_{i^{**}pt}$ . It is now evident that benefits in transport can be written as  $\sum_{pt} T_{i^{**}pt} A_{i^{**}pt}$ , and that this measure can be decomposed to bring out one group of elements of the form  $T_{ij^*pt}(\theta)(\mathcal{C}_{ij^*pt}^0 - \mathcal{C}_{ij^*pt}^1)$  and another of the form  $T_{ij^*pt}(\theta)(w_{j^*pt}^1 - w_{j^*pt}^0)$ .

In conclusion, in a land use/transport model where residential choice is a simple logit model and the logsums from all or parts of the transport choice models are included in the linear conditional indirect utility functions, the total user benefits can be got by summing

- elements of benefit calculated from changes in transport generalised cost,
- elements of benefit calculated from changes in trip attractions,
- elements of benefit calculated from changes in the characteristics of residential zones, housing prices and other housing characteristics.

However, there is nothing here that allows us to attribute these three types of elements to three different types of causes. Since transport changes can induce changes in the residential zones and vice versa, residential zone changes can show up as transport benefits, transport changes can show up as residential benefits etc.

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<sup>24</sup> The link between  $T_{i^{**}pt}$  and  $H_i$  of the land use model is simply that the individual trip frequencies for each type of  $(p,t)$  trip must be multiplied by the number of individuals per household and the number of households.

### Summary of Section 9.4:

The total user benefit UB is the sum of UB(T), UB(Att) and UB(P).

1. Benefits from generalised cost changes

$$UB(T) = \frac{1}{2} \sum_{i,j,m,p,t} (G_{ijmpt}^0 - G_{ijmpt}^1) (T_{ijmpt}^0 + T_{ijmpt}^1)$$

2. Benefits from changes at the destinations

$$UB(Att) = \frac{1}{2} \sum_{i,j,p,t} (w_{jpt}^1 - w_{jpt}^0) (T_{ij*pt}^0 + T_{ij*pt}^1)$$

3. Benefits from changes in the residential zones

$$UB(P) = \sum_i \frac{1}{2} (H_i^0 + H_i^1) (\alpha^u (U_i^1 - U_i^0) + \alpha^r (R_i^1 - R_i^0) + (f_i^1 - f_i^0))$$

where

- superscript 0 and 1 denotes the do minimum and tested strategy, respectively;
- indices  $i, j, m, p, t$  denotes origin (residential zone), destination, mode, trip purpose and time of day in that order, and \* denotes summation over the index;
- G is generalised cost, T is the number of trips;
- w is an index of the attractivity of a destination with respect to a trip purpose and time of day (see text of Section 9.4);
- H is the number of residents, U is utility from home-based activity minus rent, R is an index of environmental quality in the residential zone, f relates to the size of the zone and the alphas are constants (see text of Section 9.4).

## 9.5 The effect of requiring housing market equilibrium

It might be that the demand for housing in a zone is less than the number of houses, so that some houses are vacant. But the reverse situation, with demand exceeding supply, should never be allowed to be the outcome of the location model. That is, if demand exceeds supply we must assume that something happens in the model so that the markets clear. Models bring about equilibrium in the housing market in different ways. If the model calculates prices (rents) that clear the market, it will be these equilibrium prices that enter into the utility of residing in a zone (the  $U_i$  of the preceding section). In such models, there is no need to adjust or modify the user benefit calculations of the preceding section. However, in some models, equilibrium is imposed in the form of constraints instead of being achieved directly through the prices that the households are supposed to face in the housing market. If we ignore these constraints when we compute the user benefits, we will compute benefits for a situation that cannot happen in reality – a situation with more houses than there actually are. This is obviously wrong and calls for some correction.

The correction consists in subtracting a shadow price (shadow rent) from the utility of

residing in each zone  $i$  (the  $V_i$  of (9.5)). These shadow prices are probably model output. (If not, it will be a cumbersome task to adjust the shadow prices so that the  $H_i$  of each zone keeps within the constraint). The user benefits will then have to be computed with these additional shadow rent terms included. Just like the elements of  $V_i$ , the shadow rent term will come out as a separate term in the rule-of-half formula. If the shadow rent does not change from situation 0 to situation 1, this term will vanish.

## **9.6 On landlords, rents and shadow rents**

The total revenue from rents will normally be entered in the cost benefit summary table as revenue to the landlords. The real social cost of providing the housing services will be entered as a cost to the landlords. These two will normally not cancel out, nor will we assume that the landlords are “absentee” landlords that reside outside the city. So to get things right, we must add the net benefit to landlords in our calculation.

It might be that the households own their own homes. We treat this case just like the case with landlords. The user benefits in this case, then, are the benefits as computed above, plus the benefits to households in their capacity of owners of their own house (their own landlords).

We treat shadow rents just as ordinary rents. That is, we add the total “revenue” from shadow rents to the user benefits as calculated above. A justification of this is given in Simmonds (2001), appendix C and in the references found there. An interpretation of this might be that even if the households pay a rent that is less than what is needed to keep demand inside the supply constraints, they must nevertheless experience some other payment that constrains their housing demand. Since this payment is a transfer to some unspecified group in society, it must be entered as a revenue for somebody in the cost benefit table.

## **9.7 The underlying theory**

The whole concept of measuring social benefit as a function of individual benefits is derived from economic welfare theory. The concept of measuring individual benefits by the consumer surplus is also derived from economic theory. The most commonly used consumer surplus measures are the Marshallian Consumer Surplus and the two Hicksian measures – Equivalent Variation and Compensating Variation. The most appropriate measure for our purposes seem to be the Equivalent Variation (EV). It is the answer to the question “What is the minimum amount of money the individual must be given in the base case to make him as well off as in the strategy?” Or if the strategy makes him worse off, what is the maximum amount he would be willing to pay to avoid its implementation? Thus the EV implies an evaluation of the strategy in the base case situation, and expresses it as the sum of money that would be equivalent to the change in utility from the base case situation to the situation with the strategy.

Conversely, the Compensating Variation (CV) judges the matter from the standpoint of the situation after the strategy has been implemented. It answers the question “What is the maximum amount of money the individual would be willing to pay to avoid a reversion to the base case situation?” – or, if the strategy makes him worse off, “What is the minimum amount of money that would make the individual as well off with the strategy as without?” This seems to be the natural evaluation measure for compensating measures. But as compensating measures only form a part of our strategies, the CV is considered less appropriate in our context.

## 9.8 Be cautious, use judgement!

To decide on how to calculate user benefits in models other than (9.3), a series of questions must be answered.

*Is the model system derivable from utility maximisation?*

If not, the concept of user benefit is inapplicable to the model results. This might be the case if purely empirical or statistical relationships go into the model system, or if it contains a behavioural model that is mis-specified and cannot be interpreted as the outcome of utility maximisation. A case of such misspecification is when a multinomial logit model is used even if the choice alternatives obviously have important properties in common.

One should simply refrain from calculating user benefits in such models. What might *perhaps* be used instead in a MCA framework, is some aggregate accessibility measure for the transport system as a whole, combined with indicators of housing standard and residential area environment. The “perhaps” here is to remind us that the models where user benefit calculation is meaningless might also be bad models from the point of view of predicting aggregate behaviour.

Even if the model system is not actually derived from utility maximisation, it might nevertheless be given a utility maximisation *interpretation*. This is the case for entropy models and so called group utility models, provided it is reasonable to assume a representative consumer.

*Is there a representative consumer in the model system?*

If the aggregate demand system behaves as if it were the outcome of the utility maximisation of a single consumer, we say that a representative consumer exists. For a representative consumer to exist, the preferences of all individuals must have a peculiar structure: Demand must be linear in income, with all individuals having the same coefficient in the income term. To put it otherwise, an extra euro will give rise to the same structure of extra demand, regardless of whom it is given to. The coefficient need not be a constant, although once the model is estimated, it is usually treated as such in all models.

If we disregard for a moment land use and car ownership, disaggregate behavioural transport models almost always have the feature that income does not enter into the demand functions of the individuals.<sup>25</sup> Thus preferences do have the peculiar structure that allows a representative consumer to exist. In the case of the transport models, if individuals are all given one more euro, they will all spend it in the same way, that is, on other consumption and not on transport. Oppenheim (1995) uses the representative consumer approach very consistently to derive nested logit models (combined equilibrium models, in his terminology) and user benefit measures in such models. This does in fact show that any correctly specified nested logit model will have a representative consumer. The utility function of this consumer will be a linear combination of entropy terms, travel cost terms and an income (other consumption) term.

If we have such a model, a perfectly correct user benefit measure will be the indirect utility of the representative consumer. This is the logsum formula (9.2), appropriately specified to reflect the nested logit structure. The indirect utility function of the representative consumer is the *potential function* of the line integral that goes by the

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<sup>25</sup> Income does enter the conditional indirect utility functions of individuals, but only as a “taste parameter”, reflecting the habits of a particular socio-economic group.

name of Hotelling's generalised surplus measure. Hotelling's generalised surplus measure will often not be well defined until a specific path is given for the changes in prices from the base case to the policy case. However, given that it has a potential function, the integral is path independent and well defined in all cases. Consequently, user benefits could be measured either directly by the logsum formula or by Hotelling's measure. Hotelling's measure amounts to taking the area between the price line and the aggregate "quasi-demand" curve, as Williams (1976) calls it, in all travel markets.<sup>26</sup> And as shown by Williams (1976), the rule-of-a-half is an approximation to Hotelling's generalised surplus measure (provided it is path independent).

So where does this leave us? There are several important points.

First, the logsum formula (9.6) with (9.2) inserted) is the easy, exact and comprehensive user benefit measure in such models.

Second, it is perfectly legitimate and exact to decompose this measure and compute the benefits in each travel market by the use of the aggregate demand functions and a linear path from the base case to the policy case – that is, to apply Hotelling's generalised surplus measure with the simplest possible path. It should come as no surprise that the only data we need are the aggregate demand functions, since the correct welfare measure is the indirect utility of a single virtual consumer whose demand equals total demand. Computation market by market is a little more resource demanding, but has the advantage of bringing out a spatial distribution aspect.

Third, there is no use for the distinction between Equivalent variation, Compensating Variation and Marshallian Surplus in such models, as they all coincide since there is no income effect on transport demand.

Fourth, in this situation the rule-of-a-half will be a good approximation to the real user benefits for small changes in generalised costs, and it has the additional advantage over Hotelling's integral that it can be decomposed further into benefits concerning each of the additive terms of generalised cost. That way, time saving benefits and money saving benefits can be analysed separately for each travel relation and for all travel relations aggregated. Furthermore, if the model contains other terms of cost or benefit that are added to generalised travel costs in order to influence destination choice, say, the benefits of changes in these are also separable from the benefits of changes in travel costs. That way, benefits associated with price changes or other supply changes at the destinations – changes in zonal attractions, in short – can be separated out.

If there were no congestion, time benefits, monetary travel benefits, attraction benefits and housing benefits would each be attributable to changes in each of these elements alone. However, through congestion these elements are influenced by cost changes in other elements, so there is no easy way to ascribe a change in time benefits, say, to changes in time costs alone. This diminishes the usefulness of separating out the elements.

It follows from all of this that if the necessary assumptions for there to exist a representative consumer are found to be too restrictive, it is the models that will have to be changed, and not only the user benefit calculations. The user benefit calculations are perfectly valid as long as the models incorporate these assumptions.

It was established by Anas (1983) that the multinomial logit model could be

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<sup>26</sup>  $H_i(\theta)$  as defined above will be such a quasi-demand curve. (9.10) is an example of Hotelling's measure in the case where the path is a straight line. In our case, the path really does not matter, since  $V^*$  is a potential function.

established equally well by estimating a disaggregate behavioural model or by entropy maximisation. Entropy maximisation and logit modelling should be seen as equivalent views of the same problem. Thus our conclusions regarding user benefits in nested logit models are also valid for appropriately specified entropy models. For these two classes of model, then, the user benefit calculation poses no unsolved problems.

### **Hicksian welfare measures in the whole class of random utility models**

By Hicksian welfare measures we mean the Equivalent and Compensating Variations. We established initially that the most appropriate measure for the purpose of evaluating land use/transport strategies would be the Equivalent Variation (EV). If the marginal utility of money is not constant, EV will not coincide with the Marshallian Surplus, which means that generally, we can no longer use the aggregate demand functions to derive exact user benefits. But there is not only a problem of approximation involved here. Generally, in this case we will have to make stronger normative assumptions for an aggregate welfare measure to exist at all. There is a kind of trade-off between behavioural and normative assumptions, so that if the strong behavioural assumptions leading to a representative consumer are relaxed, some kind of explicit weighting of the individual benefits will have to be made to arrive at a welfare measure.

We are quite happy to make such strong normative assumptions (a utilitarian welfare function), or some behavioural or normative assumptions in a stochastic model setting that does the same trick, and to use the EV as our user benefit measure in the case where the marginal utility of money is not constant. Recently, Karlström has derived a formula that provides us with the opportunity to calculate EV and CV in random utility models even if the marginal utility of money is not constant, and which coincides with the logsum formula in the case where it is constant (Karlström 1999). For the whole class of Generalised Extreme Value (GEV) models, the computation can be made at negligible computational cost.

We may perhaps assume that the assumption of constant marginal utility of money is reasonable for most transport models, although once the possibility of doing without this assumption is explored, this may turn out not to be true. The cases where it will be most useful to do without this assumption, however, are when car ownership and land use are integrated with the transport modelling system. The choices of cars and residence have implications for the income that remains after the choice that are large enough to affect the marginal utility of money. Thus if an integrated land use/transport model is built in such a way that the modelling system as a whole is consistent with utility maximisation, user benefits may be computed by the Karlström formula even if a constant marginal utility of money is not assumed.

Outside random utility modelling, there might well exist models which are consistent with utility maximisation and where it is pretty obvious how user benefits are to be computed. For instance, computable general equilibrium models use CES (Constant Elasticity of Substitution) utility functions. The EV of such models can easily be computed. However, if CES functions are used, either the user benefits must be computed on an individual basis and added by way of a utilitarian welfare function, or all individuals must be assumed to have identical preferences and income. The latter assumption is often used.

This is as far as science can get us. For the remaining classes of model, we are left to use some heuristic approach or to refrain from measuring welfare.

### **Car ownership**

In current modelling systems, it is customary to include a car ownership model that is

strictly speaking not consistent with the rest of the system. For instance, the car ownership model may turn out the number of cars per household and an annual driving distance, but the annual driving distance is in no way connected to the annual driving distance that can be computed from the transport model. Probably the most sensible thing to do in such instances is to follow the suggestion by Simmonds (2001) and assume that the car has no utility outside its use, and that the utility of using the car is captured in the transport model. Thus if there is a change in car ownership, the utility is measured in the transport model, while the income available for other consumption is reduced by the increase in car holding costs. These two elements are to be included in the cost benefit analysis.

This is not entirely satisfying for two reasons. First, because of the inconsistency in the modelling system brought about by the inclusion of the car ownership model, and second because it may be assumed that the car is useful for trips outside the model area, such as holiday trips. In urban areas, for many people such trips might very well be the main reason for having a car. Nevertheless, our proposal is to follow the Simmonds approach.

### **Residence and other consumption**

Changes in residential location and the consumption of housing services are predicted in the land use model part of the modelling system. Assuming constant marginal utility of money, what is the benefit brought about by such changes?

If the model system includes the choice of location and housing consumption in a way that is consistent with utility maximisation, such as an appropriately specified nested logit model, the question has already been answered above. The logsum at the highest level of choice is the correct user benefit measure. This measure might be decomposed according to Hotelling's generalised surplus measure, as indicated above, and this decomposition might be approximated by linearisation of the demand functions (the rule-of-a-half). This forms the basis for the proposal in Simmonds (2001), which was briefly summarised in Section 9.4 above.

The proposal is to calculate the benefits associated with changes in generalised travel cost and the benefits associated with changes in the attractiveness of destinations from the transport model. Linearisation of the demand functions for trips for a particular travel purpose from one zone to another by a particular mode at a particular time of day will bring out the two elements of generalised cost and of benefit at the destination as separate elements. A third element, the benefits of locating in a particular zone and of consuming housing services, is to be computed from the land use model, also by the rule-of-a-half.

Now there are two possibilities. Either this third element is set equal to the difference between the exact benefit measure (the logsum formula) and the two elements singled out from the transport model. In this case the total will be correct, but there will be some ambiguity surrounding the size and interpretation of the three parts, which in any case are interdependent through congestion etc. Nevertheless, they might provide useful indications of the sources of the total benefit change. Or the third part is calculated independently by the rule-of-a-half, using a pre-specified indicator of locational costs. In that case, it is just as if housing and transport were two totally separate goods markets, and the total benefit of the representative consumer could be had by taking the area over the price line and under the demand curves in each of them. Assuming separability in this way has its merits, provided good data on the monetary and non-monetary locational costs can be had. Only experience can however establish if the two approaches will give similar results.

The purpose of the Simmonds approach is to establish an heuristic rule for benefit

calculations in models where the logsum does not apply. As we think Simmonds points out himself, this is somewhat of an experiment. First, it has to be established that the two methods of calculating the third element, the method of taking the residual and the method of establishing an independent indicator of locational costs, will produce broadly the same result in models where the residual can be had. Second, this will give us the confidence we need to compute locational benefits by way of the indicator of locational costs and the rule-of-a-half in other models.

We propose to use the Simmonds approach as a guide to the user benefit calculations in models that do not admit of a very clear exact method, but which nevertheless are thought to be broadly consistent with utility maximisation. For the models where this is the case, the approach is probably better than the often used approach of computing benefits only in the transport model. The implicit assumption that housing and transport consumption are two separate goods might not be too drastic, at least not for some aspects of housing service consumption. In such models, the choice is really between an approach such as this and to refrain from computing welfare at all.

More generally, if two separate models are used to derive consumption of two separate groups of goods, the two benefit measures can be added, provided we take account of a common budget constraint. That is, the available budget in each model must be total expenditure minus the expenditure in the other model. This is not an exact rule. It will also be necessary to take account of price changes in the one model in setting the budget for the other, or even to adjust (real) prices in the one model to take account of price changes in the other. But for our purposes it will be a working rule.

For instance, if work trips and other trips are thought to influence each other only through a common travel budget, and if housing location is only depending on accessibility to the workplace, the user benefits from the integrated work trip/land use model may be added to the user benefits of the other trips.



# 10 Taxes and charges

## 10.1 Introduction

The purpose of this section is primarily to derive practical rules for entering taxes and charges in the objective function from fundamental principles of cost-benefit analysis, assuming that an objective function like OF in Section 3.5.2 is used. The rules must be adapted to the particular tax system of each country.

We assume that a social accounting table like Table 3.1 is used. It is reproduced here as Table 10.1. The main principle was explained in Section 8.2, namely to enter costs including taxes in the households' and firms' accounts, and to add taxes as a revenue to the government account in the case of goods that can be produced or imported at a fixed price (this will be the main case), but add nothing to the government account in the case of goods in fixed supply or goods that cannot easily be supplied in larger quantities (labour being the main and perhaps sole example). If the reader is satisfied with such a rule and has no problem in applying it, she may skip the rest of this chapter or go directly to the last parts of it.

Even if there is only one household column in Table 10.1, more household columns can easily be introduced if there are several household groups. The firms' account is subdivided into public transport, freight transport, landlords, transport users, parking companies and toll collectors. The government account could have been divided into an account for the body in charge of transport and a central body. The last rows transform the CBA elements according to the objective function and add the other indicators.

From a CBA or social efficiency perspective, the benefit to society is the sum of individual benefits. For simplicity, let us assume that, as a consequence of a strategy, an individual gets one unit of a good. The benefit to society of letting the individual get access to this good is measured as the individual willingness to pay for the good minus the social cost of providing her with it, or  $SB = WTP - SC$ . The social cost can be higher or lower than the price  $P$  she actually has to pay, so for each individual that gets some good as a consequence of our strategy,

$$(10.1) \quad SB = (WTP - P) + (P - SC).$$

In this formula,  $(WTP - P)$  is a money measure of the perceived utility of the individual (the individual "consumer surplus"), while  $(P - SC)$  is a correction term for the case that the price does not reflect the real social cost. We assume for the moment that there is no problem with identifying  $P$ , but to apply this formula, we need to be more precise about the meaning of  $WTP$  and  $SC$ .

**Table10.1. Example of presentation of economic efficiency results by sector and other indicators**

Strategy no.:										
Euros, present values, year n prices										
	Households (a)	Firms (b)						Government (c)	External (d)	Row totals
		Public transp.	Freight transp.	Pro- perty	Transp. users	Parking	Toll collection			
Investment costs										
Transport benefits										
Location benefits										
External costs										
Column totals	UB	PS	PS	PS	PS	PS	PS	PVF	EC	EEF
Other OF indicators										
OF										
Indicators with targets										
Other indicators										

UB = user benefits, PS = producer surplus, PVF = present value of finance (financial surplus),  
 EC = external costs and EEF is the Economic Efficiency Function

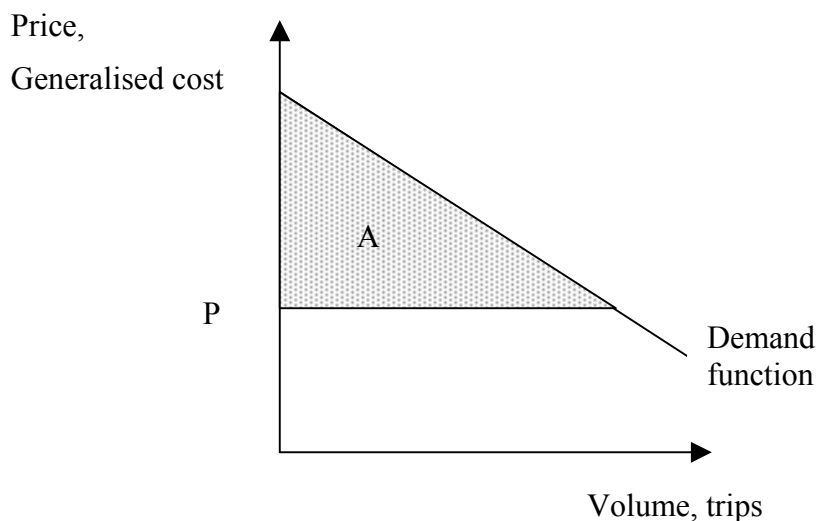
## 10.2 The first element, (WTP – P)

From land use/transport interaction models, we derive the demand for goods such as trips and housing. The demand is a function of generalised costs (the sum of link costs for the optimal route) and other prices. If we solved the model for a range of costs for a particular good (a trip, say), we would be able to chart the demand function for this good (given a fixed level of the generalised costs and prices of other goods). Given that in the short span of time we consider in the transport model, nobody would be able to make more than one trip, this demand function is an *aggregate* demand function that virtually sorts all individuals according to their willingness to pay for the trip. At a high price, only a few are willing to pay the price, but as the price falls, more and more people have willingnesses-to-pay that exceed the price.

We assume that nobody would own more than one house, so the demand functions for housing in the zones would also be aggregate demand functions that virtually sort all individuals according to their willingness to pay.

Consequently, an area such as A in Figure10.1 will represent the aggregate of all positive individual terms (WTP – P) for a particular good, while there would be similar areas for all other modelled goods as well. (If no-one is forced by buy, there will be no negative (WTP – P) terms).

Figure10.1. Aggregate demand function and consumer surplus



There may be cases where the areas under the aggregate demand curves do not represent a valid aggregate welfare measure, but this situation seldom or never occurs in the models we are using. There is also the complicating factor that as a consequence of our strategies, virtually all prices change simultaneously. But even if this makes it more difficult to show the aggregate welfare measure in a simple picture, there will nevertheless be formulas available that sum the individual (WTP – P) terms across individuals and goods.

So if the formula  $SB = (WTP - P) + (P - SC)$  is applied at the *aggregate* level, (WTP

– P) is the aggregate consumer surplus for this good as calculated from aggregate demand functions. Often, the rule-of-a-half is applied to approximate the aggregate consumer surplus. This is a practical rule for calculation of the first part of the formula. It also applies when all prices change. The result is entered – along with the consumer surpluses for the other goods – in the household column of our social accounting table.

### **10.3 The second element, (P – SC)**

Next, we turn to the second element, (P – SC). *If* the price excluding value added tax and other commodity taxes represents SC, then this element is obviously the tax revenue, and is to be entered in the government column of our social accounting table. But other possibilities exist.

The social cost of a resource or good that is consumed in a strategy is the value it would have in the best alternative use. What this value is, is again determined by individual willingness to pay.

First, consider the case of a good that exists in a fixed supply. Nothing more of it can be produced, even if a very high price could be had for it. By consuming it in the strategy, we exclude somebody else from consuming it. If that somebody had to pay commodity taxes to buy it in the market, then her willingness to pay has been revealed to be at least as high as the price including taxes. We may in fact safely assume that the resource is transferred from users in the “do minimum” situation with a (WTP – P) close to zero (a slight price rise as a consequence of the strategy would accomplish this). Consequently, the cost to society, SC, of transferring the resource from these buyers is the price including taxes.

The other extreme is a good that is produced under constant returns to scale at all realistic output levels or that is imported in any realistic quantity at a fixed world market price. If more of it is needed in the strategy, other users are not affected, and so the cost to society of providing more of it is the constant production cost or import price. This price is net of all import tolls and commodity taxes.

There will be intermediate cases, where increasing demand raises the price, as well as cases of economies of scale in the production of the good. *For our purpose, however, the two polar cases of fixed supply and infinitely elastic supply are sufficient. In the first, SC equals the market price including all indirect and commodity taxes that the marginal user pays, and in the second case SC equals the production or import price net of tolls and taxes.*

To produce the goods of transport services and housing services, inputs are needed. The same distinction between fixed supply and infinitely elastic supply is applied to them. We take the fixed supply cases to be above all labour and land. Houses and buildings are intermediate cases – in fixed supply in the short run, but not in the long run. Some resources that are not easily transported over long distances, like masses, might also belong to the fixed supply category. All other – fuel, oil, tyres, repair and maintenance services, rolling stock, equipment, goods and services for the building and construction industry etc. – are considered to be in infinitely elastic supply.

This in fact provides us with very simple and fairly correct rules of entering taxes and charges in our objective function. Before turning to them, let us once again consider what happens when we aggregate over individuals to arrive at the aggregate version of (P – SC). The aggregate P will be the total revenue from sales of the good in question, while the aggregate SC will be the area under the marginal social cost curve, or total variable costs of production plus total external costs.

External costs enter here because even if at the individual level we only considered a market transaction between a buyer/user and a seller/producer, other individuals might also be affected by the production or use of the good. Their utility or disutility from this – again measured by willingness to pay – appears when we aggregate over all individuals. Thus the private cost of production is modified into a real social cost by adding the external costs imposed on others. (Obviously, we can disregard external costs of production in the case of a good in fixed supply, but the transfer of its use from one individual to another might mean a difference to the external costs arising from the use of the good).

## 10.4 Practical rules

The application of these principles depends on the *time frame* of our analysis or model, since that determines which resources are in fixed supply and what costs are variable.

The application also depends on *the level of aggregation* or disaggregation in our model. For instance, in a model with many industries, we will have to consider if some of them are subject to different tax rules from others, and how price deviates from marginal social cost in all the different inter-industry market transactions.

Here we only consider the following:

- Household production of private car trips
- The market for public transport services
- The housing market
- The land market
- The freight transport market
- The market for business trips
- Infrastructure investment and management

Each of these is briefly discussed in the text, and the results are summarised in Table 10.2.

### 10.4.1 Household production of private car trips

Inputs to the household production of private car trips include own time, a car, fuel, and other elements of the driving cost. Also, parking charges and toll fees will have to be paid. Depending on the time frame, not all of these elements enter fully in the perceived cost  $P$ .

Together all these elements form the generalised cost of trips, which is the  $P$  of the  $(WTP - P)$  in this case. Thus at the correct value of time, the social cost of time use has already been accounted for in the calculation of consumer surplus.

The value of time is not covered here. All the other real resources in the driving cost are considered to be in infinitely elastic supply, so their SC is net of all taxes.

The correction term  $(P - SC)$  will then consist of *various* elements that go into different accounts in our social accounting table. First, the more or less pure transfer parts of  $P$  – i.e., parking charges and tolls – will have to be entered in the parking company account and the toll collector's account, respectively. The costs of providing parking space, operating parking lots and supervising parking form the SC of the parking operator account to the extent they are variable. Costs of toll collection form the SC part of the toll collector's account to the extent they are variable.

Environmental and accident costs form the SC of the part of the correction term that goes into the “external” column of Table 10.1. Finally, all commodity taxes on the elements of driving costs form the P part (revenue part) of the part of the correction term that goes into the government column. It is supposed that there are no variable costs of tax collection, so in this column there is no SC part.

No other agency is supposed to incur costs or get transfers in association with the household production of private car trips, so these three accounts (the household, government and external columns of Table 10.1) account for the whole of the necessary correction from perceived to social costs. However, if in the transport model it is assumed that travellers perceive less of their cost than they actually have to pay inside the time frame we are considering in the model, then there will be a case for including the excluded cost elements as a correction term that is added to the user benefits in the households’ account.

Elements of the fuel tax may explicitly serve to internalise external costs, like the costs of global warming or congestion costs. The names of the taxes or their purposes do however not make a difference to us. They are treated like any other taxes, and their corresponding external costs are treated like any other external costs. If the tax and the externality equal each other at the margin, the private car users have got the right incentives, but this is not a particularly good reason to delete both the tax and the externality from the social accounting table, since they might not cancel out on average. It was seen above that what should be entered in the social accounting table is the total variable cost and the total external cost, or rather the difference in the totals between the strategy case and the do minimum case. Furthermore, all taxes irrespective of their names are available for redistribution, and affect the efficiency of the economy. Since taxes matter, they should be entered in the accounts as they really are, and not be crossed out against other items.

#### **10.4.2 The market for public transport services**

The consumption of public transport services requires own time and a ticket. Together they form the generalised cost of trips, which is the P of the (WTP – P) in this case. Thus at the correct value of time, the social cost of time use has already been accounted for in the calculation of consumer surplus.

The fare is a transfer to the public transport operator. The correction term (P – SC) in this case consists first and foremost of the public transport operator’s surplus (before any fixed costs have been deducted). Thus P in the public transport operator account is total fare receipts (excluding value added tax if there is one), and SC is the area under the marginal cost curve of the operator, or total variable operating costs.

We assume the operator can reclaim value added taxes on the inputs it buys (this might be different in different countries). Thus the operator’s costs are net of incoming VAT, but not net of other taxes like taxes on fuel or taxes on investments.

There is obviously an element of the correction term that has to be entered in the government account. If there is a value added tax on tickets, then the receipts are entered in the government account. Turning to the operator’s cost side, we consider labour to be a resource in fixed supply, so that when the company uses more labour to produce more transport services, the government will not experience any change in the tax revenue on labour. All other production inputs are however in infinitely elastic supply. The VAT on these has by assumption already been reclaimed by the operator, so there is no VAT on inputs to enter. All *other* commodity taxes on inputs (perhaps mainly fuel taxes) are to be entered in the government account.

Finally, the external costs of the public transport operation are entered in the “external” column (we assume that the passengers do not directly produce any external costs except on themselves as a group). The points made above under private car trips against letting elements of the taxes and elements of the external costs cancel each other out are equally valid here.

### **10.4.3 The housing market**

In the short term, houses are in fixed supply, so any taxes on the consumption of housing will be part of the social cost of a house, and there will be no correction term (nothing to enter in the government’s account). There will however be various forms of externalities from the consumption of housing services, like neighbourhood externalities and air pollution costs from heating and other normal activities.

As long as we assume an exogenously given fixed population in our model, each with their own home, this situation will not even change with demolitions and new housing, although the externalities may change.

The existence of housing subsidies and a social housing market should perhaps call for some modifications of this rule. As we do not suppose it is modelled, the issue is not elaborated further.

### **10.4.4 The land market**

Land for residential and business purposes is likewise in fixed supply as long as a certain regulation is kept in place. If however we consider strategies where the regulations can be changed, it may be more natural to switch to the other extreme position and consider land as being in elastic supply, albeit within certain bounds. In that case, more of it can be produced for use in the strategy at a fixed price given by the market price or the assumed value of the unused land, whichever is the higher. In that particular case, the use of more land increases the revenue from property taxes in the government’s account. When the bound is reached, we are back again in the first case, where there is nothing to enter in the government’s account.

### **10.4.5 The freight transport market**

The users of freight transport are mainly firms. Although there might be different kinds of firms subject to different tax regulations, we assume as a rule that they can reclaim value added taxes on the freight services they buy. Thus  $P$  in  $(WTP - P)$  will be lower than if a private household bought freight services. There will be no value added tax revenue to enter in the government’s account, since by assumption freight transport services are never final consumption. This is all that needs to be said about the user benefits.

Turning now to the correction term  $(P - SC)$ , we first consider the part of it that is entered in the freight transport company’s account. Here  $P$  is sales excluding VAT. By assumption, freight transport companies can reclaim VAT, so their costs on purchased inputs are net of VAT, but not net of fuel taxes and other commodity taxes.

The government gets no VAT from freight transport, neither from the users nor from the transport companies. They do however get other commodity taxes from the use of purchased inputs in the transport companies. These are entered as revenue. Labour is assumed to be in fixed supply, so there is no change in labour tax revenue to enter.

Finally, of course, external costs of freight transport are entered in nature's account. These operations accomplish the corrections to social costs in the case of freight.

#### **10.4.6 The market for business trips**

It might be debated who the users of business trips are, but at least the businesses are the ones that pay. Since they can reclaim the VAT and business trips are never final consumption, the rules for entering taxes and charges in the social accounting table are exactly the same for business trips by public transport as for freight.

The difference between business trips by car and private trips by car concern the value of time and the driving costs. Leaving aside the value of time, the difference in perceived driving costs *may* be that the VAT on fuel, oil, repair etc. may be reclaimed. (Arrangements where the car expenses are covered by the employee and reimbursed in full by the firm are common, but we propose to ignore them here). In the case where VAT can be reclaimed, there will be no VAT from fuel and other driving costs to enter in the government account. Otherwise the rules are the same as for private car trips.

#### **10.4.7 Infrastructure investments and management**

We assume that infrastructure investment and management are the responsibility of the government. The actual work may be carried out by private firms or by government agencies as the case may be. The social cost should be the same.

If we operate more than one government account, there might be taxes to pay from the one to the other, and in case there are budget constraints on the both of them, it is best to enter this explicitly. If private firms do the job, the value added tax is entered as a payment in the account of the responsible body and as revenue to the central government. Of course this is a transfer between two government agencies, mediated through the private firm. Taxes on inputs except labour are treated in the same way and thus are entered both as payable by the construction firm and as revenue to the central government. Taxes on labour contribute to the expenses of the construction firm but *not* to the revenue of the central government.

If the job is carried out by government agencies themselves, there will be no VAT. With respect to other commodity taxes and labour, the situation is the same as when the job was outsourced to private firms.

### **10.5 Summary**

The results of this survey of how to enter taxes and charges are summarised in Table 10.2.

We have seen that the aggregate social benefits SB of a strategy, as measured by CBA principles, consists of the two elements  $(WTP - P)$  and  $(P - SC)$ . The first of them is the user benefit,  $UB = (WTP - P)$ . The second is a correction term that *must consist of the benefits to non-users*, since users and non-users make up the whole of society. The non-users are providers, government and "nature" (the "external" column).

Entering taxes correctly in the government account is one of the keys to performing this correction correctly. Reallocating a resource in fixed supply that is not lying idle, neither before nor after, will not produce tax revenue changes unless the potential users pay different tax rates. Utilising an unused or underused resource will increase the tax revenue. Using more of a resource in infinitely elastic supply will increase the



tax revenue by the full amount of commodity taxes.

How taxes and charges are to be treated when user benefits are calculated will be obvious from the text: We use perceived costs, including the taxes and charges that the user actually has to pay. If there are unperceived costs other than the transfers to other sectors, these are deducted from the user benefits in the same column (sooner or later they will have to be paid). How to enter taxes and charges in the government and transport operator columns should be clear from Table 10.2. The only additional remark that needs to be made is that if we suppose there is a non-zero shadow price of public funds, the government column will be multiplied by 1 plus the shadow price. The same goes for operators' columns to the extent that the government takes responsibility for their budgets.

**Table 10.2. Entering taxes and charges in the social accounting table**

Activity of the user	Enter in government account...		Enter in other accounts...
	VAT	Other commodity taxes	
<i>Trip purpose private, mode car</i>	<i>On driving costs</i>	<i>On driving costs</i>	<i>Parking and tolls in operator's account</i>
<i>Trip purpose private, mode public transport</i>	<i>On fares</i>	<i>On PT company inputs excl. labour</i>	<i>Fares excl. VAT in PT company account</i>
<i>Trip purpose business, mode private car</i>	<i>Nothing</i>	<i>On driving costs</i>	<i>Parking and tolls in operator's account</i>
<i>Trip purpose business, mode public transport</i>	<i>Nothing</i>	<i>On PT company inputs excl. labour</i>	<i>Fares excl. VAT in PT company account</i>
<i>Trip purpose freight</i>	<i>Nothing</i>	<i>On freight company inputs excl. labour</i>	<i>Rates excl. VAT in freight company account</i>
<i>Housing</i>	<i>Nothing</i>	<i>Nothing</i>	<i>Rent in landlords' account</i>
<i>Land</i>	<i>Nothing</i>	<i>Property tax in special cases</i>	<i>Nothing</i>
<i>Investment and management</i>	<i>Nothing if government is only a single sector</i>	<i>Nothing if government is only a single sector</i>	

The approach taken here builds on Norwegian official guidance (Finansdepartementet 2000) with respect to the definition of social cost and on the Common Appraisal Framework with respect to the social accounting framework. To derive the practical rules for entering taxes and charges in the social accounting table, we made use of both the concepts of willingness to pay/willingness to accept and the concept of social cost. The latter in turn was shown to be derivable from the former. Thus the terminology that a CBA could be based *either* on willingness to pay *or* on social cost is misleading.

It might be thought that since the users of business trips and private trips will in fact face different perceived costs on the same service, there is a need to adjust just one of them to arrive at the true social cost of the service. In fact, there is a need to adjust both of them, but to a different degree. Applying the rules here, we arrive at the same social cost of the same good or service, regardless of whether it is used by private households or firms. The difference is not in the SC but in the user benefits (WTP – P), where the difference in P really constitutes an inefficiency brought about by the tax system.

Regardless of whether this inefficiency is present or not, the aggregate social benefit SB always equals aggregate WTP – SC. But the *level* of aggregate SB is affected by P, since individual WTP's below P are not counted. In the market, individual user benefits  $UB = \max(WTP - P, 0)$ , that is why prices and taxes matter.

# 11 Producer and government surpluses

## 11.1 Definition

Producer surplus is one of the elements of the economic efficiency indicator. Producer surpluses is defined by annual revenue minus cost including taxes for all firms, operators and entrepreneurs. The reason for including taxes at this stage was explained in Chapter 10.

## 11.2 Producer surpluses of operators

Examples of transport sector operators are public transport companies, parking companies and toll collectors.

The relation between operators and government is different from one city to another and might also change over time. The degree of privatisation varies, as well as the types of contracts that exist between government and operators of transport services. Therefore, parts of the revenue and cost treated as producer revenue and cost in some cases may rather be treated as government revenue and cost in other cases.

Broadly, we may distinguish between a “cost plus” contract, in which the government covers all deficits of the public transport operator and expropriate all profits, and a fixed subsidy contract, which lets the operator keep all profits and take full responsibility for all cost overruns. In the first case, the operator’s account will be zero in all strategies, and any change in the net operating result must be entered in the government account. In the second case, there will be no impacts for government, as all changes go into the operator’s account. This makes a difference if a positive shadow price of public funds (Section 8.2) is assumed.

Toll collectors will probably be paying out all their profits to the government.

### 11.2.1 Operator revenues

Annual revenues for public transport companies are the fare revenues. For parking companies and toll collectors the revenues come from parking fees and toll fees. But, as indicated above, these revenues could be viewed as government revenue in some cases, depending on organisation. It might be that the government receives the revenue from the users and that the operators are compensated by the government in other ways. In this case, the revenue minus cost is obviously entered in the government column of Table.

### 11.2.2 Operator costs

The costs that a public transport company faces for operating a line might include:

- rolling stock costs (in the form an infinite chain of investments)
- labour costs (wages and social costs)

- preparation costs (costs related to cleaning the vehicle, parking it overnight, driving it to the start point of a route, and in the case of trains, marshalling a train set)
- energy costs (e.g. fuel)
- maintenance
- insurance

Some of these costs are proportional to distance. However, we would not recommend using a per kilometre approach to calculate the total costs. Some of the costs are better characterised as time-dependent than distance-dependent, e.g. the number of buses needed on a line during a period depends on how long it takes to do a round trip and on how many round trips that are scheduled during that period (that is, rolling stock costs are time-dependent).

The starting point for calculating operator costs on a line should always be the operating plan, including information on frequencies in peak and off-peak, vehicle types etc. All these factors have impacts on all the cost elements listed above.

From such information, the total number of vehicle kilometres in operation per type of vehicle can be assessed, which must be multiplied by the energy cost per kilometre to give the distance-based cost. Part of maintenance costs and possibly insurance may also be considered distance-based.

Next, the total number of vehicle hours must be multiplied with labour costs per hour to give the time-dependent operating costs.

The total number of vehicles (of different types) needed to operate the peak schedule determines the rolling stock costs, which is another form of time-dependent costs. This cost must be adjusted upward by some percentage to take account of the fact that some vehicles will be unavailable at any time because of repairs and maintenance, and the fact that the number of vehicles out of service at any time is uncertain, so that there is a need for reserve capacity. Reserve capacity as a percentage of all vehicles is less for large vehicle stocks than for small.

Finally, preparation costs and the remaining parts of maintenance and insurance depend on the number of vehicles in operation during a day.

To calculate the public transport costs of a strategy, it is useful to note the relationship

$$(11.1) \quad K = tf$$

where  $K$  is the number of vehicles in operation on a line during a certain period,  $t$  is round-trip time including turn-around time, and  $f$  is the frequency of the service.

### **11.3 Government surplus**

Government surplus is defined as tax revenue and other revenue (toll revenue, for instance) minus expenses (investment costs, infrastructure maintenance, public transport subsidies etc.) for local and national government. This will be the financial surplus which is the result of summing the entries of the government column in Table 10.1.

Remember that in this table, elements are entered without eliminating transfers first. That way we are able to see the gains and losses of a strategy for each sector. In the end, transfers will implicitly be eliminated by summing over sectors.

What to include in revenues from taxes and charges is the topic of Chapter 10.

The government column might be multiplied by a shadow cost of public funds to reflect the fact that taxation creates inefficiency in the economy.

## **12 Environmental and accident costs**

In this chapter, we suggest methods of calculating environmental and accident costs from strategic model output. These methods may or may not be the same as the ones already applied in the strategic model system that the reader is accustomed to. Anyhow, Section 12.1 provides an overview and benchmarks against which both the methods suggested later in the chapter and other methods may be judged.

### **12.1 Environmental and safety impacts, overview**

The principal environmental and safety impacts of transport and land use strategies are:

- Atmospheric pollutants
- Noise
- Danger
- Accidents
- Severance
- Visual impact

Atmospheric pollutants can be local, regional or global in their effect. Several different pollutants can be identified at the local level, including oxides of nitrogen (NO<sub>x</sub>), carbon monoxide (CO), volatile organic compounds (VOCs) and particulates of differing size. Lead and oxides of sulphur are also generated, but have become less significant. Local air quality management surveys in the UK suggest that the pollutants of greatest concern at typical UK urban concentrations are NO<sub>2</sub> and particulates of less than 10 microns in diameter (PM10s), particularly the smaller fractions of these particulates. The local pollutants are generated in different ways, and have different effects; however, the process for appraising them is reasonably similar. The most important regional pollutant is ozone which results from the more long term chemical reactions of primary pollutants, most notably NO<sub>x</sub> and VOCs. The highest concentrations of ozone can occur many miles from the sources of pollution. Carbon dioxide is different, in that it is a global pollutant which has no local impact, and can be assessed in aggregate for an urban area (or even wider still).

How to calculate the noise costs is the topic of Section 12.3.1, local and regional air pollution is covered in Section 12.3.2, while the cost related to global warming is covered by Chapter 16.

Accidents need to be categorised by level of severity and, potentially, by the nature of the victim; however, the process for appraisal is identical. For advice on the calculation of accident costs, see Section 12.4. Danger is different in that it represents a lack of safety which need not be represented by an accident record. Users (or potential users) of vulnerable modes are particularly sensitive to danger and may choose to take more time and care, reroute, switch mode or not undertake a journey at all in response. There may be significant overlaps with severance.

There are other impacts from transport and land use strategies which largely relate to land consumption (either as a result of the construction of transport infrastructure or for development). These are:

- Landscape
- Nature conservation/ecology
- Consumption of green space/urban sprawl
- Development density

### 12.1.1 Causal factors

To analyse the influence of causal factors it is necessary to consider the process by which impacts are created. For instance, for a local air pollutant, this process would involve initial emission into the atmosphere, the chemical reactions and dispersion which take place and influence air quality at the receptor and therefore the impact. These processes are only really relevant for the air pollution and noise impacts and are separated out in the impact table below. For the purposes of this section the impact is taken as being the effect at the receptor point. The severity of this impact will depend on a range of further factors, these are discussed in the next section.

The main transport factors which influence the levels of the above impacts are:

- Flow (on links or as veh-km in a network)
- Vehicle type, including vehicle age and make, engine size and type
- Technological factors, for instance the use of catalytic convertors
- Speed
- Acceleration and deceleration.

Others which are relevant in some cases and for some parts of the impact process are time since start of journey (for cold starts); link type and built form; and, for secondary impacts, meteorological conditions and pattern of development in the wider area. There will also be a set of land-use factors, which need to be added to this list.

The relevance of these to the impacts listed above is summarised in Table 12.1, where ++ indicates a strong relationship, + a weaker one, and ? an uncertain one. In many cases the latter arise from problems of quantification.

**Table 12.1. Strength of causal relationships influencing environmental effects and accidents**

Cause:	Flow	Veh type	Speed	Accn/ decn*	Cold Start	Link type	Meteo rology	Chemi stry	Built form
<b>Impact</b>									
<b>Air pollution (emissions)</b>	++	++	+	+	++				
<b>Air pollution (air quality)</b>	++	++	+	+	++		++	++	++
<b>Noise (emission)</b>	++	++	++	+					
<b>Noise at receptor</b>	++	++	++	+					++
<b>Danger</b>	+	?	+	?					
<b>Accidents</b>	++	++	++	?		++			
<b>Severance</b>	+	?	?			+			
<b>Visual Impact</b>	?	?							

\* Acceleration/deceleration

### 12.1.2 Severity

The severity of an impact is defined here as the effect it has on an individual or the population as a whole. There are a number of factors which influence the severity of a particular impact. The most obvious are the absolute level of the impact and the

location of the individual or population which might be affected (including their movement patterns). The impact might also be perceived in different ways. In some cases there is a monotonic relationship between level and severity; in others there are thresholds above which severity is markedly increased. A second factor is a change in the level of the impact from a base “do-minimum” condition; again severity can be monotonically related to level of change, or thresholds can apply. For most impacts, severity will be related to the type of link on which the impact occurs, including the frontage land uses and the extent of pedestrian and social activity. For any given land use, the severity of some impacts will be affected by the built form, including the size and spacing of buildings. Table 12.2 attempts to summarise these severity factors using the same notation as above.

It is these attributes of severity, and particularly the differences between links in a network, and types of people affected, which lead to the need for a disaggregate assessment of the distributional or equity issues arising from environmental and safety impacts.

**Table 12.2. Strength of the influence of factors that affect the environment and accidents**

Factor:	Absolute level	Threshold	Change	Link type	Built form
<b>Impact</b>					
<b>Air pollution</b>	++	++	+	++	++
<b>Noise</b>	++	++	++	++	++
<b>Danger</b>	?		?	++	
<b>Accidents</b>	++		++	++	
<b>Severance</b>	?		?	++	+
<b>Visual Impact</b>	?		?	?	+

Clearly in aggregate terms, severity will be related to the number of people affected which implies that land use and especially population density of residential areas should be taken into account. Other geographically related aspects of severity might include:

- Where thresholds might be breached
- Where big changes from some “do-minimum” might occur
- Where especially vulnerable areas exist
- Uncertainty in any of the above

The “total severity” might be calculated by some form of weighting technique, with the weights allocated on a geographical basis and related to the above factors, but this could be complicated.

### 12.1.3 Level of model

The ability of any model to estimate the above impacts depends on whether appropriate relationships between the impacts and the causal factors in the first table are included. By definition, this will not be possible, except by proxy, for danger, severance and visual impact, since these are not readily quantified. For pollutants, predictive models for emissions are available from the MEET consortium (Hickman et al 1999), but these are not detailed enough to take factors like congestion and detailed spatial considerations into account, except in an aggregate way. These factors may be important for urban air quality management. In addition, the secondary and dispersion effects are difficult to handle. For noise, simple predictive models exist, but again the dispersion and reflection effects are more problematic. For accidents similarly there



are predictive models, but there is some doubt about their reliability. With each of these three impacts, much then depends on the ability of the transport model to predict the necessary causal factors.

The most aggregate sketch planning and strategic models will typically not provide link-based data. The most that they can do is to provide estimates by zone of total traffic (in veh-km) and average speed. They are not therefore able to distinguish the effects of acceleration and deceleration, cold starts, link type or built form from the first table, except in a very approximate way. They will thus provide approximate estimates of impacts, and these will be particularly approximate in situations where there are marked differences in speed across the network. Equally, they are unable to estimate effects for individual links and types of built form, and hence say little about the distribution of impacts. However, such models usually provide estimates for more than one time period, and thus enable the effects of traffic throughout the day to be estimated. They also typically provide information on changes in vehicle movements for a wider range of modes, including bus and rail, although the relationships between impacts and causal factors are typically less well developed for these other modes.

Conventional network models perform rather better than this, in that they do estimate speed by link, and thus provide more accurate estimates of impacts. They also identify effects by link, and can therefore indicate the distribution of impacts. Few, however, estimate acceleration and deceleration directly, and identification of cold start traffic, while possible, may be complex. They often also focus solely on peak period conditions. Their main weakness is that they provide so much data that it becomes difficult to assimilate. Microsimulation models are able to estimate levels of acceleration and deceleration directly, but are too detailed for appraisal of city-wide strategies.

## **12.2 External costs in the economic efficiency indicator**

The accident cost and the cost of noise and local/regional air pollution are grouped under system external costs.

Since in our models, the households and individuals will be both travellers and residents, it might be argued that the environmental costs are borne by them and will be somehow included in the user benefits. However, we do not expect the indicators of environmental qualities in the housing model to capture and be sensitive to all of the environmental impacts of a strategy as measured from the transport model. This is why we propose to add the environmental costs as measured from the transport model to the CBA and present them as system external costs.

Accident costs pose a similar problem. They will to some extent be internalised in the choices of the travellers. However, they are not a part of generalised cost in our transport models, and this is why we have to treat them as wholly external.

## **12.3 Calculation of environmental costs**

The environmental costs included in the economic efficiency indicator are noise costs and air pollution costs.

### **12.3.1 Noise**

Noise costs are only considered relevant for noise levels exceeding predefined limits.

Typically, national governments have set the limit to 55 dB(A) for noise perceived outdoor during daytime. For night time the corresponding limit is 45 dB(A). An indoor limit might also be defined: 30 dB(A) with doors and windows shut. Since the noise level is fluctuating, it is usually transformed to find the equivalent continuous 24 hours sound pressure, dB(A) Leq. Weighting the Leq to account for the fact that noise is more annoying during the night than during the day produces various measures of the weighted equivalent sound pressure level. One of these is EFN, which weights noise between 00.00 and 06.00 ten times (10 dB) more than during the day. The EU working group on indicators recommend two indicators, the Leu and the Leu(n). The first divides the day into three periods, of which the 4-hour evening period is given a penalty of 5 dB relative to the daytime, and the 8-hour night period is given a penalty of 10 dB. The Leu(n) consists only of the (unweighted) night period.

Noise from traffic is a complicated matter in many respects. The perceived level of noise depends partly on the volume and composition of traffic and on how far away from the source of noise the individual is located. Topography also matters. Further, a change in the actual emission of noise may be perceived differently depending on the original noise level.

Obviously, some sort of unit cost related to traffic volume is a very simplistic approach. A scheme for noise cost calculation should preferably include the aspect of existing noise level, how many persons are affected and how far away from the source they are located. Further, one would need some knowledge on how a change in traffic volume would affect these variables. Finally, a valuation in money terms is needed. The principles of willingness to pay and willingness to accept is relevant here – see Section 9.7 about compensating and equivalent variation.

A pragmatic approach is to use a unit cost per vehicle kilometre which is different for the different vehicle types and which also distinguish between urban and rural areas.

When there are many sources of noise, the resulting noise level is by no means the sum of them. Instead, the difference between the noise levels of the two sources determines the total impact. Only if this difference is small does the second source contribute appreciably to the total noise level.

Similarly, the effect on the noise level of removing one of many equally strong noises is small. This would make the marginal cost of noise per vehicle kilometre small in highly congested or heavy traffic areas. On the other hand, there will usually be more people exposed in such areas. These two counteracting influences on the noise impact and cost may make the assumption of a constant unit cost per vehicle kilometre acceptable as a very crude approximation, except for sparsely populated (rural) areas, where the unit cost is much closer to zero.

### **12.3.2 Air pollution**

Emissions from traffic have impacts on the local and regional environment and on global warming. The global impacts are predominantly related to emissions of CO<sub>2</sub> and will be treated by a separate indicator described in Chapter 16.

Regarding the local and regional emissions, we want to establish indicators of the cost of air pollution for the pollutants CO, NO<sub>x</sub>, VOC, and particulates (PM). Even if the smallest particulates (less than 2.5 micrometres) are the most harmful, it will probably be easier to establish emission rates and valuation for particulates less than 10 micrometres. If needed, we should also be able to derive an indicator of SO<sub>2</sub> costs from fuel consumption and the sulphur content of fuels. The indicators will be denominated in monetary units, and so they may be presented singly or aggregated.

In principle, we need to consider emission, the dispersion of the harmful substances through the air, their chemical reactions and interaction with pollutants from other sources, the resulting air quality at different places in the city, and the number of people (buildings, crops) exposed to these air conditions. We then need to assess the damage inflicted on the recipients in monetary terms. Since there is no way we can do this in the strategic analyses we aim for here, we will have to rely on knowledge produced elsewhere and on reduced forms of such air pollution modelling. In particular, we want to be able to compute *emissions* as accurately as possible, while relying on other sources for the average cost per emitted kilogram of the pollutants in the particular conditions prevailing in urban areas like ours.

Air pollution costs are a typical case of the need to be able to supplement analyses at the strategic level with more detailed analyses from time to time, to ensure that the simplified relationships of the strategic models are broadly in line with the results from detailed air pollution modelling in each particular city.

Since in many cases, the urban area we study will also be composed of less densely inhabited areas, the sources that will be most useful to us will include costs per emitted kilogram in both urban and rural conditions. We might then subdivide the urban area in urban, rural and intermediate areas, each with their own cost of emission. To the extent that the *emission* indicators admit of spatial disaggregation, our cost of air pollution indicators will do the same, and this may form the basis for presentation of results in the form of maps.

The general form of the indicators will be

$$(12.1) \quad APC = C \cdot EF \cdot A$$

where *APC* is the cost of air pollution indicator, *C* is the cost per emitted kilogram of substance (incorporating in a very simplified way the dispersion of the pollutants in the air, the dose and the numbers of exposed receptors, the damage done to them and the cost per damage), *EF* is the emission factor in kilograms per vehicle kilometre and *A* is the activity in vehicle kilometres.

It must be pointed out that there will be considerable uncertainty surrounding these indicators, stemming from the emission factors, the problems of integrating emission models and transport models, the transferability of the unit costs, and the uncertainties inherent in the underlying dispersion modelling, the dose-response functions and the costs of damage estimates.

With respect to the emission factor *EF*, there are basically two options open to us. The first is to assume constant average emission rates per vehicle kilometre for the different types of vehicle and fuel. The rates will nevertheless change due to technological development and its rate of penetration in the vehicle fleet, which are factors that belong to the scenario assumptions. They might also be differentiated across classes of road (urban, rural, highway). This refinement will require some extra programming for most models.

More and more it is recognised that the effects of congestion on air pollution and global warming merit at least as much attention as the traditional problems of delays and time losses. As congestion increases, emissions to air can increase very rapidly. To be useful for the evaluation of strategies, our indicators of energy use and air pollution should therefore be sensitive to speed. The other option, then, is to make emission rates a function of average vehicle speed.

The MEET project (Hickman et al 1999) provides the appropriate functional relationships. However, since the functions are estimated from full real-world driving cycles, the application of this methodology must be based on average conditions in fairly large areas or zones. The MEET methodology cannot be applied at the link level. By and large, there is no easy relationship between transport models and emission models, which have developed separately. Applying the methodology to the output from transport models will therefore be somewhat experimental.

Consequently, we divide the urban areas into areas of suitable size. Presumably, homogeneous driving conditions in an area will produce better results. Some consideration should also be given to the need to define the areas such that the volume of walking and cycling can be had, and such that the conditions with respect to interaction between slow and motorised modes are similar throughout the area. From the transport model (or from empirical evidence) we compute vehicle kilometres and average speed for the different types of vehicle in each area in each strategy. This might require some programming. Finally, each area is characterised by its population density as being urban, rural or intermediate. This is done to make the right choice of unit cost per emitted pollutant.

Applying the MEET methodology, there is also scope for further refinement. For instance, changes in the number of cars can be used to compute changes in evaporation (only gasoline, not diesel), and changes in the number of trips can be used to assess emission from cold starts.

Improvements in fuel efficiency and cleansing technology and changes in the composition of the vehicle fleet will obviously matter for the emission factors. This must be built into the description of the scenarios. The ensuing shifts in the emission factors are uncertain, but some clues are contained in Hickman et al (1999) and other sources. Unless it can be derived from the network model, assumption will have to be made about the shares of different public transport modes in the total public transport supply.

Next, we turn to the unit costs. Table 12.3 shows some possible sources for the unit costs and their values. The sources are Eyre et al (1997), EUNET (as reported in Grant-Muller et al (2001)), ECMT (1998), Eriksen et al (1999) and SIKA (2000). Prices are 1995-1999 prices and it is assumed that 1 euro = 0.625 pounds = 8.25 NOK = 8.80 SEK. The value of life is assumed to be 2 million pounds in the Eyre et al study.

**Table 12.3. Costs in Euro per emitted kilo of pollutants from transport**

	SO <sub>2</sub>		NO <sub>x</sub>		VOC		PM <sub>10</sub>		
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Small town	Rural
<b>Eyre</b>	52	7	13	9	3	3	92		14
<b>EUNET</b>		1.7		4.5			185*		
<b>ECMT</b>			8	4	8	4			0
<b>Eriksen</b>	9	2	8	4	8	4	206	25	0
<b>SIKA</b>	27	2.3	10	6.8	8.5	3.4	864	216	0

\* PM<sub>2.5</sub>

The "rural" category of Eyre et al is probably somewhere in-between the "small town" and "rural" categories of Eriksen et al, which makes the PM values comparable. An explanation of the high "urban" PM value of Eriksen et al might perhaps be the considerable problems in Norway with high levels of PM, not so much because of exhaust emissions as because of studded tyres. The NO<sub>x</sub> and VOC values of Eriksen et

al are taken from ECMT. The urban values shown for SIKA apply to Stockholm inner city, which might explain the very high PM<sub>10</sub> value. The SIKA small town value of PM<sub>10</sub> applies to Stockholm's surroundings, but is very similar to the corresponding value for a small to medium sized town.

Some other valuable sources of unit costs of air pollution will be Nellthorp et al (1998) and Watkins et al (2001).

### 12.3.3 Non-transport sources of emission and backward linkages

Modelling *total* emissions in the city is beyond the scope of the rather coarse strategic planning that we consider in this guidebook. Considering total emissions could involve environmental input-output modelling. In particular, that would be useful if we intend to apply a dispersion model to draw detailed conclusions about the local air quality or noise in each part of the city, or to study environmental equity impacts.

The *strategies* we are testing and assessing involve only land use and transport policies. Unless such policies are very different from each other with respect to the amounts of money that consumers must use for transport and housing, they will not influence general consumption of other goods and services very much. The level of general consumption is rather given by the *scenario* assumptions. So except for differences due to energy use and emissions from housing and transport, the indicators from environmental input-output analysis will mainly be indicators of the sustainability of *scenarios*, not strategies. Furthermore, as long as the stock of houses or the forms of energy used in homes do not change much, emissions from housing will also be fairly constant, even if households relocate within the given stock of houses.

Consequently, as a first approximation, we propose to take non-transport emission as exogenously given. The question then arises if we should somehow take account of backward linkages (the emissions from the production of fuel and vehicles) in our transport and land use planning, or if they can be ignored altogether.

With respect to greenhouse gas emissions and energy use, we want in principle to include life-cycle emissions, since the point of emission does not matter. But except for the greenhouse gases, any indicators of emissions from backward linkages must be kept separate from the direct emissions. The reason is that we do not know where these emissions occur. Probably they are irrelevant for dispersion modelling and for the assessment of the costs of local and regional air pollution in the particular city we are studying.

By consulting sources such as Hickman (1999) or Eyre et al (1997), we can fairly easily find the emissions due to the production of the fuels. Estimates of life-cycle costs of the production of cars and houses can also be found in the literature. However, considering the other challenges of establishing environmental indicators, except for CO<sub>2</sub>, we do not make it a priority to keep track of these backward linkages at present.

If dispersion models are used, there will be a need to include emissions from the *local* production sector in them. Thus we cannot totally abstract from the production sector and the question of what industries are located where.

## 12.4 Calculation of accident costs

### 12.4.1 Proposed approach to accident costs

Accident costs can be computed at different levels of spatial detail. At the most aggregate level, we could use constant accident risks and average costs per accident per vehicle kilometre throughout the urban area. Two forms of spatial disaggregation are however possible: different accident risks and possibly different average costs in different parts of the city, and differentiation with respect to road classes (urban, rural, highway). At either of these levels, one could also make a distinction between accidents involving only cars, accidents involving only slow modes and accidents involving a car and pedestrians and cyclists. It is this latter form of differentiation that will be the most useful for our purposes.

Let us call the first category (accidents involving only motorists) M-accidents. The second (involving only slow modes) is called S-accidents, and the third (involving both cars and pedestrians/cyclists) X-accidents. As explained in Section 12.2, we treat all accident costs as external costs. Therefore, let the total cost of an average accident of these three types be  $C_M$ ,  $C_S$  and  $C_X$ , respectively.

The term “average accident” takes into account the average severity of an accident, i.e. the occurrence of fatalities, serious injuries, slight injuries and material damage. In the total cost of an average accident, the cost to society of a fatality, of an injury and of material damage is valued in terms of money. The unit costs  $C_M$ ,  $C_S$  and  $C_X$  can be found in manuals like Elvik and Vaa (2003). European costs can also be found in Persson and Ödegaard (1995).

Consider a particular part of the transport system. It might be the whole city, or all roads of a particular class, or it might be all roads in a particular area of the city (a zone or rather an aggregate of zones). The choice of spatial detail depends on the available data on accident risks and traffic volumes. One would also like traffic conditions to be as uniform as possible in each part of the transport system that we consider. Let the traffic volumes in this part of the system, measured in vehicle kilometres, be  $M$  for the motorised mode and  $S$  for pedestrians and cyclists. The risk per vehicle kilometre of a car-only accident is denoted by  $r_M$ , the risk per vehicle kilometre of an accident involving only slow modes is  $r_S$ , and the risk per *car kilometre* of an accident involving pedestrians or cyclists is denoted by  $R$ . Building on Jansson (1994), it can be shown that the total change in accident costs from the base strategy in this part of the transport system is

$$(12.2) \quad dTC^A = C_M r_M (1 + El_M r_M) dM + C_S r_S dS + C_X R M \left[ (1 + El_M R) \frac{dM}{M} + El_S R \frac{dS}{S} \right]$$

The total change in accident costs from a base strategy to a tested strategy consists of three terms. The first is the cost of M-accidents, the second the cost of S-accidents and the third the cost of X-accidents. The data we need comes from three sources: From the *transport model* we must be able to derive  $M$ ,  $S$  and  $dM$ ,  $dS$ . The elasticities and risks can be taken from sources like Lindberg (1999), Persson and Ödegaard (1995), Elvik (1994), Elvik and Vaa (2003) or Fridstrøm (1999), although it must be admitted that they apply at the national level and need some adjustment for use in urban contexts. We will treat the elasticities and risks as constant parameters.

A land use/transport policy measure could influence vehicle-kilometres or accident risks, or both, for one or more modes. For example, a land use measure influencing the location of houses and workplaces might encourage the use of public transport and thereby reduce vehicle-kilometres travelled by private car. This would in turn affect

accident costs.

A measure to reduce risk can easily be modelled as a change in  $R$ .<sup>27</sup>

A reasonably informed choice of parameter values can be made by modifying the values from the above sources to reflect the particular circumstances in a city, taking advantage of what can be known a priori.

Jansson (1994) applies theoretical arguments to derive the relationship

$$(12.3) \quad El_M R + El_S R = k - 1$$

where  $k$  is a parameter between 1 and 2. As slow modes increase, the risk perceived by motorists should not go down, so  $El_S R$  should be positive. Also, it should be below 1, with a value closer to 1 if we are in "car territory" and closer to 0 if the motorists must pay more attention to the pedestrians and cyclists. The latter case is probably typical of inner city conditions.

As motorists increase, the chance of each one of them to hit a pedestrian will probably decrease, so  $El_M R$  should be negative, but not as low as  $-1$ , which would mean that the number of accidents was constant. By the above formula, a value closer to  $-1$  would go together with the other elasticity being closer to 1 (highway), and an  $El_M R$  closer to 0 will go together with an  $El_S R$  closer to 0 (inner city).

#### 12.4.2 Implementation issues

To model car-only and slow-mode-only accidents poses less problems than the modelling of X-accidents. The slow-mode-only accidents can probably be assumed to have the same risk everywhere in the urban area. With respect to car-only accidents, some form of spatial differentiation is preferable, based on evidence about  $r_M$  or statistical evidence from the city.

The X-accidents are more difficult. There are two implementation issues. The first issue is: At what level of spatial differentiation will it be possible to derive traffic data for the slow modes? The second is if it will be possible to set specific values for the elasticities and risks at the chosen level of aggregation.

In the kind of models that are customarily used for strategic planning, walking and cycling trips are not assigned to the network of road links. So if we are going to use traffic volumes from the models, we cannot use links as the basic area for the calculations. Aggregate zones may be used, but this raises several problems. How are we going to assign walking and cycling trips to the chosen zones? How large should the zones be to fit the data on elasticities and risks that we have?

With respect to assigning walking and cycling trips to zones, there seem to be two main options. The first is to assume that walking and cycling trip distances are divided evenly between the origin zone and the destination zone (and that no such trips pass through other zones). The other option is to aggregate over the zones to a level where walking and cycling trips become predominantly internal trips in the zones.

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<sup>27</sup> The total change in accidents for a measure that affects both the risk and the traffic volume would be  $d(RM) = RdM + MdR$ .

There is also an option to disregard model traffic data for the slow modes altogether. Then it will be possible to apply the urban/rural/highway distinction with respect to motorised traffic volumes. Risks per vehicle kilometre for the motorised modes by type of road are for example available in Elvik et al (1997).

The resulting indicator could be able to reflect the impact on X-accidents of measures that reduce the risks. However, the impact on X-accidents due to changing volumes of walking and cycling can *not* be captured by such an indicator. The third term of the total accident cost formula would lose one of its elements, the one depending on  $dS$ . Our advice is to try to develop an indicator at the zonal level, not at the level of road types. The main reason is that this could also be used as an indicator of liveable streets (see Chapter 15).

Each type of *public transport* will have its own accident risk and cost of an average accident. Fixed accident rates per vehicle kilometre may be assumed. However, accidents involving buses and pedestrians/cyclists could probably be assessed together with cars. Accidents involving rail and cars could in principle be assessed using the same model as for cars and slow modes.



## 13 Walking and cycling benefits

Walking and cycling benefits have been largely ignored or only very incompletely assessed in formal analysis of transport projects. Walking and cycling are not only means of transport, but also are very popular activities in their own rights. Adding to the complexity, they form integral parts of other activities, such as downtown shopping and public transport trips. It might be that to come to grips with walking and cycling benefits, these three different reasons for walking and cycling must be kept apart. For walking and cycling as the chosen primary mode to get from one point to another, *travel time savings* will matter, although other elements such as the cost of maintenance and fear of theft of the bicycle and the physical effort and discomfort will presumably also form parts of the generalised cost (Elvik 2000, following Brundell-Freij et al 1987). For walking and cycling as leisure activities, time savings will obviously matter *less*.

Elvik (2000) surveys and discusses the state-of-the-art with respect to cost-benefit analysis of measures to promote walking and cycling. The survey shows that research is needed to capture walking and cycling benefits in a better way. Nevertheless, something can be done already.

To some extent, the benefits to the non-transport forms of walking and cycling are covered by our liveable streets indicator. Accident impacts for all pedestrians and cyclists are also covered in Section 12.4. Measures that reduce the accident risk are simply assessed by changing the risk parameters relating to accidents involving only slow modes and accidents involving slow modes and a car. It needs to be pointed out that the first of these,  $r_s$ , is by no means to be ignored, even if such accidents are rarely counted as traffic accidents. See Elvik and Vaa (2003) for evidence. The three main remaining impacts will be time savings for those that use walking and cycling as a transport mode, increased security, and the health effects.

Even if our modelling of walking and cycling trips leaves much to be desired, we will have to rely on transport model output. From this it follows that time savings can be computed and combined in an ordinary measure of user benefit calculated for example by the rule-of-a-half. We might want to use time values in line with the values of time for other modes, although the scant evidence there is suggest somewhat higher values.

This leaves us with the health and security issues. According to Elvik, there is evidence that the positive effects of walking and cycling as physical exercise outweigh the negative effects due to exposure to pollution. Therefore, a positive value should be attached to the number of trips by these modes, or perhaps to the total kilometres. What value is however not clear, and any value will be experimental at this stage.

Security may be false or real. An excessive feeling of security may cause accidents. Luckily, some measures increase both security and safety, while others (pedestrian crossings) induce a false sense of security. Still others (roundabouts) increase the feeling of insecurity but actually decrease the number of accidents – possibly as a result of the feeling of insecurity. Obviously, there is little chance of including security effects in a satisfactory manner, so we propose to leave them out.

In the end, we are left with accidents, user benefits as calculated in the ordinary way and a health effect. These effects are independent of each other – perhaps not in reality, but at least in our models, where health and safety considerations form no part

of generalised cost. Consequently, if some composite measure of user benefits is used, including the benefits of walking and cycling trips, we would be double-counting if we added anything else than accidents and the health effect.

Transport and land use strategies are important to public health. The ways in which the strategies influence health have been identified. They consist of the health impact of air pollution from transport, production and housing, the accident impacts, and the impacts of physical exercise in the form of walking and cycling. If a city wants to focus the health implications of transport/land use strategies, an indicator consisting of these three elements may be formed and reported. It should however be pointed out that such an indicator should not be included in the objective function or the targets without making the appropriate changes in other indicators to avoid double-counting. Also, more research is needed to form a good overall health indicator.

# 14 Equity indicators

## 14.1 Aspects of equity

Sustainability is often decomposed into economic, ecological and social sustainability. We have not used this distinction. However, it is clear that broadly, economic sustainability can be identified with the objectives of economic efficiency and growth, ecological sustainability can be identified with the environmental objectives, and social sustainability is related to the social inclusion and equity objectives.

Equity, like the related concepts of justice, fairness and right, is not a simple thing. Different people have different concepts of equity, but also, which of the aspects of equity that seems important will depend very much on the particular context and circumstances (Langmyhr 1997). This calls for a variety of indicators and some serious thought about which of them to use in each case.

A first distinction can be made between formal equality (treating all people equally) and outcome equality, which may imply unequal treatment. Our social inclusion objectives are based on the notion that the outcome of a strategy should be favourable for the disadvantaged in the transport system, at least if their basic needs with respect to accessibility are not met. Outcome equality might also be required with respect to different geographical areas and income groups. Such aspects have proven to be very important in the opposition to road pricing (Langmyhr 1997). On the other hand, the principle of formal equality may be invoked to make all users pay the same and letting no-one use the transport system for free while others must pay, and to demand that the revenue is recycled to those who paid the charges.

A lot of other considerations will also be relevant, among them fairness in the form that government should keep to its promises, and procedural fairness (a transparent and democratic planning process). These aspects are not covered here. A comprehensive survey of equity arguments raised in the discussion about the Norwegian toll rings can be found in Langmyhr (1997).

## 14.2 Indicators of income inequality

Indicators of income inequality will inevitably have a normative as well as a descriptive content. The normative content becomes clear if we consider the properties that we want such an indicator to have. Some of them will be fairly uncontroversial. But to arrive at a definite mathematical formulation, we will also have to make more controversial choices. In experiments where people are asked if they consider an income distribution to be more or less unequal than another, usually none of the properties wins unanimous support. This is why we should be aware of the normative choices we make when we pick a particular indicator.

Suppose we have recorded the income of the individual members of a given population and ordered them according to income. We want to measure the inequality of this distribution of income. The first property that we want our measure to have is *anonymity* (or symmetry). It says that if two members of the population swap incomes, the measure should be unchanged. It does not matter *who* the rich and poor are.

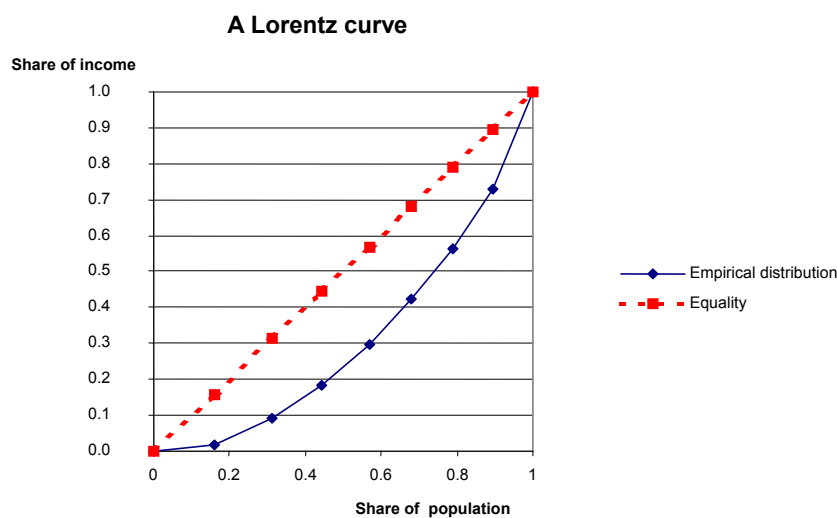
Women earning twice as much as men is equally bad as men earning twice as much as women.

The next property is the *Pigou-Dalton property* (the transfer principle). It says that if you take an amount from a richer person and give it to a poorer person, inequality should diminish as long as the poorer person is still poorer than the rich after the transfer.

These properties seem uncontroversial. The *population principle* is also perhaps uncontroversial. It says that if we replace each income earner by the same number of clones, the inequality measure should not change. The controversial properties, however, are mainly two. *Scale invariance* says that if you multiply each income by the same positive constant, inequality is unchanged. That is often felt to be a rightist view. On the other hand, *translation invariance* says that if you add the same amount to each income, inequality is unchanged. This is often felt to be a leftist view. A compromise between these principles – a centrist view – is possible but probably mathematically cumbersome.

The *Gini coefficient* is the most commonly used income inequality measure. It can be explained with reference to Figure 14.1 below. On the horizontal axis, a population is ordered by income from the lowest to the highest. On the vertical axis is the cumulative share of total income. If everybody had the same income, any ten per cent of the population would have ten per cent of the income, and the straight line “Equity” would be produced. In reality, the twenty per cent with the lowest income has only about 3 per cent of total income, the forty per cent with the lowest income has only about 25%, etc. This is shown by the “Empirical distribution” curve. This curve is called a Lorenz curve. (In actual fact, the depicted Lorenz curve shows the income distribution of Norwegian taxpayers in 1995). Obviously, the area between the two curves is an indicator of income inequality, ranging from 0 for perfectly equal distributions to 0.5 for distributions where one person earns all income. The Gini coefficient is twice this area to get a measure of inequality between 0 and 1.

Figure 14.1. Lorenz curve for the taxpayer population of Norway 1995.



For our purposes, probably the most useful formulation of the Gini coefficient is:

$$(14.1) \quad G = \frac{1}{2n^2 \bar{x}} \cdot \sum_{i=1}^n \sum_{j=1}^n |x_i - x_j|$$

Here we have assumed a population of  $n$  individuals with incomes  $\mathbf{x} = (x_1, x_2, \dots, x_n)$ . The average income is  $\bar{x}$ . Suppose however that there are instead  $n$  income groups with incomes  $\mathbf{x} = (x_1, x_2, \dots, x_n)$ ,  $n_i$  members of group  $i$ ,  $i = 1, \dots, n$  and  $\sum_i n_i = N$ . Then

$$(14.2) \quad G = \frac{1}{2N^2 \bar{x}} \cdot \sum_{i=1}^n \sum_{j=1}^n n_i n_j |x_i - x_j|.$$

The Gini obeys the first three principles and scale invariance, and consequently does not exhibit translation invariance.

The Gini coefficient is not *additively decomposable*. Additive decomposability means that if the population consists of groups, the inequality measure can be decomposed into a term showing inequality within groups and a term showing inequality between groups. This is obviously useful for our purposes. For instance, our population belong to different zones, and it might be interesting to see to what extent the unequal distribution of benefits among income groups is due to the unequal spatial distribution. The class of additively decomposable inequality measures was characterised by Shorrocks (1980). It turns out that the members of this class that exhibit the properties of symmetry, the Pigou-Dalton transfer principle, the population principle and scale invariance are of the following form:

$$(14.3) \quad S_c(\mathbf{x}) = \frac{1}{nc(c-1)} \sum_{i=1}^n \left[ \left( \frac{x_i}{\bar{x}} \right)^c - 1 \right] \quad \text{for } c \neq 0 \text{ or } 1$$

$$S_0(\mathbf{x}) = \frac{1}{n} \sum_{i=1}^n \log \frac{\bar{x}}{x_i}$$

$$S_1(\mathbf{x}) = \frac{1}{n} \sum_{i=1}^n \frac{x_i}{\bar{x}} \log \frac{x_i}{\bar{x}}$$

where  $\mathbf{x} = (x_1, x_2, \dots, x_n) > \mathbf{0}$  is the distribution of income among the  $n$  members of the population, and  $\bar{x}$  is the mean income. The constant  $c$  can take all real values. This class of functions  $S_c$  is called the class of *generalised entropy measures*. For some values of  $c$ , they behave rather oddly as measures of income inequality. For instance, for  $c > 1$ , the measure is very sensitive to transfers of income among the rich, while for  $c < 0$ , it is very sensitive to transfers of income among the poor. Furthermore, only  $S_0$  will have the property that when decomposed, the weights on the within-group terms are constants and sum to 1. Thus  $S_0$  seems a very good candidate for our inequality measure.<sup>28,29</sup>

<sup>28</sup> The weights on the within-group terms of  $S_l$  will also sum to 1, but will be functions of between-group inequality. On the other hand,  $S_l$  (and all measures with  $c > 0$ ) has the property that there is an upper limit to inequality, given by  $\log n$  in the case of  $S_l$ . This allows for a normalisation of the measure and is obviously convenient for expressing targets.

<sup>29</sup> The  $S_0$  and  $S_1$  measures are originally due to Theil (1967). Theil measures used to be denoted by  $T$ , but since they are special cases of the Shorrocks measures, we denote them by  $S$ . For an application of entropy measures to residential location, see Hårsman and Quigley (1998).

Decomposition of  $S_0$  takes the form:

$$S_0 = B + \sum_g w_g S_0(\mathbf{x}_g) = B + \sum_g \frac{n_g}{n} \frac{1}{n_g} \sum_{i=1}^{n_g} \log \frac{\bar{x}_g}{x_i^g} = B + \sum_g \frac{1}{n} \sum_{i=1}^{n_g} \log \frac{\bar{x}_g}{x_i^g}$$

(14.4) where

$$B = \frac{1}{n} \sum_g n_g \log \frac{\bar{x}}{\bar{x}_g}$$

Here, the groups are indexed by  $g$ , the population in group  $g$  is  $n_g$  and average income in group  $g$  is  $\bar{x}_g$ .  $B$  is the across-groups inequality measure, resulting from abstracting from all income differences inside groups.  $(n_g/n)$  is the weight of the inequality inside group  $g$  in the total measure  $S_0$ .

All of the measures treated so far exhibit scale invariance. For political balance and for technical reasons, we will also have a need for inequality measures displaying translation invariance. Of course, if we are not certain which of our inequality measure embody the norms and values of the decision makers, there is a third option, namely to present the distributional impacts of a strategy in a raw form, for the decision makers themselves to pass judgement on whether or not inequality has decreased.

The Kolm measure (Kolm 1976) obeys the first three principles and *translation invariance*. It is

$$(14.5) \quad K_a(\mathbf{x}) = \frac{1}{a} \log \left( \frac{1}{n} \sum_{i=1}^n \exp(a(\bar{x} - x_i)) \right)$$

where  $a > 0$  is a transfer sensitive parameter.

The technical reason for applying (14.5) is that it allows some (or all)  $x_i$ 's to be negative, whereas (14.3) does not.

### 14.3 Intragenerational equity objectives and indicators

In principle, we might incorporate intragenerational equity across income groups in a welfare function along the lines suggested by Atkinson (1970) and others. To be able to use different indicators to measure different aspects of equity, and in order not to make the interpretation of the objective function too difficult, we prefer to have intragenerational equity expressed by separate indicators. These indicators might be included in the objective in an additive way for the purposes of MCA. If the objective function is CBA-based, however, it would be better not to include them in the objective function. Nevertheless, they could and should be included among the targets.

In the context of land use/transport planning, the relevant equity issues concern the distribution of benefits and costs of our strategies. Our *first concern* is with the distribution of these benefits and costs viewed in isolation. For instance, we might find it unacceptable if only a small minority bears all costs, or conversely if only a small minority gets all benefits. A particular attitude towards the distribution of costs and benefits would be to accept only strategies where there are no losers. In all practical instances, this would require us to design a very detailed system of compensation to losers, and to measure inequality after compensation.

Our *next concern* is with the distribution of land use and transport benefits and costs among socio-economic groups and over space. This covers a lot of issues. One in particular has been singled out as an indicator of social inclusion, namely the distribution between those with and without a car. Another issue, which seems to be very important in practice, is the distribution between those inside and those outside the urban area under study. The urban population is reluctant to implement measures such as road pricing, which benefit mainly the population outside the city (through government revenue, which is the main part of the benefits). To keep the benefits inside the city, they might prefer more inefficient measures such as restrictions (Daganzo 1995), or they might require the revenue to be recycled to local public transport, for instance. Finally, there are concerns about the distribution of net benefits among city households with different income levels, household types such as single persons and couples with and without children, the sexes and the households at different locations.

*Which* of these issues we are going to measure by indicators of inequality depend (among other things) on the data that can be produced from each model. In some models, the population will be highly segmented *in the land use model*, while in others, all households are identical at this level. With respect to *the transport model*, some models can compute benefits from transport for each household income class and household type for each of the zonal populations, while others provide less information. Obviously, for each model system a choice must be made concerning what the relevant aspects of equity are, if the inequality should be measured in the transport model or the land use model, and which socio-economic groups it is possible to consider.

Thus depending on the model, the population of the city might be partitioned into groups whose members share a set of characteristics: they belong to a household with a certain level of household income per consumption unit, they live in a certain zone, they have a certain level of car availability, they belong to a household of a certain type and they have a certain sex etc. For each of these groups we should be able to compute the benefits and costs of a strategy, or else we must make the list of characteristics shorter. The inequality indicators must be computed as the inequality between individuals belonging to these groups or groups formed by considering only a subset of these characteristics.

The net benefit from a strategy for any such group may be positive or negative. Even the average individual benefit across groups may be negative. That is why we need a translation invariant inequality measure to assess the inequality of the distribution of benefits and costs of a strategy, viewed in isolation (that is, not on the basis of how the strategy contributes to relieving or aggravation *other* inequalities in society). This is what we need the Kolm measure for.

If we measured the inequality of the distribution of net benefits across *income groups*, we would not know if a reduced level of inequality was a good or a bad thing, since we probably want a more equal distribution of income as well as an equal distribution of net benefits. Consequently, we propose to use the Kolm measure to measure the unequal distribution of net benefits across individuals located in different zones (assuming all individuals in a zone get the same average zonal net benefit). We may also use it to measure the unequal distribution of net benefits among those without and those with access to a car, and among males and females (assuming all car owners, males etc. get the same average benefit for their group). This is possible because in these instances, we know that less inequality is better. However, for these dichotomies a simpler solution might be to record male and female (car/no car) shares of the total net benefit if it is positive, and of the net loss if it is negative.

Instead of the distribution of net benefits, we might have been interested in the distribution of accessibility as measured by an accessibility index (see for instance Geurs and Ritsema van Eck (2001) for an overview of accessibility measures). The main difference is that in the first instance, we are interested in the change from the do minimum brought about by a strategy, whereas in the latter we are interested in absolute levels. Since accessibility measures are positive, any scale invariant inequality measure can be applied to them. However, we assume that decision makers will mainly be interested in the distribution of benefits across space and different household groups and how fairly they are distributed across income groups, and not in the distribution of accessibility per se.

Turning now to income inequality, we want our strategies to *counteract* income inequalities. This they can do if land use/transport benefits count as an addition to other income, and if this addition is proportionally greater for the low income groups. Thus we form a *generalised income* consisting of the individual's household income per consumption unit plus net benefits from the land use/transport strategy. (Our data on generalised income will inevitably be somewhat distorted since net benefits in the do minimum strategy are conventionally set to zero, but this is something we have to live with). We use the  $S_0$  inequality measure to measure income inequality with respect to generalised income.

The same form of generalised income was also used for the same purpose in the AFFORD project (Fridstrøm et al 2000), although there the Gini coefficient was used. The methods used to compute net benefits per income group could of course be more or less refined. They may be based on detailed calculations of the benefits accruing to all individuals belonging to a certain income group, taking account of where they live, their car availability, their household type, sex etc., or one may have to ignore some of these differences. The income concept should be household income per consumption unit. A consumption unit is defined in the following way: Each household member is assigned a weight, equal to 1 for the first adult person in the household, 0.7 for any additional adults and 0.5 for children up to 17. With small variations, these weights are in line with OECD recommendations for household consumer surveys. The number of consumption units in the household is given by the sum of the weights attached to all household members. This definition was also used in AFFORD.

With the  $S_0$  measure, the generalised income inequality may easily be decomposed into a part due to locational differences and a part due to income differences in the zones. Alternatively, the decomposition can be made with respect to household type or car availability. Although it would be possible to decompose first with respect to location and then further with respect to car availability, say, this will probably not give very clear results.

#### **14.4 Proposed set of indicators and targets**

We propose to use the following indicators:

1. A Kolm measure of the inequality of the spatial distribution of net benefits of the strategy.
2. A map presentation of the spatial distribution of the net benefits from the strategy.
3. A Theil  $S_0$  measure of the inequality of the distribution of generalised income. Generalised income is defined as the sum of household income per consumption unit and net benefits from a strategy. A decomposition of this measure based on location should be considered.
4. For the social inclusion objective, a Kolm measure of the inequality of the



distribution of net benefits from a strategy among those that have and those without access to a car.

5. With respect to an objective to retain benefits inside the city, the indicator will be government revenue as a percentage of total net benefits in the strategy.

All indicators should be computed after any assumed recycling of government revenue has been made.

We do not think it feasible to include more than one or two of these indicators as targets in a constrained optimisation. Our main proposal is to use a target on the inequality of generalised income as measured by  $S_0$ . Only experience can tell what the target should actually be to produce optimal strategies that are judged to be equitable as well as good in other relevant aspects.

### **14.5 For what year should the indicators be computed?**

The equity objectives apply to any year and not just to the more sustainable situation of year 2020 or 2030. Thus it might be useful to have the indicators computed for all years. Targets could be set with respect to a mix of the indicator values of different years. The mix that recommends itself is to use the weights on annual values that are used in the objective function.

### **14.6 Future development**

Systematic inclusion of equity issues in the appraisal framework by way of inequality indices must still be considered as experimental. Further research will be carried out in the Fifth Framework SPECTRUM project. As experience with applying inequality indicators to transport strategies accumulates, further advice on the choice of parameters etc. might be given. Even if, at the moment, we are reluctant to include the inequality indicator in a CBA-based objective function, this might change if decision-makers get more confident about these indicators and how they work.

Inequality indicators applied to accessibility seem to be very well suited to measure the level of goal achievement with respect to a fair distribution between central and peripheral areas. This is perhaps more relevant for the appraisal of national and EU-wide strategies than for urban strategies. If low levels of accessibility leads to social exclusion, it might be relevant to define a minimum level and to apply indicators and methods from research on poverty (such as Foster et al (1984) or Essama-Nssah (2002)).

## 15 Liveable streets and neighbourhoods

We need indicators of liveable streets to help us assess urban land use and transport strategies with respect to their achievement of the difficult-to-quantify objectives of a lively, thriving and safe inner city and safe outdoors conditions for children in residential areas. Presumably, streets and neighbourhoods are liveable if something else than just transport is taking place there, such as social life, strolling, playing etc. For this to happen, safe areas must be set aside, and this usually means less motorised traffic. Two indicators are discussed here: "Vulnerable user accidents" and "Local activity index". While the first might be included in the economic efficiency calculations if the data can be had, the second cannot.

### 15.1 Vulnerable user accidents

While accident reduction is a very important goal in itself, it might also be that the level of accidents involving vulnerable users can be used as a proxy variable for liveable streets and neighbourhoods. This needs to be verified, but we feel confident enough to use it.

To construct the "liveable street" indicator and come to grips with walking and cycling benefits, we need to distinguish between accidents involving only cars, accidents involving pedestrians and cyclists only, and accidents involving both a car and vulnerable road users. This was done in Section 12.4. The issue of spatial detail was also discussed there.

Consider a zone or some larger area. It may be assumed that the less car traffic there is inside this area, the better will be the possibilities to achieve the lively and safe streets and neighbourhoods that we aim for. Also, it may be assumed that if such conditions are created, the volume of walking and cycling will go up. This feedback can generally not be modelled fully in current transport models. One of the reasons for that is that a large part of the ensuing walking and cycling will be in the form of leisure activities, but our current models generally only recognise walking and cycling as forms of transport.

Nevertheless, there is enough here to suggest that our measure of X-accidents (Section 12.4), as given by the last term of the total accident cost formula (12.2), performs well when the liveable streets objective is achieved and less well when it is not achieved. It performs well when car kilometres go down. If a high share of walking and cycling is in itself contributing to liveable streets, the proposed indicator will work even better.

We propose to use the negative of the third term of the accident cost formula (12.2) as an indicator for the liveable streets objective. Broadly speaking, the indicator will be larger for a strategy where motorised traffic increases less or decreases more in per cent than the slow modes. In fact, this indicator is also "anti-traffic" of all kinds, which may be interpreted as giving a premium to the strategies that leaves the streets to be used for other purposes than the travel purposes in our model. The aspirations of writers like Adams (1999), Himanen (1993), and Knoflacher and Himanen (1991) might be adequately reflected by our indicator, although at a very strategic level.

Incidentally, if  $M$  is vehicle kilometres in the base case strategy,  $S$  is non-motorised

kilometres in the base case and  $dM$  and  $dS$  are the changes from the base case to the tested strategy, then an indicator like

$$(15.1) \quad I = -\frac{1}{M} \left( \frac{dM}{M} + \frac{dS}{S} \right)$$

would perform very much in the same way, without being bothered by the accident interpretation.

## **15.2 Double-counting**

Obviously, the accident cost indicator and the liveable streets indicator overlap. Double-counting is avoided by including the accidents cost indicator in the objective function in all cases, and then attach a somewhat higher weight to the X-accidents if the liveable street objective is seen as particularly important.

## **15.3 Local activity index**

Destination choice in transport models and residential choice in land use models usually involve measures of the attractiveness of each zone. In the transport model it is differentiated with respect to travel purposes, and in the land use model it might in addition measure qualities of the environment and services. The travel purposes that are relevant in the context of liveable streets are shopping and other leisure activities. If we believe that the attractivity measure for these travel purposes is based on variables that reflect the qualities that make streets and neighbourhoods liveable, we can use it as an indicator for liveable streets. We call this indicator a local activity index. It can be estimated for each zone.

# 16 Cost of global warming

## 16.1 Proposed approach

CO<sub>2</sub> is the most important greenhouse gas. With respect to greenhouse gases, the geographical location of emission does not affect the impact (global warming). However, very complex models of the climate are needed to predict the contribution to global warming, and still more complex analysis is needed to predict the economic consequences of global warming. The considerable uncertainty about damage costs calls for another approach. The approach we adopt is to assume that certain political targets have been set (or will be set) at the EU or world level, and that these targets have been broken down to the national level. We will then be able to utilise studies of the cost to the national economy of reaching these national targets. The marginal cost of achieving the last tonne of reductions is the unit cost per tonne we will use.

Our CO<sub>2</sub> indicator is the total CO<sub>2</sub> emission from transport and housing in tonnes multiplied by the unit cost derived in this way. The relevant targets at the world level that are used to derive the unit cost are the Kyoto targets for 2010 and some more ambitious target (closer to a sustainable situation) for a later year.

Our approach transforms the problem of computing the cost of global warming in the distant or very distant future to a problem of assessing *the cost of transition* to a stable sustainable or near sustainable level. Since in our modelling, we are not able to forecast urban transport and land use in the very distant future, such a redefinition of when the costs are supposed to occur is necessary.

CO<sub>2</sub> emissions are very closely tied to fuel consumption, with different emissions per litre for the different fuels. Consequently, we need to be able to compute fuel consumption in transport. The two options open to us are either to assume a constant fuel consumption per vehicle kilometre, or to make fuel consumption a function of average speed in appropriately defined areas. The latter option is preferred. See Section 12.3.2 for more details on how to do this.

Energy consumption in housing may also be influenced by our strategies. The choice of floorspace may be modelled in some land use models, and this decision will obviously have an impact on energy use per housing unit. Alternatively, it may be assumed that housing units in certain areas are larger than in others, and/or need more energy for heating because they have all four walls and the ceiling facing the outside. Based on such assumptions, the land use models may be used to infer the change in energy consumption in housing from the base case strategy. At least in some countries, statistics exist that can be used to find out how energy consumption increases with floorspace across different types of housing units (flats, single houses). If data can be found, we prefer to include energy consumption (and thereby CO<sub>2</sub> emissions) from housing in the indicator.

## 16.2 Deriving the CO<sub>2</sub> cost

We need a simple assumption to be able to derive the marginal cost of CO<sub>2</sub> emissions. The problem that we pose is: What would be the level of a national CO<sub>2</sub> tax, set to assure that a national political target of CO<sub>2</sub> reductions (or a national obligation

according to an international agreement) is reached? It makes sense to assume that for 2010, this target is the Kyoto target. For the EU, the Kyoto target was subsequently transformed into a national target for each of the EU countries. Some countries have broken them further down by sector. So these targets exist and will probably be used even if the Kyoto agreement is not implemented. In addition, we need a more long term target, say for 2020.

The main source of information on how to set such a tax is Chapter 8 of IPCC (2001). Basically, two kinds of targets are studied there, the Kyoto targets for 2010 and targets to stabilise the level of CO<sub>2</sub> in the atmosphere at particular levels (450, 550, 650 and 750 ppmv). The latter are long term targets that can be reached more quickly or slowly, along different development paths.

For a variety of reasons, the studies surveyed in the IPCC report produce very different results. The differences are due to such factors as industrial structure of the studied countries, baseline assumptions on technology, taxes etc., assumptions on implementation mechanisms, assumptions on recycling of the revenue, whether or not the CO<sub>2</sub> tax is used together with other instruments with an influence on CO<sub>2</sub> emissions, and whether or not side benefits such as less local air pollution are counted as factors that counteract the marginal costs of reaching the target. Since the costs of reaching the target are spread over a number of years, the assumptions on the discount rate are important. Of course, model differences are also important.

When a value is chosen for the tax, some consideration should be given to which of these assumptions we think are the most realistic. The most important choice for the tax to reach the short term target seems to be the assumption on international trade in permits and other implementation mechanisms. With respect to the long term target, the chosen stabilisation level is also very important.

We will assume that a market in permits is established inside the EU and Norway. This is equivalent to applying the same tax rate in all of these countries. The importance of assuming either a common level of a European CO<sub>2</sub> tax or a European market in permits is that this makes the unit cost of CO<sub>2</sub> emission the same regardless of where the emission occurs – which of course it is. *Note that this assumption is for the derivation of the CO<sub>2</sub> indicator only.* The actual scenario that we assume and the strategies that we test can be with or without such a tax, but the CO<sub>2</sub> indicator for the short and long term will be the same, regardless.

### 16.3 The short term (2010) CO<sub>2</sub> cost

We will assume that a market in permits is established inside the EU and Norway. This is equivalent to applying the same tax rate in all of these countries. It seems that on this assumption, a tax rate in 2010 of 50 euros per tonne of CO<sub>2</sub> is broadly in line with the bulk of the model studies surveyed in IPCC (2001).<sup>30</sup> Assuming no alternative fuels, we could perhaps assume that a kilogram of petrol and a kilogramme of diesel both give rise to 3.15 kilograms of CO<sub>2</sub> emissions. The specific weights of petrol and diesel are set to 0.74 and 0.84 kilograms per litre, respectively. Thus the tax per litre is  $0.74 \cdot 3.15 \cdot 0.05 = 0.12$  euro per litre on petrol and  $0.84 \cdot 3.15 \cdot 0.05 = 0.15$  euro per litre on diesel.<sup>31</sup> These values could be applied to all years up until 2010,

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<sup>30</sup> In principle, the tax rate that is reported from the top-down (general equilibrium) models is equal to the marginal avoidance cost that is reported from the bottom-up models.

<sup>31</sup> The assumptions on technology and institutional arrangements like trade in permits, as well as the assumptions on national tax policy, really belongs to the specifications of scenarios.

as the point of introducing it gradually is probably lost in a land use model where the real costs of making the transition to lower CO<sub>2</sub> emissions do not appear.

This tax can be interpreted as being equal to the marginal cost to society of reaching the Kyoto CO<sub>2</sub> target in a cost efficient way. We may or may not assume that the tax is actually implemented. There may be other, equally efficient ways of reaching the target which might be assumed instead. The marginal social costs of CO<sub>2</sub> emissions will stay the same under such alternative assumptions.

## **16.4 Applying the CO<sub>2</sub> cost**

*There are two cases:* The case where a tax like the one we derived is actually implemented at the national or EU level, and the case where it is not. We treat each in turn.

If we believe the national government is going to address the issue of global warming by imposing fuel taxes, this should appear in both the do minimum and every do something, that is to say it is separate from the process of local transport policy making. How is the CO<sub>2</sub> tax to be understood? Is it an addition to other fuel taxes (whether or not they are also called CO<sub>2</sub> taxes is immaterial), or is it including present taxes? That depends on the assumptions of the models used to derive it. Probably, they have broadly taken the current structure of taxes and charges as given when the tax or marginal avoidance cost has been calculated. In that case, the new tax is an addition to the old taxes. But in some instances, they might also have improved the tax structure as an additional measure to lower the cost of reaching the target. If we want to use the tax derived from a study that makes such assumptions, we too should assume that these additional measures are taken.

In the objective function, the CO<sub>2</sub> tax should appear in *three* places. First, it is an increased cost to the car travellers and the public transport companies as well as an increase in housing costs. This needs to be included in the land use/transport models in the form of some new coding. Second, it is a revenue to the government, and third it is an external cost of CO<sub>2</sub> use. In the absence of a shadow price of public funds, the latter two entries cancel out. They should nevertheless be retained to get the correct picture of the financial surplus of the government and to address issues of revenue recycling and compensations.<sup>32</sup>

In the second case, the tax is not actually implemented. Instead we assume that some equally efficient measures are taken. They might include sectoral targets, although sectoral targets will be difficult to set right and will obviously have to be backed by other policy instruments than the CO<sub>2</sub> tax. Now there is nothing to add to the user costs (no extra coding) and no extra revenue for the government. The third element, the external cost of CO<sub>2</sub> use, is however the same as in the first case and must be added to the objective function.

## **16.5 The longer term (2020) CO<sub>2</sub> costs**

The optimal path to stabilise CO<sub>2</sub> in the atmosphere at a certain level is a much more involved problem than the problem of implementing the Kyoto target, as there is a need to model emissions and atmospheric levels for at least 100 years onward. This also entails the need to model technological change, etc. The results given in IPCC

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<sup>32</sup> This is a particular instance of the recommended approach from Section 3.1 and Chapter 8.

(2001) are not useful for deriving numbers, but qualitative aspects of the solutions might be useful. The lower the targeted stabilisation level, the higher the costs and the implied tax. The tax to reach the target rises gradually from stabilisation level 750 to 550, but steeply from 550 to 450. Also, since abrupt changes would mean scrapping of still useful equipment etc., the optimal path of emission is only gradually departing from the baseline path.

We suggest to use a tax of 200 euros per tonne of CO<sub>2</sub> for 2020. This is not based on hard evidence at all, but on the fact that for the long term, much larger reductions in CO<sub>2</sub> emissions than the Kyoto target will be needed. Also, there will probably still be a need in 2020 to apply a high CO<sub>2</sub> tax to induce fuel efficient cars and shifts to alternative fuels.

Assuming the tax is raised gradually from 50 to 200 between 2010 and 2020, there should already be a fair proportion of alternatively fuelled cars in 2020. This should somehow be taken into account in the calculation of the objective function (We assume it is not modelled in the transport model). If say 25% of the fleet do not emit CO<sub>2</sub>, or all vehicles emit 25% less on average, in our calculations it is as if the tax were 150 per tonne.

Even so, we propose to retain the values 50 and 200. But the long term CO<sub>2</sub> tax level will obviously be a clear candidate for extensive sensitivity testing.

## **16.6 City targets and city fuel taxes**

If a national CO<sub>2</sub> tax is assumed, it does not preclude the simultaneous use of fuel taxes as a local policy instrument that may be optimised. It does however raise the lower bound on fuel taxes.

Since it might make a difference to the use of compensation to local inhabitants, the size of local transport budgets and the tightness of financial constraints, we should set out clearly our assumptions on the division of the revenue from a strategy between local and national government. A local fuel tax will probably go into local government coffers, while a national fuel tax will not.

Some cities might want to set city specific targets on CO<sub>2</sub>. In general, this is not to be recommended, since it is very difficult to get the information to set the target right. The only option might be to use the land use/transport model to do repeated constrained optimisations with different levels of the target, and settle for the one with a shadow cost of CO<sub>2</sub> (the Lagrangian multiplier) as close as possible to the marginal social cost of CO<sub>2</sub> found from national studies.<sup>33</sup> This is because if the marginal costs differ between cities and sectors, the CO<sub>2</sub> reduction is not reached in a cost efficient way. But if this is the method of setting the target right, we might as well do without the target and just include the right (national) marginal cost in the objective function.

If a city target is applied nevertheless, we should make sure that this does not affect the formulation of the objective function. The same objective function must be used for all comparisons of strategies. It might be with or without the CO<sub>2</sub> element, but we cannot compare the constrained case with no CO<sub>2</sub> in the objective function with the unconstrained case with CO<sub>2</sub> included in the objective function.

The case for a target instead of simply valuing CO<sub>2</sub> by the marginal cost is much

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<sup>33</sup> To be specific, the Lagrangian multiplier should be zero if the marginal costs of CO<sub>2</sub> are already included in the objective function, and equal to the marginal cost if they are not.

stronger for 2020 than for 2010, since we know very little about the right value to use anyway. We do not know what level of ambition with respect to CO<sub>2</sub> in the atmosphere such a target would represent, though. There is nothing to suggest that the target should be the same in physical terms or in per cent for all cities.

Finally, if we want to model a case where political resistance hinders the national CO<sub>2</sub> policy, we should reduce the tax as perceived by travellers and transport companies and the government. We should however not reduce it at the third place where it is entered, as an indicator of external costs of global warming.

## **16.7 What if recent fuel taxes differ from those in the CO<sub>2</sub> cost estimate?**

Recall that in our objective function (3.1) there is a weight  $\gamma_t$  on CO<sub>2</sub> emissions  $g_t$  in year  $t$ . It is possible to convert these values to values and volumes of the two fuels, petrol and diesel. Suppose this has been done. Fuel will then appear three times in the social accounting table. First it appears as a disbenefit to travellers, valued by the market price. Next, the tax component of this market price appears as income to the government. In this process, the perceived cost of fuel is corrected so that only the production price remains (see Chapter 10). According to Chapter 10, we also have to add the external cost to arrive at the real social cost. The global warming element of this external cost is the  $\gamma_t$ . This means that as the fuel tax is raised or lowered from the level that was assumed when the marginal cost of reaching the target was estimated, the  $\gamma_t$  itself should be adjusted. If the optimal CO<sub>2</sub> was actually implemented, the  $\gamma_t$  would be reduced to zero. This effect should be taken into account when the actual  $\gamma_t$  is set.



# 17 Visualisation

This chapter will give an overall description of possible presentation methods concentrating especially on visualisation of the output of transport/land use plans and LUTI-models. Geographical Information Systems (GIS) is covered in Section 17.2 and other forms of presentation in 17.3. The new opportunities for visualisation of model results provided by GIS can only be exploited to the full if one respects simple rules for effective visual communication. In fact, the new opportunities could easily lead to misleading and bewildering presentations. We believe that to avoid that, the advice given in Section 17.1 will be important.

## 17.1 Visualisation using maps

A representation is never the same as the thing being represented. The critical trick is to get the abstractions right, to represent the important aspects and not the unimportant. The appropriate type of a representation depends upon the task (Norman 1994).

### 17.1.1 Map symbols and visual variables

On a map representation, three geometric categories of map symbols and six visual variables are used. Symbols on flat maps are point symbols, line symbols, or area symbols. Most general-purpose maps use combinations of all three, whereas statistical maps, which portray numerical data, commonly rely upon a single type of symbol (Monmonier 1996).

Each of the six visual variables (size, shape, greytone value, texture, orientation and hue) excels in portraying one kind of geographic difference. Shape, texture and hue are effective in showing qualitative differences (e.g. land uses). For quantitative differences, size is more suited to showing variation in amount or count, whereas greytone value is preferred for portraying differences in rate or intensity. Some visual variables (hue or greytone value) are unsuitable for small point symbols or thin line symbols (Monmonier 1996).

Norman (1994) uses the terms additive and substitutive representation:

- Additive representation: If you wish to increase the value, you simply add something extra to the symbol already there. Nothing present has to be changed (e.g. tally marks).
- Substitutive representation: If you wish to increase the value of a previous symbol, you must substitute a new symbol for the previous one (e.g. Arabic numerals).

The proper way to present a map is to use an additive scale (an ordered sequence of density) to represent an additive dimension (rates or intensities) and a substitutive scale (different hues) to represent a substitutive dimension (differences in kind) (Norman 1994.).

### **17.1.2 Generalisation**

Clarity of a map demands geometric generalisation because map symbols usually occupy more space on the map than the features they represent occupy on the ground (Monmonier 1996). For some maps geometric accuracy is less important than linkages, adjacency and relative position (e.g. linear cartograms portraying subway and rapid transit systems).

Content generalisation promotes clarity of purpose or meaning by filtering out details irrelevant to the map's function or theme. It has two essential elements:

- selection – choosing only relevant features
- classification – recognising similarities among the features so that a single type of symbol can represent a group of similar features (Monmonier 1996).

Occasionally the “template effect” of standardised symbols will misinform the map user by grouping functionally different features. Standard symbols, designed for ready, unambiguous recognition, are common in cartography and promote efficiency in both map production and map use. Difficulties arise when a standard symbol must represent functionally dissimilar elements. Generalised highway intersections are a prime example of how information obscured by the template effect can mislead or inconvenience a map user (Monmonier 1996).

Computers generally play a positive role in map analysis. Particularly promising is the ability to generalise the geometry and content of maps. However, a generalisation program can produce radically different cartographic pictures from a single database, because it can use different sets of weights or priorities to produce different patterns (Monmonier 1996).

### **17.1.3 Choropleth maps**

Choropleth maps portray geographic patterns for regions composed of area units. Usually two to six greytone symbols represent an equal number of non-overlapping categories for an intensity index such as population density (Monmonier 1996).

A single set of numerical data can yield markedly dissimilar maps. Areal aggregation can, for instance, have a striking effect on the mapped patterns of rates and ratios. Also by manipulating breaks between categories of a choropleth map, a mapmaker can often create two distinctly different spatial patterns. Classification ought not to subdivide distinct clusters of homogenous data values, and natural breaks between them, if any occur, should be used. Class breaks of particular meaning (e.g. average values) should also be taken into account (Monmonier 1996).

### **17.1.4 Colours**

In the case of a choropleth map, colours can be confusing if not used carefully. The use of a single hue is preferred. A partial spectral scale (e.g. yellow-orange-red) can also be as consistent and convenient. The full-spectral sequence is not recommended, as the spectral hues have no logical ordering in the mind's eye. A double-ended scale is sometimes useful for maps showing e.g. positive and negative rates of change (Monmonier 1996).

According to Tufte (1984), colour often generates graphical puzzles, which are cryptographical mysteries for the viewer to decode. A sure sign of a puzzle is that the graphic must be interpreted through a verbal rather than a visual process. Despite our

experiences with the spectrum in science textbooks and rainbows, the mind's eye does not readily give a visual ordering to colours, except possibly for red to reflect higher levels than other colours.

Because they do have a natural visual hierarchy, varying shades of grey show varying quantities better than colours. The shades of grey provide an easily comprehended order to the data measures. Central to maintaining clarity in the face of the complex are graphical methods that organise and order the flow of graphical information presented to the eye (Tufte 1984).

Maps using colours to portray differences in kind can benefit from contrasting hues. For example vegetation maps, road maps, zoning maps and land use maps showing a variety of features can benefit from different hues, provided that somewhat similar hues represent somewhat similar features and radically different hues represent radically different features (Monmonier 1996).

Tufte (1997) also writes about the design strategy of the smallest effective difference: make all visual distinctions as subtle as possible, but still clear and effective. In designing information, the idea is to use just noticeable differences, visual elements that make a clear difference but no more – contrasts that are definitive, effective and minimal. An example is a map that depicts depth (blue, bathymetric tints) and altitude (tan, hypsometric tints) in colour gradations with a scale “the deeper or the higher, the darker the colour”. To indicate depth, the contour lines can be labelled by numbers, a design that enhances accuracy of reading and nearly eliminates any need to refer back to the legend. In contrast, if the whole rainbow is used to depict depth, the aggressive colours, so unnatural and unquantitative, render the map incoherent.

Minimal distinctions reduce visual clutter. Small contrasts work to enrich the overall visual signal by increasing the number of distinctions that can be made within a single image – small differences allow more differences. In practice, the appropriate size of small contrasts will depend on the context, priority of particular elements, number of differentiations and characteristics of those viewing the image (Tufte 1997).

### **17.1.5 Narrative graphics of space and time**

An especially effective device for enhancing the explanatory power of a map is to add the time dimension to the design of the graphic. One form of time-space graphics is a small multiple. Small multiples resemble the frames of a movie: a series of graphics showing the same combination of variables, indexed by changes in another variable. The design should remain constant through all the frames, so that attention is devoted entirely to shifts in the data. This kind of graphic is good at showing for example the levels of air pollutants at different times during the day (Tufte 1984).

### **17.1.6 Maps and urban and regional planning**

For presentations, a particularly interesting and forceful graphic is the concept diagram; a schematic, somewhat stylised map intended to demonstrate the general layout and functional relationship of a plan's main elements. On a concept diagram, the developer or planner uses lines to subdivide space, highlight patterns of movement, and suggest revitalisation of the central city (Monmonier 1996).

Maps are also an important part of an environmental impact statement (EIS). Detailed oversize maps might accompany the EIS in an appendix, to supplement smaller-scale, more generalised maps in the body of the report. Potentially significant sources of error are the transfer of information from the source map to the common base and the

generalisation of these small-scale maps. Additional problems arise when the boundaries and other data are transferred from unrectified aerial photographs (Monmonier 1996).

### **17.1.7 The power of visualisation**

We generally think that a visual map presentation is better than just a table; on the other hand with nice maps you can easily mislead and cheat the public. The same also applies to the scaling effect of graphs and diagrams.

In his book “How to Lie with Maps” Monmonier (1996) (cynically) gives us eleven rules for polishing the cartographic image. The rules implicitly illustrate the power of a planner using maps for presentation as well. Monmonier’s rules are:

1. Be shrewdly selective.
2. Frame strategically.
3. Accentuate the positive.
4. If caught, have a story ready.
5. Minimise the negative.
6. Dazzle with detail.
7. Persuade with pap.
8. Distract with aerial photographs and historical maps.
9. Generalise creatively.
10. Enchant with elegance.
11. When all else fails, try bribery.

## **17.2 Basics and potential of GIS (Geographic Information System)**

### **17.2.1 Definition of GIS**

Although the term GIS cannot be exactly defined, here are some attempts at a definition:

1. A GIS is an information system that is designed to work with data referenced by spatial or geographic co-ordinates. In other words, a GIS is both a database system with specific capabilities for spatially referenced data, as well as a set of operations for working (analysis) with the data. (Star and Estes, 1990)
2. A GIS is a computer-based tool for mapping and analysing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the visualisation and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it useful for explaining events, predicting outcomes, and planning strategies. Mapmaking and geographic analysis are not new, but a GIS can perform these tasks better and faster than conventional methods.

GIS is closely related to several other types of information systems and databases, but it is the ability to manipulate and analyse geographic data as well as spatial relations between objects that sets GIS technology apart. Although there are no hard and fast

rules about how to classify information systems, GIS stands out from desktop mapping, computer-aided design (CAD), remote sensing, database management systems (DBMS), and global positioning systems (GPS) technologies with respect to its versatility.

Geographical Information Systems are emerging as an important tool in public participation as they are able to put across information in a readily understandable way to the lay person. As such they can be used as a medium to aid participation with all the different stances above. GIS can also be combined with the Internet in the form of a website which can then provide feedback to decision makers and a useful public participation tool which can be used in the information, consultation and, conceivably, the deciding together stances. See Kingston et al. (1998) for an example of how this has been used in environmental decision-making.

### **17.2.2 Geodata, conversions and analysis**

Possibly the most important component of a GIS is the variety of data. A GIS will integrate spatial data and related tabular data with other data resources and can use a database management system (DBMS) to manage spatial data.

Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. Data capture – putting the information into the system – is the time-consuming component of GIS work. Identities of the objects on the map must be specified, as well as their spatial relationships. Editing of information that is automatically captured can also be difficult. However, today many types of geographic data already exist in GIS-compatible formats.

The primary requirement for the source data is that the locations of the items are known. Location may be annotated by x, y and z coordinates of longitude, latitude, and elevation, or by such systems as postal codes or highway kilometre markers. Any item that can be located spatially can be fed into a GIS.

It is likely that data required for a particular GIS application will need to be transformed or manipulated in some way to make it compatible with the rest of the system. For example, geographic information originally at different scales (detailed street centre line files; less detailed census boundaries; and postal codes at a regional level) needs to be transformed to the same scale (degree of detail or accuracy) before integration. Projection conversion serves as a good example of manipulation. A projection is a fundamental component of mapmaking. It is a mathematical method for transferring information from the earth's three-dimensional curved surface to a two-dimensional medium, e.g. paper or a computer screen. Different projections are used for different types of maps because each projection is particularly appropriate for certain use. For example, a projection that accurately represents the shapes of the continents may distort their relative sizes.

#### **Graphic data**

Geographic information systems work with two fundamentally different types of geographic models: the vector-model and the grid-model. In the vector model, information about points, lines, and polygons is encoded and stored as a collection of x, y, z coordinates. The location of a point feature, such as a bus stop or a bore hole, can be described by a single pair of x, y coordinates. Linear features, such as roads and rivers, can be stored as a collection of point coordinates. Polygonal features, such as zone boundaries and school districts, can be stored as a closed loop of coordinates.

The vector model is extremely useful for describing discrete features, but less useful

for describing continuously varying features such as accessibility costs or soil type. The grid model has evolved to model such continuous features. A grid image comprises a set of grid cells with the related data, much like a scanned map or picture. Both the vector and grid model used for storing geographic data have unique advantages and disadvantages.

### **Data layers and overlay analysis**

In a GIS different data items or different data from different sources may each be stored in its own data layer, which the system is capable of combining according to the user's needs.

The overlay analysis is the most important and best known in GIS analysis for gaining new information. Integration of different data layers involves the overlay process. At its simplest, this could be a visual operation, but analytical operations require one or more object classes to be joined physically. This overlay, or spatial join, can for instance integrate data on soils, slope, and vegetation, or land ownership with tax assessment.

To answer proximity questions like "How many houses lie within 100 m of this road?" GIS technology uses a process called buffering to determine the proximity between objects. First a buffer is generated around an object then the overlay analysis starts.

### **17.2.3 Visualisation**

For many types of geographic operations the end result is best visualised as a map or graph. Maps are very efficient in storing and communicating geographic information. Map displays can be integrated with reports, three-dimensional views, photographic images, and other output such as multimedia.

### **Geographic reference**

Geographic information contains either an explicit geographic reference, such as a latitude and longitude or national grid coordinate, or an implicit reference such as an address, postal code, census tract name, bus line identifier, or road name. An automated process called geocoding is used to create explicit geographic references (position) from implicit references (descriptions such as addresses). These geographic references allow locating features, such as a business or residential areas, and events, such as an earthquake, on the earth's surface for analysis.

### **Interactive Graphic**

GIS users have different possibilities to look at their data. While interacting with GIS in front of the monitor there are two possible ways to make use of the system. One can graphically select an object or objects and make a query to the database: which object, object class, attributes etc. One can also use GIS to make the query using the database and show the results graphically: show all objects of a class or show all objects with a certain thematic and/or spatial property.

The advantage of these query methods compared to ordinarily designed maps is that the whole information is not always visible. This form of compression allows an interactive graphic to carry more information than a map. Only a framework of displayed data is necessary for geographical orientation. The rest is displayed on demand.

### **Graphic presentation**

A thematic map is the analogue standard output product of GIS. A map produced by a GIS tries to compete with the state of the art of producing maps manually. If we take the aesthetic and artistic requirements of cartography into consideration we often do not regard a GIS map as equal to a hand made map. The production of a map requires, apart from the feeling for graphical effects, a reasonable basic knowledge of cartographic techniques and rules. However, in many cases and due to the fast development of GIS suites, GIS's output capabilities are perfectly satisfactory.

Discrete phenomena can be shown by symbols that change their size according to a value, or geometric symbols. This connects the topic and the quantity information in an appropriate way. Local charts, as line, bar, column, pie, area etc., illustrate the quantity distribution of different parameters of the objects. Distributions of point objects or quantitative information of a point object can be shown by local symbols. Line objects and their attributes, e.g. boundary class, traffic density on a road), can be demonstrated by changes of the line style and weight.

Areas or spatial objects with blurred boundaries, as often experienced in nature, belong to the group of continuous phenomena. As means of layout there are the isolines, demonstrating the altitude, and isochrones, demonstrating distances of equal travel time.

Spatially and/or temporally changing phenomena can be represented by lines of movement or a line string cartogram. Changes in continuous objects are presented with arrows that show the movement between two sites marked with different line styles.

### **Alternative presentation**

Traditional cartographic presentations are limited due to their static character. They are forced to reduce an at least four-dimensional sphere into a two dimensional map. This is why new alternative presentation methods often are superior to traditional maps.

Aerial and satellite picture maps are important for GIS applications as background information because of their richness in content and readability.

Computer animations can represent changes of the geosphere (temporal animation of population development). They also can visualise a change of viewpoint (non-temporal animation of a walk through a landscape).

### **Non-graphical presentation**

By using a GIS and its database it is possible to formulate queries and present their results in the form of lists, tables and reports i.e. reproduce basic data. These queries reach from simple survey questions (how many objects, how many points, lines and surfaces?) to combining/integrating geometric and descriptive data.

Alphanumeric format (e.g. survey statistics, tables, collections of documents, ASCII-files) is especially useful for delivering data to external tools (model calculation, statistics software etc.) or reports.

### 17.2.4 Evolution of GIS in land use and transportation planning

Figure 17.1 illustrates the minimal application of GIS to land use and transportation planning. It is used merely to prepare data for input to land use and transportation models, and to display the results. Figure 17.2 illustrates a more integrated use of GIS with land use-transportation models. The integrated GIS, land use and transportation models approach calls for data transfers at a number of points in the process. It also calls for interfacing GIS with the models, not embedding one within the other. Granzow and Lockfeld (1991) contend that GIS and travel demand models should be appropriately interfaced to preserve the computational emphasis of modelling and the data-processing emphasis of GIS.

Figure 17.1. GIS used for inputs and outputs

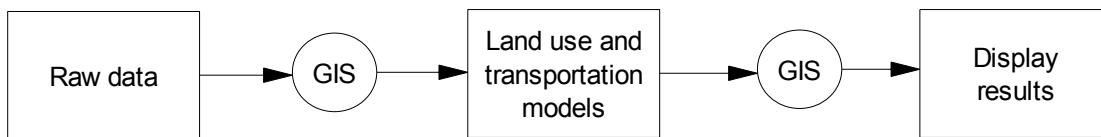
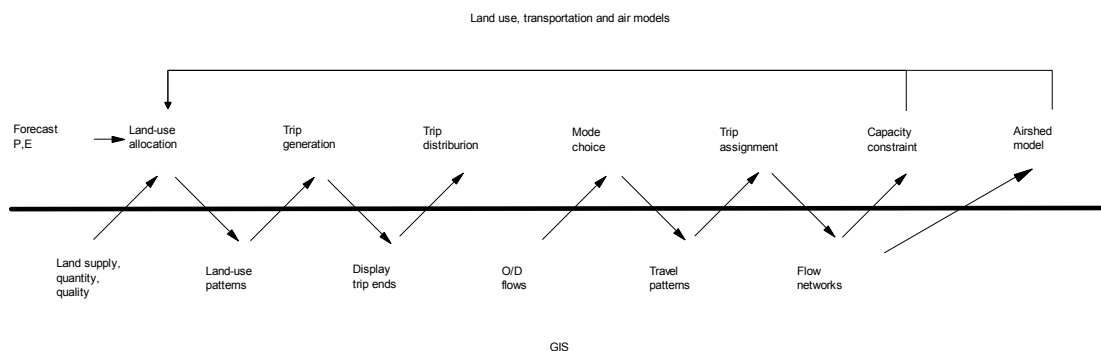


Figure 17.2. Integrating GIS and models



GIS can support the land use and transportation modelling process by two types of improvements. First, improved data will help achieve better modelling. Second, the improved visualisation of model inputs, internal workings, and outputs will help to achieve consensus on results. Whether improvements in the rational planning model will lead to improved decision-making is another matter.

### 17.2.5 Examples of the use of GIS in land use and transport planning

Governmental institutions have to deal with very widespread areas of responsibility. Especially with respect to public decisions and the production of aid for decision-makers, GIS has found its entry into this set of problems. Topics like land register, forestry, land utilisation, environmental planning, transport planning and ecological monitoring are mentioned here out of many.

Concerning especially the use of GIS in transport planning and traffic engineering the following examples shall be mentioned:



- Public transport demand/supply planning and analysis (Figure 17.3, Figure 17.4)
- Accessibility studies
- Network planning and capacity analysis (Figure 17.5)
- Traffic flow analysis
- Population and work place densities (Figure 17.3, Figure 17.4)
- Route maps (Figure 17.6).

**Figure 17.3. Thematic Map on Work Places Classified into Two Groups**

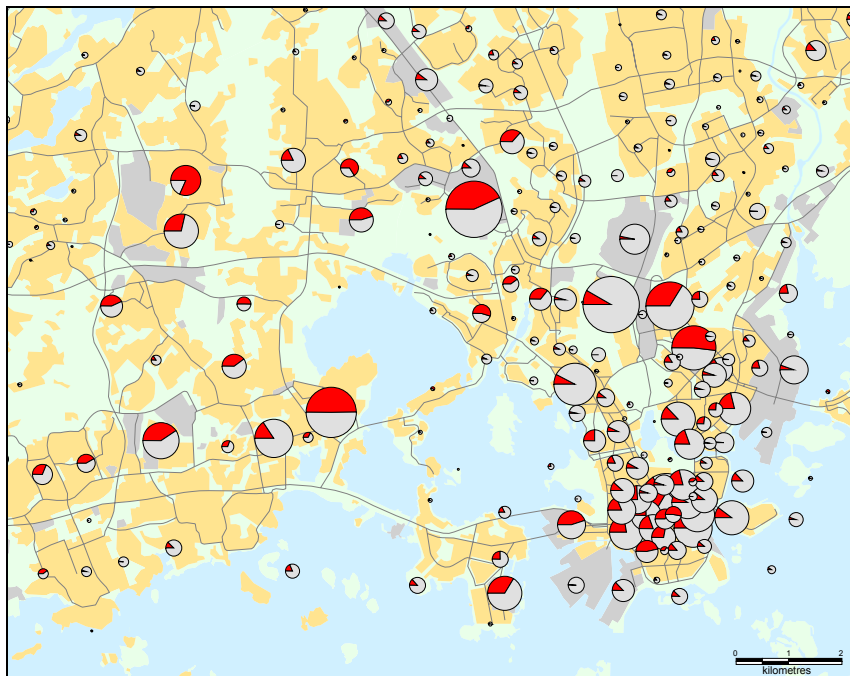


Figure 17.4. Work Place Intensity by Focal Method

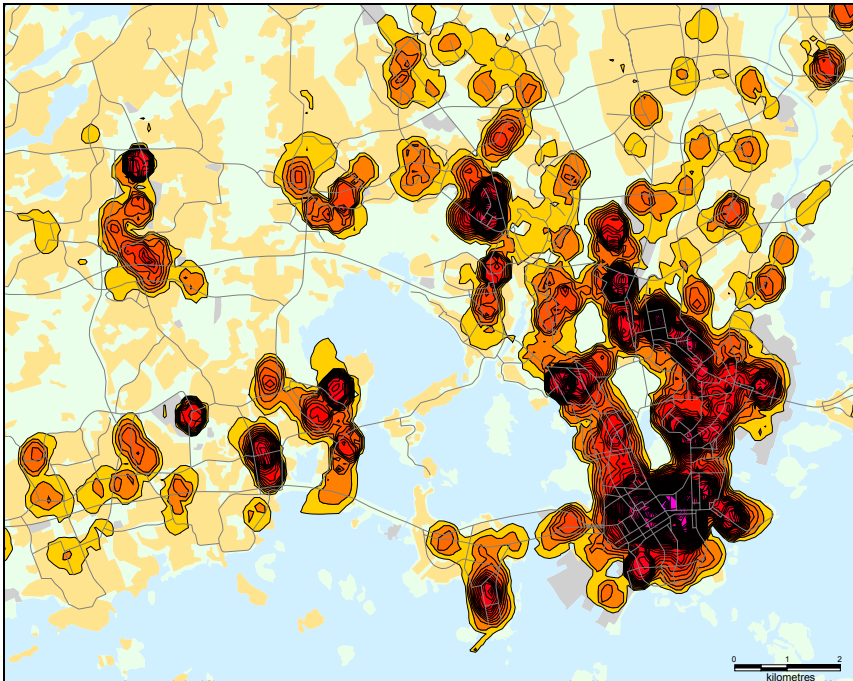


Figure 17.5. Traffic Flows in Helsinki MA Main Road Network

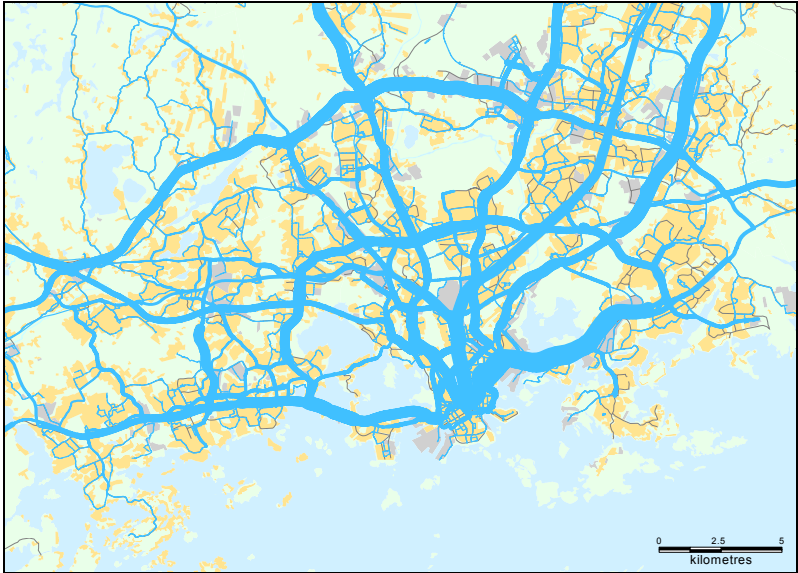
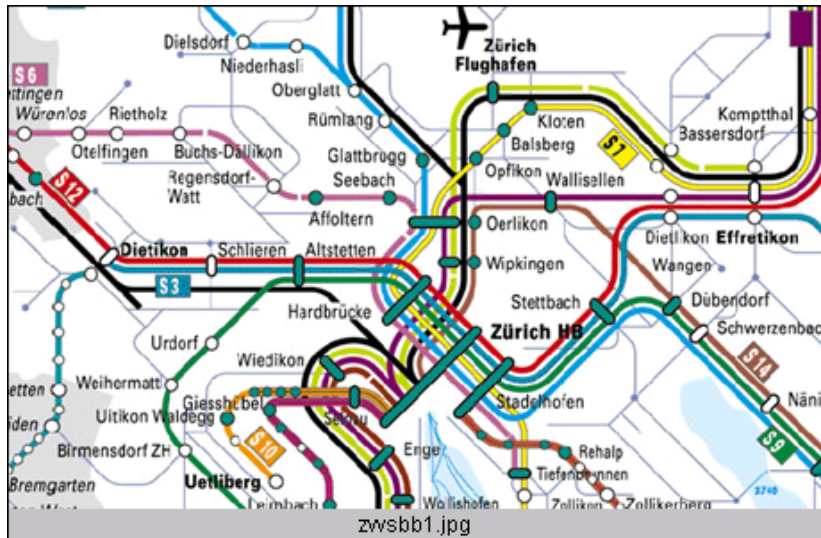


Figure 17.6. Public Transport Route Map



A stronger integration of GIS and transport planning can be realised in different ways:

- Construction of certain traffic planning functionality into existing GIS software.
- Adding certain GIS functionality into existing traffic planning software.
- Construction of a new GIS-based transport planning software.
- Combination of GIS software and transport planning software via interface.
- Application of OGIS definitions (organisation for the definition of GIS standards). Usage of ODBC and OLE (open database connectivity and object link and embedding).

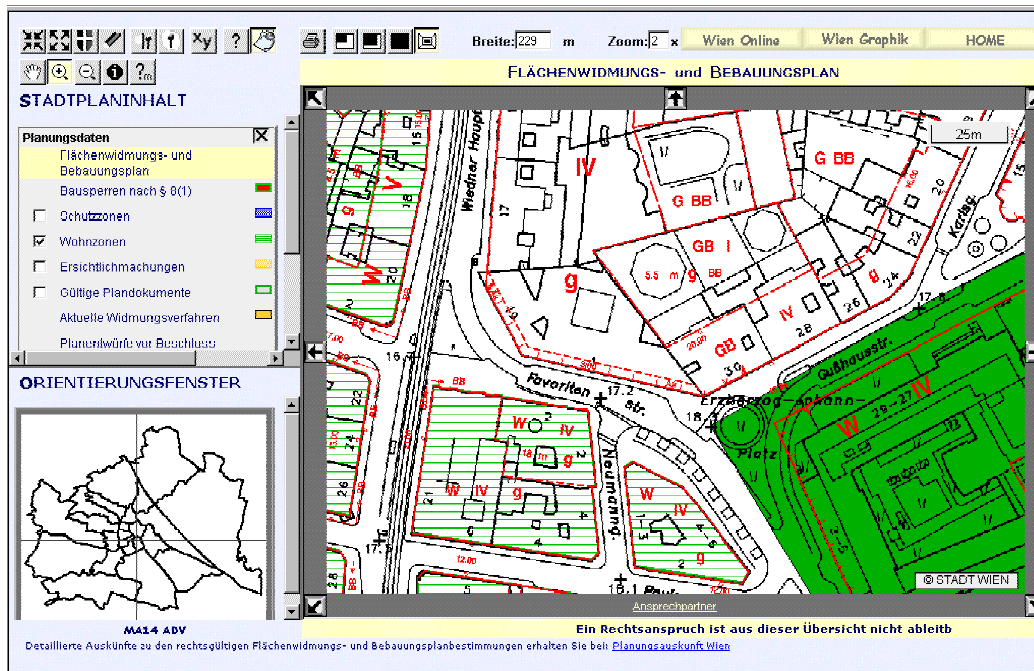
The ideal case of a complete integration could be a user orientated open product with GIS and transport planning functionality. This product allows adaptation to user needs in the form of a toolbox and allows inclusion of special topics or data.

The number of potential users of classic transport planning software is quite small compared to GIS software. Therefore, the development of an open, user friendly and widely applicable product with user-friendly price is hardly possible.

Land use plans, construction plans and transportation plans should be developed interactively. The interaction of GIS and transport software can support each other and make the daily work easier by optimising the use of big data sets, adapting the user interface for often used work flows by supplying easy-to-use buttons, visualisation of spatial phenomena and by quick access to different scenarios etc.

GIS tools can also be provided on the Internet. An example is a town map that is interactively accessible to the public (Figure 17.7).

Figure 17.7. City development plan as Internet service



## 17.3 Other Presentation Methods

### 17.3.1 General

Although GIS is a state-of-the-art method to present the impacts and characteristics of land use and transport policies, other methods are needed as well. There are many types of results that are not suitable for output using GIS. In addition, different interest groups and different situations may need their own specific ways to present the results.

### 17.3.2 Conventional Data Presentation

Most transport and land use actions can be presented as maps and plans. Physical measures can be shown as illustrations and simulations, both for public and decision-makers and may be placed in the internet for free use. Some simulations may even be interactive thus giving the user the freedom to choose what he wants to see.

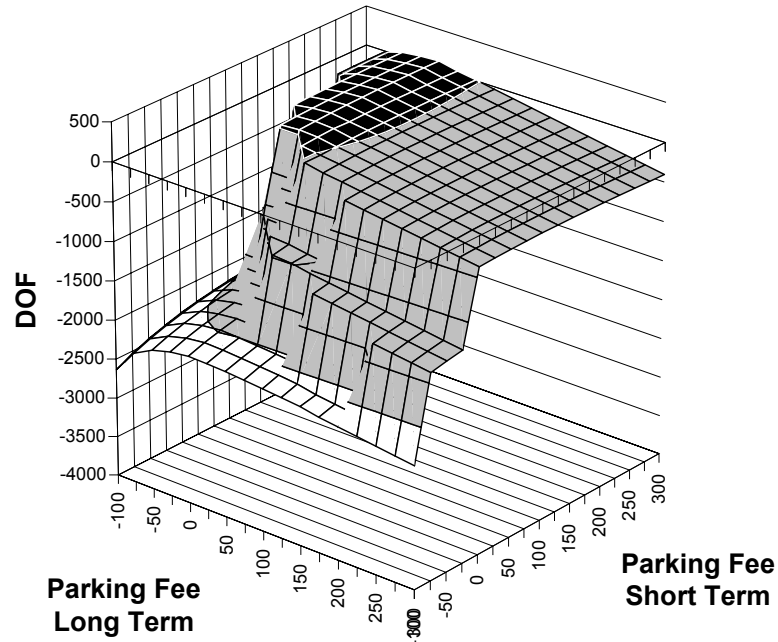
CBA and other economic indicators, including calculations and input data, may be presented as tables and charts. MCA output is often best presented using graphs and impact matrices. Individual indicators (like environmental or social impacts) can make use these same presentation methods. In Table 10.1 of Chapter 10, magnitude and incidence of a strategy is described. This kind of table presentation has to be detailed enough to be transparent to the reader. Also the physical magnitudes (minutes/vehicle, accidents/year, etc.) are needed as background for understanding a CBA.

### 17.3.3 Model Performance

As impact analysis is typically based on model tests, it is important to conduct sensitivity analysis and present its results. In addition to pure mathematical methods for calculating statistical measures of confidence (interval, coefficient, band etc.) more experimental sensitivity tests are often even more useful and illustrative.

One way to show the results of modelling tests is to illustrate them as performance surfaces in three dimensions. The value of the objective function forms a surface shaped according to the sensitivity of the function to the even changes of the two policy variables reviewed. An example is shown in Figure 17.8.

**Figure 17.8. Objective function variation for the objective function DOF with variation in long and short term parking changes**



Although the 3-dimensional presentation is an excellent way to show several indicators simultaneously, very clear conclusions can be drawn from more conventional presentations in two dimensions as the following examples show:

**Figure 17.9. Sensitivity test of operating costs for public transport frequency increase in the objective function HOF**

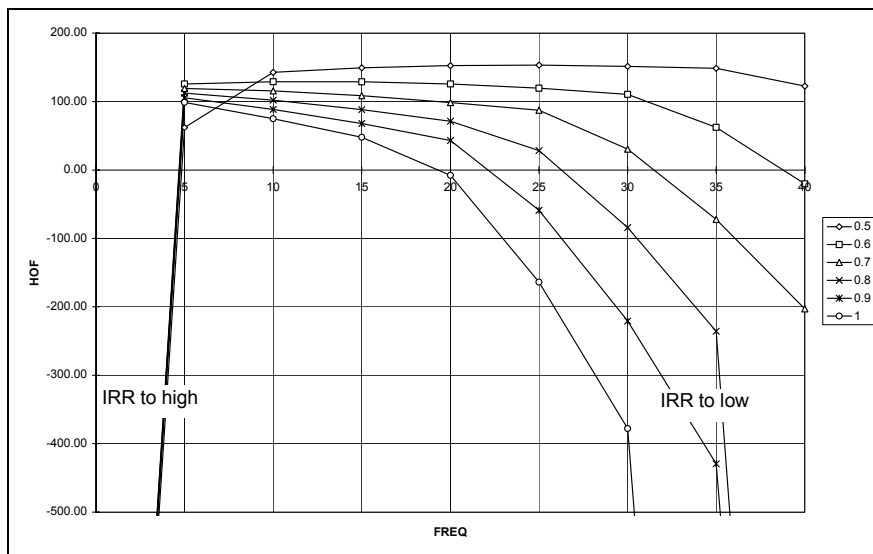


Figure 17.10. Feasible areas for the policy measures PT frequency and fares concerning the half-regulated objective function HOF

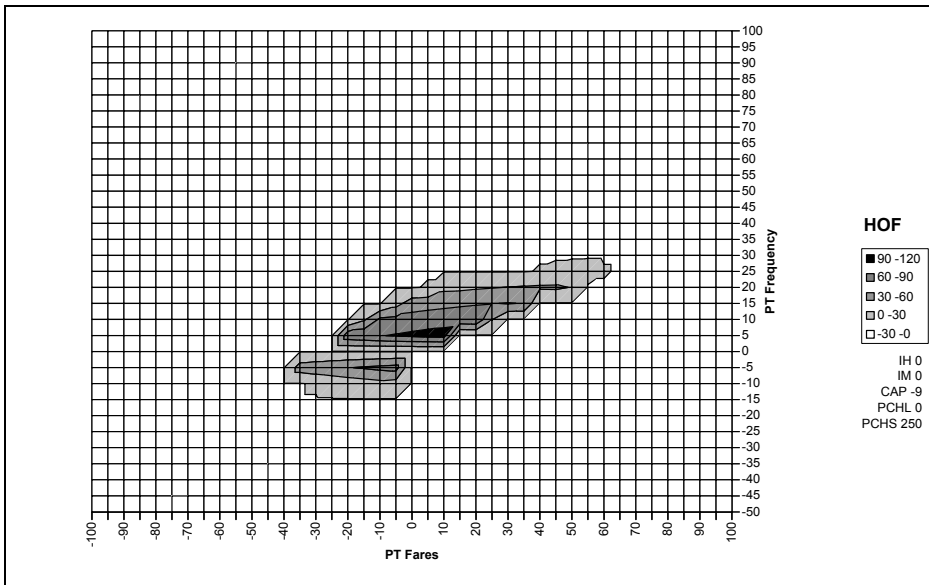
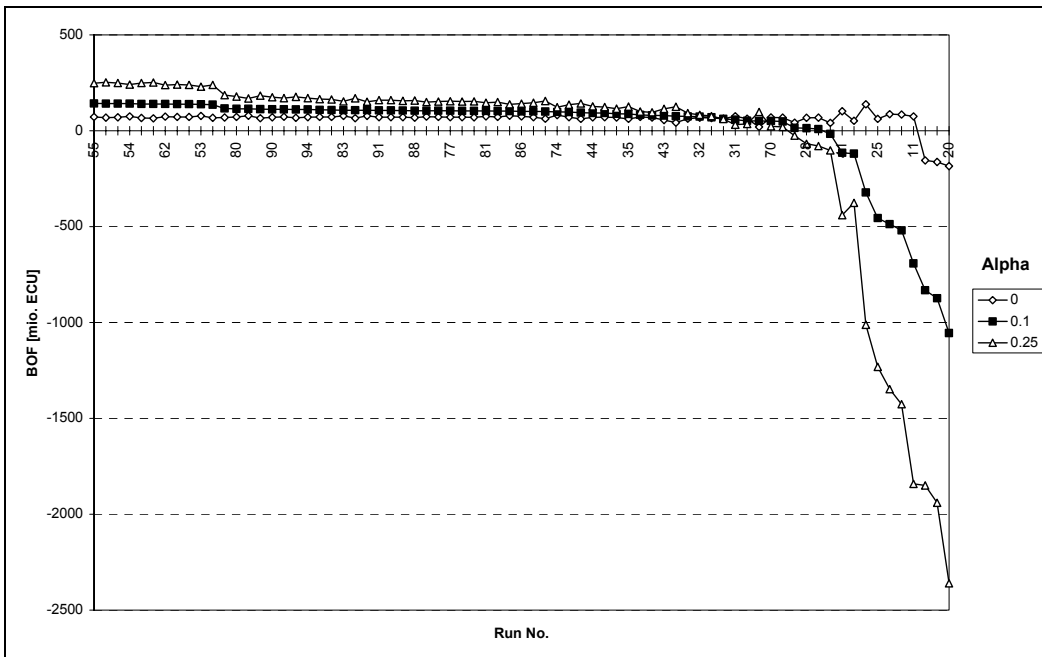


Figure 17.11. Sensitivity test for weight factor alpha (sets the balance between the economic efficiency and the sustainability part of the objective function)



# 18 Optimisation algorithms

## 18.1 The downhill simplex method (AMOEBA)

### 18.1.1 The Core Optimisation Algorithm

The method applied within the PROSPECTS Sketch Planning Model is based on the downhill simplex method in multi-dimensions due to Nelder and Mead (1965). It solves a multidimensional minimisation, i.e. finding the minimum of a function of more than one independent variable. In the optimisation problem of Chapter 7, we are concerned with maximisation, not minimisation, but a slight reformulation – changing the sign of each term in the objective function – makes the method work equally well for that case. The method requires only function evaluations, not derivatives.

A simplex is a geometrical figure consisting, in  $N$  dimensions, of  $N + 1$  points (or vertices) and all their interconnecting line segments, polygonal faces etc. In two dimensions, a simplex is a triangle. In three dimensions it is a tetrahedron, not necessarily the regular tetrahedron.

In general the method is only interested in simplices that are nondegenerate, i.e. which enclose a finite inner  $N$ -dimensional volume. If any point of a nondegenerate simplex is taken as the origin, then the  $N$  other points define vector directions that span the  $N$ -dimensional vector space.

The method requires an initial starting point, that is, an  $N$ -vector of independent variables. The algorithm is then supposed to make its own way downhill through the  $N$ -dimensional topography, until it encounters an (at least local) minimum.

The downhill simplex method must be started not just with a single point, but with  $N+1$  points, defining an initial simplex. If one of these points is taken to be the initial starting point  $\mathbf{x}_0$ , then the other  $N$  points can be expressed as:

$$(18.1) \quad \mathbf{x}_i = \mathbf{x}_0 + \lambda_i \mathbf{e}_i \quad i = 1, \dots, N$$

where  $\mathbf{e}_i = (0, \dots, 1, \dots, 0)$ , that is, a vector with 1 as the  $i$ 'th element and 0 elsewhere, and  $\lambda_i$  is a constant which is set so as to reflect a guess at the problem's characteristic length or scale ( $\lambda_i$  could be different for each vector direction).

For example in a 3-dimensional policy space, if we let  $\mathbf{x}_0 = (x_{01}, x_{02}, x_{03})$  be the initial set of policies, the initial simplex defined by equation (18.1), consisting as it is of the set  $X$  of the  $N + 1$  points  $\mathbf{x}_0, \mathbf{x}_1, \mathbf{x}_2$  and  $\mathbf{x}_3$ , would be a tetrahedron made up as follows:

$$(18.2) \quad X = \begin{pmatrix} x_{01} & x_{02} & x_{03} \\ x_{01} + \lambda_1 & x_{02} & x_{03} \\ x_{01} & x_{02} + \lambda_2 & x_{03} \\ x_{01} & x_{02} & x_{03} + \lambda_3 \end{pmatrix}$$

where:

$x_{01}$  to  $x_{03}$  = initial levels of policy measures 1 to 3

$\lambda_1$  to  $\lambda_3$  = initial guesses at the scale of the simplex which depends upon the ranges considered for each measure.

The policy measures to be optimised can be defined by the user along with feasible input ranges for each measure. The initial simplex is then generated automatically from the minimum and maximum for each measure as follows:

$$(18.3) \quad x_{0i} = x_i^{\min} + \frac{x_i^{\max} - x_i^{\min}}{3}$$

and

$$(18.4) \quad \lambda_i = \frac{x_i^{\max} - x_i^{\min}}{3}$$

where:

$x_i^{\min}$ ,  $x_i^{\max}$  are the minimum and maximum values for policy measure  $x_i$ .

This is equivalent to assuming that the initial guess ( $x_{01}$ ,  $x_{02}$ ,  $x_{03}$ ) for each of the three policy instruments is one third of the feasible range and that the scale of the problem ( $\lambda_1$ ,  $\lambda_2$ ,  $\lambda_3$ ) is also one third of the feasible range. This then ensures that the movement of the simplex is initially within the bounds of the problem as defined by the user. It also frees the user from the responsibility of defining the initial simplex and is easily generalised for N dimensions.

The function is evaluated at each of the points of the initial simplex. The downhill simplex method now takes a series of steps, most steps just moving the point of the simplex where the function is largest ("highest point") through the opposite face of the simplex to a lower point. These steps are called reflections, and they are constructed to conserve the volume of the simplex (hence maintain its nondegeneracy). When it can do so, the method expands the simplex in one or another direction to take larger steps. When it reaches a "valley floor", the method contracts itself in the transverse direction and tries to ooze down the valley. If there is a situation where the simplex is trying to "pass through the eye of a needle", it contracts itself in all directions, pulling itself in around its lowest (best) point. The routine's name AMOEBA is intended to be descriptive of this kind of behaviour (Press et al 1990).



The possible steps are shown in Figure 18.1(a)-(d) for the 3-dimensional case where the simplex is a tetrahedron. The simplex at the beginning of the step is drawn with solid lines. The simplex at the end of the step (drawn dashed) can be either:

- (a) a reflection away from the high point,
- (b) a reflection and expansion away from the high point,
- (c) a contraction along one dimension from the high point, or
- (d) a contraction along all dimensions toward the low point.

An appropriate sequence of such steps will always converge to a minimum of the function (though not necessarily a global minimum).

For each new point the procedure simply requires an evaluation of the function to be minimised. For its application in solving the land-use transport problem defined within this guidebook, there is a requirement to run a land use/transport model at each step and use its output to calculate the respective value of the objective function.

The method can handle hard constraints or discontinuities within the objective function, though the form of the penalties should be selected to aid the movement of the *amoeba* through the search space.

### 18.1.2 Prior belief and the Restart option

As mentioned previously, it is possible for the optimisation process to find a local rather than a global optimum. In addition, the algorithm may be fooled by a single anomalous step that, for one reason or another, failed to get anywhere. Therefore it is frequently a good idea to *restart* a multidimensional minimisation routine at a point where it claims to have found a minimum. This restart is achieved by reinitialising N of the N+1 vertices of the simplex in a fashion similar to equation (18.1), taking  $\mathbf{x}_0$  to be the claimed minimum or *current best* solution.

The *prior belief* of the decision maker can be used as a basis for the other N points during the restart option as follows for the three dimensional example:

$$(18.5) \quad X_{restart} = \begin{pmatrix} x_{1C} & x_{2C} & x_{3C} \\ x_{1PB} & x_{2C} & x_{3C} \\ x_{1C} & x_{2PB} & x_{3C} \\ x_{1C} & x_{2C} & x_{3PB} \end{pmatrix}$$

where:

- $x_{iC}$  = Current Best solution for policy measure i
- $x_{iPB}$  = Prior Belief for policy measure i

Using this method to assign the restart simplex has a dual purpose:

- it provides an independent restart option
- it takes account of the prior belief of the decision maker within the search process, thus bringing in expert knowledge and avoiding some of the pitfalls of automated

processes.

The use of a restart option is not expensive in terms of computation effort as the simplex has already a converged solution as one of the vertices, and if this were a true minimum then the process will converge back to this point in a small number of iterations.

### 18.1.3 Centralised versus Decentralised approaches

The *core* algorithm described in 18.1.1 can be applied in a centralised or a decentralised approach. In the centralised approach, all policy measures are optimised simultaneously to find the minimum of the objective function. This simultaneous optimisation is analogous to centralised traffic signal control whereby all signal settings in a network are optimised simultaneously within a central computer.

One of the problems with the use of a centralised approach may be a restriction on the number of measures which can be considered without causing problems in the N dimensional topography or search space. It may be that as the number of measures increases, the changes in the objective function become more difficult to relate to changes in the N measures.

A possible solution to this problem is to break the problem down into sub-problems of the same type, and to apply the core algorithm to each sub-problem independently. This application of the algorithm is a *decentralised* approach and again it has analogies in the traffic signal control field whereby some systems treat junctions as individual optimisation problems with constraints from neighbouring junctions.

Inevitably, a decentralised approach involves more actual optimisations than a centralised approach. However, since each sub-problem consists of fewer variables, these optimisations will certainly have fewer iterations. Thus the total number of iterations required for convergence of the whole problem may be less than in the centralised approach. Indeed this was found to be the case in the SAMI case study (SAMI Deliverable 3, 2000).

### 18.1.4 Re-parameterisation

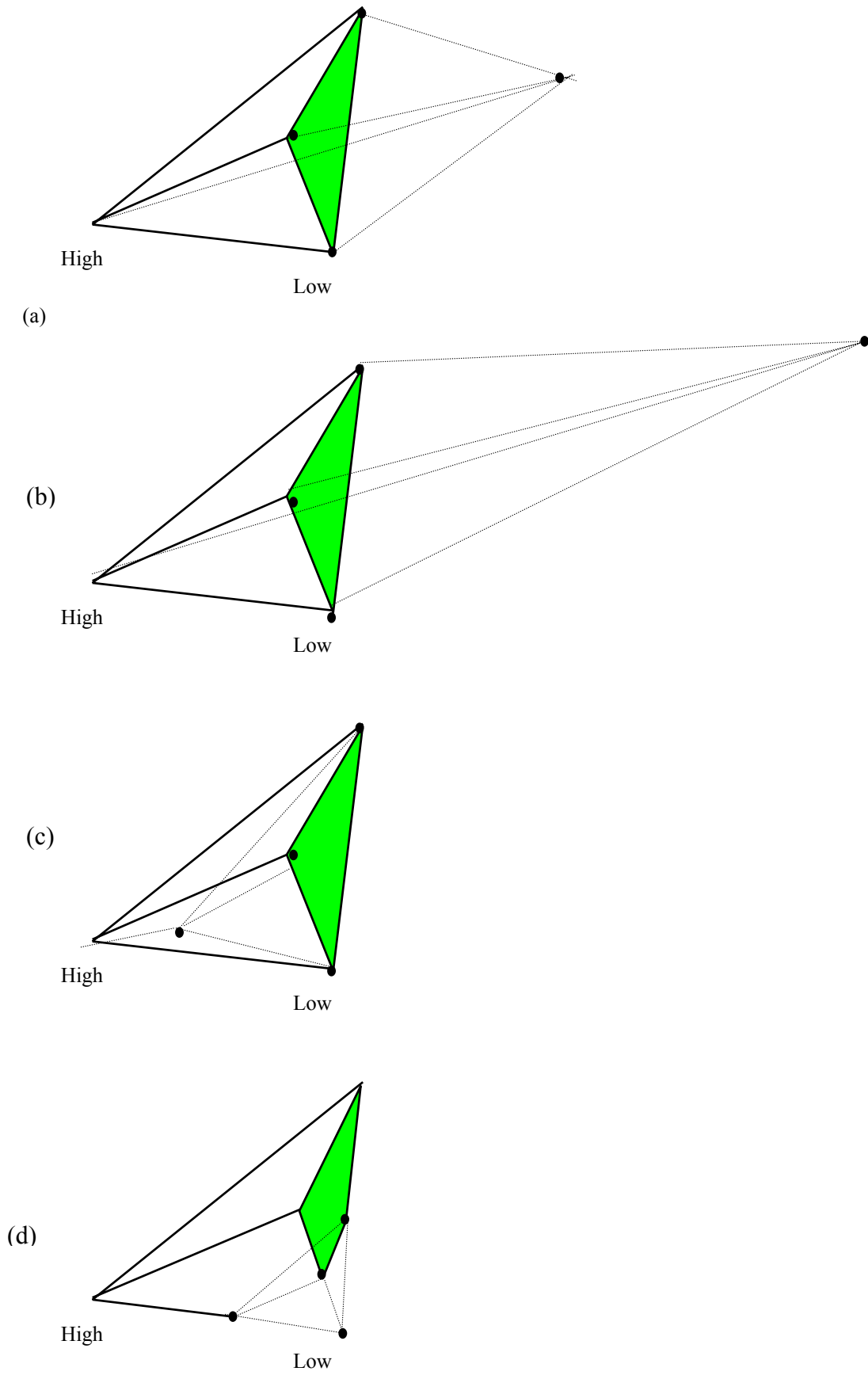
As we discussed in Chapter 7, one approach to deal with upper and lower bounds on policy instruments is that of re-parameterisation. Policy instruments  $x_i, i = 1, \dots, m$  are economically interpretable and constrained between a lower and an upper limit,  $x^{(l)} \leq x \leq x^{(u)}$ . Unconstrained optimisation with respect to  $\mathbf{x}$  may give meaningless estimates  $\hat{\mathbf{x}}$  or estimates that are outside the bounds. However, transformation of the parameters (policy instruments) with the re-parameterisation of the form suggested by Vold et al (1999),

$$\xi(x) = \ln((x - x^{(l)}) / (x^{(u)} - x))$$

ensures that an original parameter  $x$  stays within its definition area during unconstrained estimation.

Since  $e^\xi = (x - x^{(l)}) / (x^{(u)} - x)$  is equivalent to  $x(e^\xi + 1) = e^\xi x^{(u)} + x^{(l)}$ , we have a unique inverse transformation  $x(\xi) = (x^{(u)} e^\xi + x^{(l)}) / (1 + e^\xi)$ .

**Figure 18.1(a)-(d). Possible outcomes for a step in the downhill simplex method**



Assume there are no constraints in the maximisation problem (7.1) of Chapter 7 except the upper and lower bounds on the policy instruments (which we indicated by requiring that the strategies  $\mathbf{X}$  should belong to a certain set  $K$ ). Let us denote the whole set of policy variables transformed in the way indicated by  $\xi$ . If there are  $n$  policy instruments,  $\xi$  is an  $n$ -dimensional vector. We can now transform the maximisation problem from the problem of maximising the objective function  $OF(\mathbf{X})$  given  $\mathbf{X} \in K$  to the unconstrained maximisation problem to maximise  $f(\xi) = OF(\mathbf{X}(\xi))$ , where  $\xi$  can take any value, and use the AMOEBA routine in an unconstrained manner to find

$$W(\hat{\xi}) = \min_{\xi \in R^n} -f(\xi) = \max_{\xi \in R^n} f(\xi).$$

Let us say that we start the AMOEBA process at the point  $\mathbf{x}_0 = (x_{01}, \dots, x_{0n})$  and specify upper and lower bounds  $x_i^{(u)}$  and  $x_i^{(l)}$  for each of the instruments. The elements of the initial simplex defined by (18.1) are then transformed by

$$\xi_i(x_{0,i} + \lambda_i \cdot e_i) = \log((x_{0,i} + \lambda_i \cdot e_i - x_i^{(l)}) / (x_i^{(u)} - x_{0,i} + \lambda_i \cdot e_i))$$

It is then guaranteed that function evaluations at the final estimate  $\hat{\mathbf{x}}(\hat{\xi})$  and at the algorithmic search path are such that the values of the original parameters (policy instruments) are within their lower and upper bounds.

## 18.2 The regression approach to optimisation

This section describes the optimisation methodology used in the OPTIMA and FATIMA projects developed by Fowkes et al (1995, 1998) and further by May et al (1995) and Shepherd et al (1997).

### 18.2.1 Basic Method

The basic method is summarised by the flow chart given in Figure 18.2. For the sake of simplicity, it is assumed in the following description that the objective function being considered is Net Present Value (NPV). However, exactly the same procedure is used for other objective functions.

**Step 1** concerns the precise definition of the objective function (as summarised in Section 3.5 of the guidebook). **Step 2** covers the selection of transport policy measures for the optimisation process.

**Step 3** involves making a set of initial transport model runs of various combinations of these measures, selected according to an orthogonal design (so that as wide as possible “space” of transport measures is covered). The minimum number of initial runs,  $n$ , can be derived from the following rule of the thumb:

$$n = (2 * c) + d + 5$$

where  $c$  is the number of “continuous” policy instruments and  $d$  is the number of

“discrete” policy instruments<sup>34</sup>. This number of runs will allow a linear regression to be made with both squared and linear terms for continuous measures and dummy variables for discrete measures. Hence in the case where we have five continuous variables and two discrete variables, a standard set of 18 runs is needed. Using the output from the transport model and other output, the NPV is estimated for each run.

**Step 4** involves the creation of a regression model to explain the NPV in terms of the policy variables. Since there are five continuous variables and two discrete variables, the 18 runs will only (meaningfully) allow this regression to be made in terms of linear and squared terms: i.e. there is not enough data for cross-product terms (e.g. fare\*frequency).

**Step 5** uses the regression model from Step 4 to estimate the optimum set of transport policies via simple calculus. For example let the single continuous policy variable be  $X$  and the dependent variable be  $f$ , and suppose we calibrate the regression equation :

$$f = a + bX + cX^2$$

$$\frac{df}{dX} = b + 2cX = 0 \text{ for turning point; i.e. turning point at } X = \frac{-b}{2c}$$

$$\frac{d^2f}{dX^2} = 2c \text{ which must be negative for a maximum and positive for a minimum.}$$

Suppose we are maximising : we then require  $c$ , the coefficient of the squared term, to be negative and calculate the optimum value of  $X$  from  $X = \frac{-b}{2c}$ .

This method is easily extended to cover boundary values, interaction terms and discrete measures as discussed below. The regression models can also be weighted so that the higher values of the objective function receive a greater weight than lower values; see Section 18.2.4.

**Step 6** runs the transport model with the optimum set of transport policies estimated in Step 5. Other runs are carried out in this step which can be distinguished into two main types. Firstly, packages are tested that are “similar” to the estimated optimal set from Step 5, and which would be expected to yield high NPVs. Secondly, sensitivity tests can be carried out for two purposes. The first purpose of sensitivity tests is that they can help establish what is “driving” the optimal set of policies (i.e. which measures are dominating the attainment of high NPVs). The second purpose is that they can help identify if a maximum has been achieved which is only a local and not global maximum, thus indicating that “another hill must be climbed” in the optimisation process.

**Steps 4 to 6** are then repeated iteratively until convergence is achieved. The user makes **three** convergence criteria tests (one subjective and two objective):

- (a) Is the user satisfied that the latest regression model is satisfactory from a subjective viewpoint? For example, the user might be able to make a suggestion, by observation, for a new optimum based upon the results around the existing

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<sup>34</sup> Note that a policy instrument may have more than one “optimised” level depending on the policy “profile” as discussed earlier in the guide, e.g. continuous variables generally have two “optimised” levels in the short and long run years. It is important to include all such variables in the regression model and to account for them in the initial orthogonal design.

optimum.

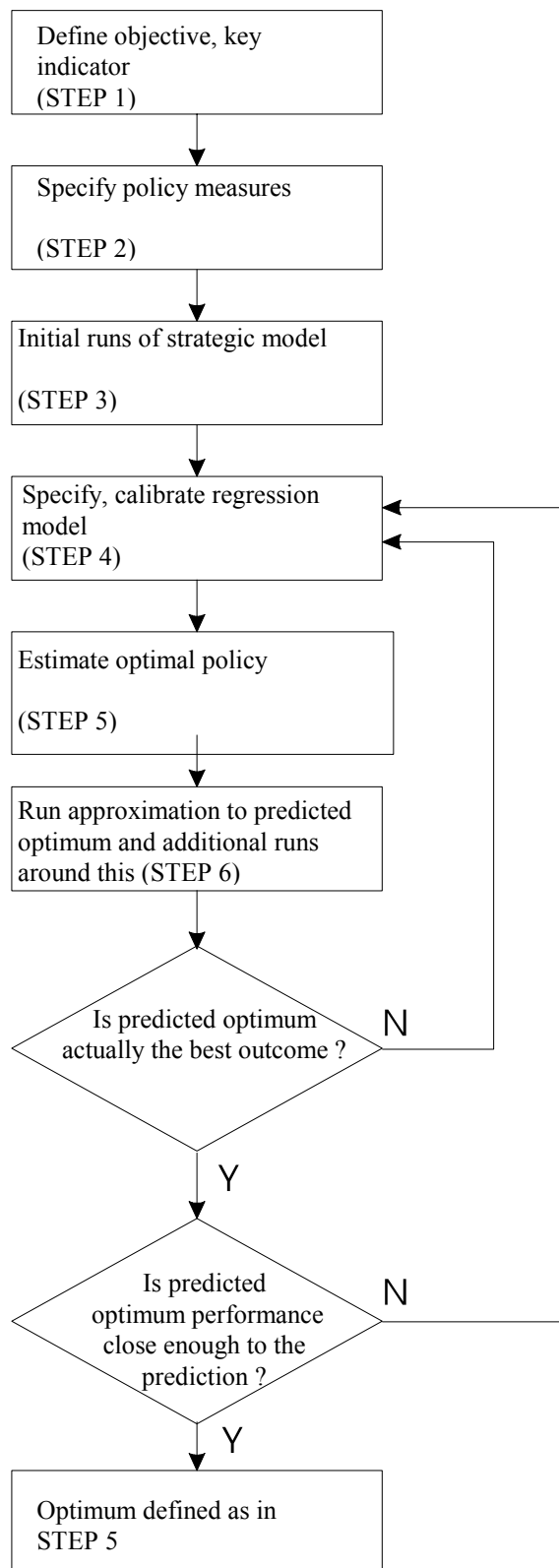
- (b) Is the latest regression model analytically satisfactory? When creating a regression model, there are three conditions that should be satisfied, with the first being the most important:
- (i) The regression coefficients for each variable must be significant at 95 % confidence level i.e. the t-values must be greater than or equal to 1.96 (i.e. the standard errors for each variable should be less than half the absolute value of the estimated coefficient).
  - (ii) The model should predict the highest runs (i.e. those with the highest NPV) better than lower runs.
  - (iii) Where possible the convexity or concavity of the quadratic function for each variable (i.e. whether they have a maximum or a minimum) should fit prior belief as to whether they would in fact be convex or concave; i.e. the regression should make sense in policy terms.
- (c) Compare the “true” NPV for the latest optimal set of policies (as calculated by the transport model) with the “estimated” NPV (as calculated by the latest regression model). The process **has not converged** if<sup>35</sup>
- (i) the regression value is more than 10% greater than the true value from the transport model run;
  - or** (ii) the regression estimate is less than the value from the transport model run<sup>36</sup>;
  - or** (iii) the NPV from the “optimal” transport model run is less than the NPV from another run already carried out.

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<sup>35</sup> These convergence criteria might need to be relaxed in certain cases. For example, it is sometimes difficult for the regression process to represent accurately the effect of a minor measure which contributes only a relatively small amount to the objective function. However, it is still useful for the optimiser to attempt to reach the criteria stated.

<sup>36</sup> If the regression estimate is less than the transport model run, it must generally be assumed that a better regression can be found by adding the “new” information from the latest transport model run. If a subsequent regression can represent this new run accurately, the regression is automatically superior to any other regression obtained before.

Fig. 18.2: The optimisation process



### 18.2.2 Boundary Values

Where policy instruments have upper and lower bounds it is possible for the max/min to be outside the feasible range of values. Let the upper and lower bounds for policy instrument  $X$  be represented by  $X_U$  and  $X_L$  respectively. Let  $X_{max}$  and  $X_{min}$  be the location of the unrestricted local maximum and minimum for function  $f$ .

Suppose we are maximising and that the lower bound is zero, then we have the following conditions for finding a maximum.

**Table 18.1. Finding maximum  $f$  from  $f = a + bX + cX^2$  with  $0 \leq X \leq X_U$**

<b>b</b>	<b>c</b>	<b>Conclusion</b>
positive	positive	$f$ is continuously increasing as $X$ increases, so set $X=X_U$
positive	negative	$X_{max} = \frac{-b}{2c} > 0$ If $X_{max} > X_U$ set $X=X_U$ Else set $X=X_{max}$
negative	positive	$X_{min} = \frac{-b}{2c} > 0$ If $f(X_U) > f(0)$ set $X=X_U$ Else set $X=0=X_L$
negative	negative	$f$ is continuously decreasing as $X$ increases, so set $X=0$ .

### 18.2.3 Interaction Terms

Consider now two policy variables  $X$  and  $Z$ , which not only affect  $f$  individually, but which have an interaction effect. Most often we might expect such an interaction effect to be negative, i.e. some of the benefits of changing  $X$  are the same as those of changing  $Z$ . Put another way, once we have optimised with respect to  $X$ , there is less room for improvement when optimising with respect to  $Z$ . In any event we may write:

$$f = a + b_x X + c_x X^2 + b_z Z + c_z Z^2 + gXZ \tag{18.6}$$

$$\text{where } 0 \leq X \leq X_U; 0 \leq Z \leq Z_U$$

To find the stationary points we set partial derivatives to zero:

$$\begin{aligned} \frac{\partial f}{\partial X} &= b_x + 2c_x X + gZ = 0 \\ \frac{\partial f}{\partial Z} &= b_z + 2c_z Z + gX = 0 \end{aligned} \tag{18.7}$$



Solving the two equations given by (18.7) for X and Z gives:

$$X^* = \frac{2b_x c_z - b_z g}{g^2 - 4c_x c_z}$$

$$Z^* = \frac{2b_z c_x - b_x g}{g^2 - 4c_x c_z}$$

These values of X and Z give us turning points for f. To investigate if we have a maximum, we have to look at the second order conditions.

$$\frac{\partial^2 f}{\partial X^2} = 2c_x$$

$$\frac{\partial^2 f}{\partial Z^2} = 2c_z$$

$$\frac{\partial^2 f}{\partial X \partial Z} = g$$

Both  $c_x$  and  $c_z$  need to be negative for a maximum. To ensure that we do not have a saddle point we require:

$$4c_x c_z > g^2$$

If a saddle point is indicated, or if a minimum is indicated when we are maximising, then we should move to the best edge solution available. If we are looking for a maximum and  $c_x < 0$  while  $c_z > 0$ , then  $X^*$  should still be investigated, and chosen if in range. The same argument applies vice versa for Z or for minimisation<sup>37</sup>.

### 18.2.4 Weighting

It is most important to realise that the simplified regression model will not fit exactly the true transport model (although it may fit exactly data points from the true transport model, for example if we fit a regression model with the same number of parameters as there are data points). If we do not use a weighting, we should expect the fit to be equally good for all points, and in particular for all values of the dependent variable. If we are trying to maximise the dependent variable, we will want the fit (i.e. the quadratic approximation) to be best for the higher values of the dependent variable.

Let f be the dependent variable, and  $f_{\max}$  and  $f_{\min}$  be the highest and lowest values of f so far observed (from the transport model).

Form 
$$W = f + 1.1|f_{\min}|$$

---

<sup>37</sup> Note that in the OPTIMA and FATIMA project complicated regression models were investigated by use of an excel spreadsheet and the solver option for maximising subject to constraints.

$$W2 = W^2$$

$$W4 = W^4$$

etc.

This procedure gives a greater “weight” to the higher values of  $f$ . Try values of  $W$ ,  $W2$  and  $W4$  when forming the regression model. Note that too high a weight can have the effect of throwing out too much data, but some weighting will usually be beneficial. Past experience has shown that  $W2$  and  $W4$  are usually good starting points.

### 18.3 Constrained optimisation of the OF function

Algorithms for constrained optimisation are capable of solving problems of the very general form of (18.8) and are often capable of calculating the optimal Lagrangian multipliers (shadow prices):

$$(18.8) \quad \begin{aligned} & \max_{\mathbf{X}} OF(\mathbf{X}) \\ & s.t. \\ & h_i(\mathbf{X}) = 0, \quad i = 1, \dots, m \\ & g_j(\mathbf{X}) \geq 0, \quad j = 1, \dots, n \end{aligned}$$

Luenberger (1984) gives a general introduction to the theoretical basis for constrained optimisation algorithms.

Implementations of constrained optimisation algorithms are available as part of many commercial software packages and as free FORTRAN – and C library routines, available on the Internet, which can be linked into conventional programs. An example is Prof. Dr Peter Spellucci’s optimisation algorithm DONLP2<sup>38</sup>, which is available on the Internet in both C and Fortran code with user guides. Further to this J.C. Culioli and J.P. Skudlarek have provided an implementation of the Method of Multipliers (also known as the Augmented Lagrangian Method) for use in the Mathematica software package. This can be downloaded from the Mathematica website, <http://www.wolfram.com> and was applied in the PROSPECTS Oslo case study.

Algorithms that are part of commercial software packages are often easy to understand and use on simple examples but programming work is required in order to make them communicate with the software in which the objective function  $OF$  is implemented. Library routines that are programmed in the same programming language as the  $OF$  can often be directly linked in and applied. However, these algorithms are often less self-explanatory, more demanding to understand and some programming skills are required making them operational.

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<sup>38</sup> The methodological description in the Users Guide says: “The algorithm is based on a sequential equality constrained quadratic programming method (with an active set technique) with an alternative usage of a fully regularized mixed constrained sub problem in case of non-regular constraints (i.e. linear dependent gradients in the “working set”)....”

# 19 Some experience

This guidebook provides advice on urban transport and land use planning at three different levels:

## 1. A logical structure

At the most general level, we provide a *logical structure* to the planning process (Section 2.2) and discuss its implication for each of the steps in the process. This kind of advice is contained in the Decision-Makers' Guidebook and in Chapters 1-2 of the present guidebook. The logical structure may be seen as a typical example of a *planned* approach to the challenges confronting our cities, but, as we have tried to show, the knowledge produced by such an approach will be vital even to the consensus-led and vision-led approaches.

More or less systematically, planning along the lines of this logical structure has been carried out in cities for a long time. For a number of reasons (Lee 1973, Lee 1994), such planning has from time to time fallen into disrepute. Models may have been too large-scale, too black-box in character, and with a too weak theoretical basis. The *dirigiste* ambitions of the planning institutions were (often deservedly) undermined by deregulation and split political responsibilities. Furthermore, the planning objectives were often less than clear and did not cover the whole range of concerns of politicians and the public.

With the widespread concerns about urban sustainability of the last few years, integrated land use and transport planning has re-emerged once more – and this time, as we have tried to show, with a clearer set of objectives, better models and tools, and more concern for the interactions between decision-makers, planners and the public.

Without mentioning any particular study, it must be pointed out that studies broadly in line with our logical structure have been carried out in many cities in the last decade. Still many more are under way.

## 2. The appraisal framework and the use of optimisation

Within the broad and flexible logical structure, this guidebook suggests a particular *appraisal framework*, consisting of a set of seven objectives with sub-objectives, a set of indicators for these objectives, and the use of these indicators to form an objective function and to set targets. The appraisal framework and a suitably simple but comprehensive modelling system are the two basic elements we need to perform *optimisation*, which is a useful method of developing interesting strategies, studying the synergy between policy instruments when they are used optimally, and increasing our knowledge about the potential for improvement of the transport and land use system.

This specific appraisal framework has only been applied fully in the PROSPECTS project. The intergenerational equity objective was however already included in the OPTIMA project in a similar way. Efficiency and equity indicators broadly in line with our appraisal approach were used in the AFFORD project. Optimisation was used in all three of these projects and in FATIMA and SAMI.

The general experience is that it works. Our suggested method of including the intergenerational equity objective in the objective function does rank greener strategies and

strategies with positive long-term effects higher (OPTIMA 1998, Minken 1999). Results of considerable interest for the issue of implementation of road pricing may be derived from equity analyses applying inequality indicators to model output (Fridstrøm et al 2000). Optimising with an ordinary transport model is feasible and does produce better strategies quicker (Fowkes et al 1998, May et al 2000 and Timms et al 2002). Even constrained optimisation is quite feasible, although we are not guaranteed that a global optimum is found (FATIMA 2000).

PROSPECTS experience confirms this (Shepherd et al 2003). In PROSPECTS, we considered for the first time strategies consisting of policies that may change with time. Also for the first time, optimisation was applied to time-marching models, where actions early on have consequences for the system at later stages. Some conclusions from the PROSPECTS tests are given in Section 19.1.

### **3. Indicators and parameters**

Some of the indicators we propose are pretty standard. This goes for the economic efficiency indicator, although with the following qualifications: First, it needs to be pointed out that standard methods of multi-modal cost benefit analysis are not very well established in all countries, and that unsuitable methods taken from CBA manuals of highway projects (based on fixed matrix assumptions) are often used in practice. Wrong applications of the rule-of-half are also common. If there is no sound national guidance on multi-modal studies, one may wish to consult the British GOMMMS (DETR 2000c) to compare with our guidance and to complement it. Second, our advice on how to treat taxes constitutes an advance on most current practice. However, it needs perhaps to be pointed out that it does not entirely agree with British practice. Third, our proposal for the calculation of user benefits in integrated land use and transport models must still be considered as experimental, and more experience with it is needed. But at least, Chapter 9 will make it possible for the reader to judge what will be missing if she decides to apply simpler methods.

Our suggestions for indicators of local air pollution and noise are also pretty standard, we think. This is why we do not provide definite unit values and other empirical estimates: These can be found in the literature we refer to in Chapter 12, in national guidance and in new studies that appear all the time.

Our indicators of (intragenerational) equity and accident costs should be well founded in theory, but little used in practice. Simply because there is so little experience, these must be regarded as somewhat experimental. PROSPECTS tests have provided some experience, but less than we would have liked.

Land and fossil fuel are perhaps the two most important non-renewable resources to be considered in land use and transport planning. We treat these two very differently. The constraints on CO<sub>2</sub> emissions are assumed to apply at a world or national level, which means that the cost of keeping within these restrictions (the unit cost of CO<sub>2</sub>) can be taken as given at the local level (Chapter 16). We are however not at all certain that the specific values we have suggested are the ones that should be used in all studies. In some of the PROSPECTS studies, the long-term value of 200 euro per tonne seemed to make the CO<sub>2</sub> costs savings rather high compared to other benefit and cost elements. This may however depend very much on the assumptions made regarding the future development of fuel efficiency and fuel technology. Indicators of land use, on the other hand, will mainly be used to set local land use targets, and these targets will be used as constraints in the optimisation problem and give rise to shadow costs. Only further experience can tell how much such targets will influence the ranking of strategies.

Finally, our indicator of liveable streets is the most experimental of all, and our

indicator of economic growth potential is the one we feel least confident about. PROSPECTS did not produce evidence to test or validate these indicators.

PROSPECTS experience with some of the indicators is given in Section 19.2, along with experience with setting important parameters like the intergenerational equity parameter.

#### **4. Presentation and implementation issues**

Within the print deadline of this guidebook, we did not get the time to present results of the PROSPECTS tests to city authorities, so there is not any evidence on how well the appraisal framework communicates with decision-makers and the public except what was reported in PROSPECTS Deliverables 1 and 2. As reported there, the general framework was well received.

## **19.1 PROSPECTS experience**

### **19.1.1 The tests**

The PROSPECTS tests involved the six cities Edinburgh, Helsinki, Madrid, Oslo, Stockholm and Vienna. Edinburgh, Helsinki and Oslo are all similar in size, whereas Stockholm, Vienna and especially Madrid are larger cities. Modelling in Vienna covered the city itself; in all other five cities, the whole metropolitan area was modelled. At least in Oslo, this included some very sparsely populated areas.

Full land use/transport models were available for Edinburgh, Oslo and Stockholm. A transport only model was used for the Madrid case study. In Edinburgh, the DELTA/START modelling package (Simmonds and Still 1999, Simmonds 2001a) was used. In the terminology of Section 7.2.4, this is a time-marching model. In Oslo, the RETRO transport model (Vold 1999) was integrated with a simple land use model. In Stockholm, the IMREL transport model (Anderstig and Mattsson 1991, Boyce and Mattsson 1999) was integrated with the SAMPERS transport model. The Oslo and Stockholm models are both equilibrium based models in the terminology of Section 7.2.5.

At the same time, a Sketch Planning Model (SPM) was developed and applied to all six cities. The SPM is a strategic, interactive land-use and transport (LUTI) model of the type outlined in Section 6.6, and is documented in Pfaffenbichler et al (2003). It is a time-marching model in the terminology of Section 7.2.4.

All tests took the form of optimisation with respect to sustainability, i.e. solving the constrained optimisation problem (7.1), and performing subsequent sensitivity tests. As described in Section 7.2, the policy instruments could be varied separately in two chosen years of the 30 year appraisal period, with interpolated levels for the intermediate years.<sup>39</sup> Optimisation was carried out for a particular scenario, and not across scenarios.<sup>40</sup> The regression-based optimisation algorithm (Section 18.2) was applied to DELTA/START and SAMPERS/IMREL, a constrained optimisation algorithm (Section 18.3) was applied to RETRO and the AMOEBA algorithm (Section 18.1) was applied to the SPM.

The objective function incorporated the objectives of economic efficiency, including

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<sup>39</sup> In the RETRO tests, policy instruments were only varied in one year.

<sup>40</sup> Optimisation was carried out separately for two different scenarios in the RETRO tests, while the other tests involved only one scenario (except for sensitivity testing).

the costs of accidents, noise, local air pollution and CO<sub>2</sub> emissions, and equity between present and future generations. For some of the tests, constraints on finance were included by imposing a limit on the present value of finance (PVF). Constraints in the form of local targets on CO<sub>2</sub> emissions were also investigated using the SPM, while accident and equity targets were investigated for the RETRO study.

The policy instruments studied in all six SPM studies were public transport fare, public transport frequency and fuel tax changes. In some of the cities road pricing and parking charging schemes were tested in addition to the common set of policy instruments. The instruments were optimised for peak and off peak periods in years 2006 and 2016. The tests of the large-scale models involved more diverse instruments, such as a light rail scheme and a road pricing cordon in Edinburgh or tolls at the present toll cordon, public transport frequencies and a dense land use strategy in Oslo.

One of the two scenarios assumed in the Oslo RETRO study involved a national fuel tax rise, assumed eventually to lead to a fleet of smaller and more fuel efficient cars. The other involved the converse assumption: cheaper fuel and no improvement in the fuel consumption of private cars.

A fuller description of models, tests and results is contained in Shepherd et al (2003).

### **19.1.2 Some SPM results**

Here, we can only include a few of the results from Shepherd et al (2003). With respect to the SPM, we outline the results from Vienna and Edinburgh and comment on the Oslo SPM model. Some characteristics of the results from the large-scale models are outlined in Sections 19.1 and 19.2.

For *Vienna*, the optimal strategy found in the initial optimisation of the common set of instruments suggests to halve the public transport fares in peak and off peak in year 2006 as well as in year 2016. Public transport peak frequency should be slightly decreased. A higher decrease is suggested for year 2016 than for year 2006. Off peak frequency should be increased by about 50% in year 2006 as well as in year 2016. The fuel tax should be increased by about 20% in year 2006 and reduced back to about the same level as in the starting year in year 2016. However, the PVF of this strategy is highly negative (about –2.6 billion Euro). The CO<sub>2</sub> emissions are reduced by about 8% in year 2006 compared to the emissions in year 2001. In subsequent years, however, CO<sub>2</sub> emissions resume their long-term tendency to rise, and reach 2001 levels before the end of the period. Consequently, the tested instruments are not able to bring about long-term sustainability with respect to CO<sub>2</sub>.

As strategies requiring higher public spending are very unlikely to be accepted, an additional optimisation using an objective function constrained by PVF was performed. The results again suggest to halve the public transport fare in peak in year 2006 and 2016. For off peak, an increase by about a third for year 2006 and a decrease to about a half in year 2016 is suggested. Changes in peak frequency are about the same as in the unconstrained result, but the increase in off peak frequency should be lower (about 40%). Finally, a fuel tax increase of about 180% in year 2006 and about 30% in year 2016 is recommended. PVF is close to zero for this strategy. The CO<sub>2</sub> emissions are reduced by about 12% in year 2006, but resume their tendency to rise afterwards and reach 2001 levels at the end of the period.

Introducing a road pricing cordon as an additional instrument produces similar results, since the optimal road pricing charge is moderate – about 1 euro in peak in 2006 and decreasing slightly over the years, and no tolls in off peak unless the PVF constraint is in place, in which case it is 0.3 euro in 2006, decreasing to zero in 2016. The optimal

fuel tax is slightly lower with this toll charge in place. The inclusion of the additional instrument is however able to produce better results with respect to CO<sub>2</sub>.

The *Edinburgh* SPM optimisations produced optimal strategies that were comparable to previous optimisation studies in *FATIMA* and *AFFORD*, where the transport model *START* was used. For the common set of policy instruments the optimal policy was to reduce fares by 50% in all periods and across all years, to increase frequencies substantially and to pay for this via increased fuel taxes. The optimum as measured by the OF value with the inter-generational equity factor equal to 0.1 was found to be insensitive to changes in frequency and fuel tax increases. It was found that lower increases in both frequency and fuel tax gave rise to very similar outcomes in terms of the OF values; however the present value of finance was markedly different moving from a net profit of more than 1 billion euro to a net loss of 500 million euro as fuel tax increases were limited to say 50% from the optimum of 200% followed by 67%. This suggests that constrained optimisation should be used where there is a need for self-financing packages.

The study also investigated a toll cordon around the city centre and parking charges in the same area. Contrary to the *Vienna* tests, the fuel tax instrument was not used in these tests. Also, the toll cordon covered a fairly small area in the city centre. The unconstrained optimal policies produced too little government revenue, so a constraint on PVF had to be imposed. The optimal constrained solution was to reduce fares gradually and to a lesser extent than in the unconstrained case, and to increase frequencies gradually to around 55% in the peak and 70% in the off-peak – all paid for by increased tolls of 10 euros in the peak and 6 euros in the off-peak.

The solution to constrain PVF to be positive led to a package which generated surpluses in the earlier years to finance better services in the long run. CO<sub>2</sub> emissions, although reduced, did not meet the Kyoto target and continued to grow afterwards.

Comparing the fuel tax instrument and the cordon toll, the fuel tax was seen to be more effective in terms of reducing environmental externalities but both packages resulted in similar long-term mode shifts. The main difference between the packages was the amount of finance generated and ownership of any financial surplus. The toll charge produced just enough revenue to pay for the improved public transport services, whereas with fuel taxes, car users were hit in money terms and the excess revenues would not necessarily come back to the *Edinburgh* area.

The land use effects of the strategies were relatively minor. This is because development in all cases is constrained by the model to meet the projected growth. In addition, as the SPM location model only represents one group of residents we cannot display any variations by socio-economic group.

Transferability of a simple model from one city to another requires the model to be flexible and to offer enough opportunities for calibration to the particular circumstances of that city. Features of the SPM that worked well in densely populated study areas like *Vienna* turned out to create problems in *Oslo* and other study areas that included very sparsely populated areas. Such areas typically have low public transport frequencies and long distances to get to the bus. In the *Oslo* SPM study, this produced some unreasonable time costs and elasticities. Further research is required to make the SPM more suitable for urban areas with such features.

### **19.1.3 Experience with the appraisal framework**

The general features of the appraisal framework suggested in this guidebook were easily implemented in all the case studies. As a rule, though, each modeller chose to

apply her own favoured methods to compute accident, noise and local pollution costs, or the methods that were prescribed in the national guidance of her country. The same goes for calculations of public transport costs. All of this is of course entirely compatible with the flexible general approach.

None of the teams ventured to experiment with indicators of liveable streets and neighbourhoods, and none of them assumed that there would be economic growth impacts that were not captured by the economic efficiency indicator.

There were interesting new questions thrown up by the results, especially with respect to:

- whether or not the optimal strategies were really sustainable in the full sense,
- how to explain the observed time paths for net benefits and the policy instrument levels,
- how the intergenerational equity parameter  $\alpha$  (Section 3.5) interacted with environmental constraints and PVF-constraints to produce the optimal solutions,
- implications of the result for guidance on the normative choices that have to be made, including the choice of  $\alpha$ , the type of CO<sub>2</sub> constraint that should apply, etc.,
- whether or not optimal local strategies will have to rely on a particular scenario (vehicle technology, national tax policy) to be sustainable in the full sense.

All of these questions are left for future research, and it is hoped that the KonSULT website will be able to report progress on these issues as this research develops.

#### **19.1.4 Experience with optimisation**

The AMOEBA algorithm was shown to work well with the SPM model for unconstrained and constrained problems. The restart option proved useful if a lower tolerance was used in the restarted optimisation. Otherwise the rerun stops quite soon after the initial set of runs and the solution is not significantly improved.

The Edinburgh and Stockholm large-scale models tested the regression based approach. For Edinburgh, the regression models pointed towards the correct policy space in the first iterations of the process, but regression models were more difficult to form as the optimum solution was developed. The regression model failed to rank the top strategies and some variables became insignificant. It was thought that this failure was partly due to the insensitivity of the OF values to the short run variables and partly due to correlation between the variables, all of which were related to the road pricing cordon.

The Oslo LUTI case study used an implementation of the multiplier method in the Mathematica software package by J-C Culioli and J.P. Skudlarek, applied to a polynomial approximation of the objective function. An interesting feature of this method was that once the response surface for the objective function was generated, one may experiment with constraints afterwards without making any extra model runs. All components of the objective function and the constraints were scaled such that the units were Meuro instead of euro. This was necessary in order to make the determination of the shadow costs converge properly.

In general, all of the tested algorithms have been shown to work for the problem at hand (the problem (7.1) of Chapter 7). The difficulties that were experienced in some cases were mainly that it sometimes became difficult to determine optimal policies for 2006. This may be due to the low value (0.1) that was chosen for the intergenerational constant  $\alpha$  in all the optimisations, putting too much stress (from a technical point



of view) on the interests of future generations; or to the constraints on the end year and they way they interact with the intergenerational equity parameter; or to problems from having to set levels for the same policy variables for two different years.

Our conclusion is that setting separate levels for the policy instruments at two different years is a great leap forward in terms of modelling sustainability and implementation paths. Some initial problems will have to be expected.

## **19.2 Experience with individual indicators and parameters**

### **19.2.1 User benefits**

As explained in Section 9.4 and shown in the box at the end of that section, it will generally be possible to compute user benefits in an integrated land use/transport model as the sum of three parts. The three parts are:

- elements of benefit calculated from changes in transport generalised cost,
- elements of benefit calculated from changes in trip attractions, and
- elements of benefit calculated from changes in the characteristics of residential zones, housing prices and other housing characteristics.

All the PROSPECTS tests based their calculations of user benefits on the general advice of Simmonds (2001) and Chapter 9. However, they drew different conclusions as to the particular approach they chose. Some used logsums and some used rule-of-a-half approximations, and based on the general advice of Chapter 9, some teams consciously decided to leave out elements of the user benefit which they deemed insignificant in their particular circumstances. Generally, no big problems were experienced.

The data to compute the three elements can either be taken from the land use model or the transport model. If taken from the land use model, the benefits of increased accessibility may be separated from other (location) sources of benefit – and the accessibility benefits may eventually be further separated into the two first elements above. Edinburgh initially applied this approach, but concluded that it requires further research. There appeared to be inconsistent estimates of user benefits in year 2006 when compared to the traditional rule of a half approach. These errors were also present in subsequent years and gave rise to optimal tolls which were significantly different from previous results reported in May et al, (2000) where no land use response was modelled. Thus they reverted to calculating the user benefits based on the traditional rule of a half applied to changes in generalised costs in transport, including benefits based on changes in other variables affecting location other than accessibility, but ignored the benefits due to changes in trip attraction (which they assumed to be insignificant for the policies tested here). This approach gave much more consistent and reasonable looking results in terms of policy.

As stated in Chapter 9, our approach to user benefit calculations must still be considered experimental. The problems experienced in Edinburgh needs to be looked into. No similar problems were reported from the other teams.

### **19.2.2 Intergenerational equity parameter**

The intergenerational equity parameter alpha (Section 3.5.2) was set to 0.1 in all optimisations. In sensitivity test, alphas between 0 and 1 were used. As explained above, the value of 0.1 might be low from a technical point of view when used in optimisations. It might also be low from a normative point of view, and values between 0.25 and 0.5 might correspond better to decision-makers' values in many

cases.

The sensitivity tests were able to throw some light on the normative question of how to set alpha. It turned out that the choice of alpha in the time-marching models was closely related to the way the benefit profile developed over the period. Low alphas correspond broadly to optimal strategies where net benefits increase with time, thus “leaving the system in a better shape to the next generation”, whereas high alphas may allow the system performance to deteriorate over the years. However, Edinburgh experience indicated that the optimal strategy was rather insensitive to the choice of alpha. This may be due to the constraint on PVF. More generally, constraints will also influence the benefit profile. The choice of alpha may need to be considered in the light of this.

### **19.2.3 Equity and accidents targets**

The Oslo RETRO tests assumed a target on the maximum allowable inequality of the distribution of net benefits among the zones. Such a target may for instance stem from the need for different local authorities to agree to a strategy if it should stand a chance of being implemented. There must be something in it for all. A Kolm inequality measure applied to the net benefits in the zones of the model was applied as an indicator of this distributional objective. The target was that inequality should not increase as a consequence of the strategy. It turned out that the optimal strategy in both of the two scenarios fulfilled this requirement, so the constraint was not binding. In the scenario where the national government had reduced the fuel taxes, the optimal strategy was able to improve equity more than in the scenario where fuel taxes had been increased.<sup>41</sup>

Also, a target of 5% reduction in accident costs was imposed. This may seem little, but it turned out to be a binding constraint in both scenarios. The implication is that it will be necessary to rely on specific instruments of accident reduction, not modelled in our strategic studies, to achieve more substantial reductions.

As can be expected, a target on accidents was more difficult to achieve for the scenario with lower fuel taxes.

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<sup>41</sup> The optimal strategy in this case was to promote a denser land use and to increase charges at the toll ring as well as public transport frequency.

# Glossary

In this section, we explain some of the concepts that crop up in the text, and provide the interpretation of these concepts that we want to apply.

## *Accessibility*

The accessibility of an activity to an individual located in a zone is the ease with which the individual can access places where the activity can be performed.

## *Analytical*

Rational, usually numerical, approach to understanding an issue.

## *Appraisal*

The process of providing decision-makers and stakeholders with sufficient information to pass judgement on a strategy, rank strategies or choose a strategy to implement.

## *Appraisal framework*

A matrix with strategies as columns and their achieved indicator values as rows. See Section 3.1 and, in particular, Table 3.2.

## *Assessment*

The process of passing judgement on a strategy or any other matter.

## *Barriers*

Impediments to the free use of a policy instrument, in so far as these impediments are removable in principle.

## *Benefit/cost ratio*

As a rule, the benefit/cost ratio is the net present benefits (to households, firms and “nature”) of a project, divided by the net present value of the costs incurred by the government to implement the project (investments and maintenance minus government revenue). Shows how much society gets back from each euro of taxpayers’ money expended in the project.

The exact definition in each case may however depend on which budget it is that must be respected in selecting the projects. Thus in some cases, it will be more appropriate to divide by the costs of a particular government agency, and include the impacts on other agencies in the net present benefits. See *cost benefit analysis*.

## *Brownfield*

A location which has already been built-on or which has been the site of industrial processes which have degraded the environment. This contrasts with *greenfield* locations, which are still in an undeveloped state and whose environment is essentially not degraded. Agricultural land is generally viewed as being greenfield even if it is not in its original, virgin, state. Long-abandoned developments (e.g. pre-historic sites) would not generally be classed as brownfield.

## *Compensation*

Any payment in cash or in kind made to losers from a strategy with the purpose of covering their losses in part or in full.

## *Complete ordering*

A complete ordering of strategies rank all strategies. An incomplete ordering would

sometimes not be able to tell which one of two strategies is the better.

*Consensus*

Broad agreement among *stakeholders*.

*Constraint*

An equation or an inequality that – together with other constraints – defines the feasible region of the policy space. (For instance, the constraint  $x_1 + x_2 \leq 1$  defines the feasible region as any combination of the two policy instruments  $x_1$  and  $x_2$  that respects the rule that their levels should sum to no more than 1. If  $x_1$  and  $x_2$  are discrete variables that only take the values 0 or 1, this constraint says that both cannot be used at the same time).

*Cost-benefit analysis*

Appraisal of the *economic efficiency* of a strategy. Takes many forms. The most common form, used by road authorities, assumes a constant travel pattern for car trips and computes the total travel cost (time and money) of making these trips with and without a road project. Multi-modal cost benefit analysis, on the other hand, takes into account that travellers may change their behaviour by changing mode, destination etc. This requires a methodology similar to the one of this guidebook. In some countries, accident costs and environmental costs are included in a cost benefit analysis, in other countries they are not.

Costs and benefits at different dates need to be *discounted*. If economic efficiency is the sole objective, the strategy with the highest *net present value* should be chosen. Under a budget constraint and with strategies consisting of divisible and independent projects, the highest net present value is achieved by selecting projects according to their *benefit/cost ratio*.

*Demography*

The science that studies and predict populations, their size and composition (by age and sex) and how it evolves over time.

*Deregulation*

Making profit maximisation the objective of public companies, and allowing them new degrees of freedom of action to achieve this objective. May or may not be part of a plan of *privatisation* (selling public companies). Closely linked to *liberatisation* (removing the public company's former monopoly rights and subjecting it to competition – in its market or for its market).

*Discounting*

The process of transforming a stream of benefits and costs occurring at different dates  $t_1, t_2, \dots$  to their equivalent values at a common date  $t_0$ . These equivalent values are called *present values*, and their sum is called the *net present value* of the stream of benefits and costs. The factor that achieves the transformation from date  $t_i$  to date  $t_0$  is called the discount factor. For a constant discount rate  $r$ , the discount

factor is  $\frac{1}{(1+r)^{t_i-t_0}}$  if time is discrete and  $e^{-r(t_i-t_0)}$  if time is continuous. Among

the discount rates that decrease with time, logarithmic discounting attracts the most interest (Heal 2000). Section 8.3 discusses discounting.

*Economic efficiency*

Economic efficiency as used in this guidebook is measured by a utilitarian welfare function (the Economic Efficiency Function, EEF). It includes external costs of accidents, noise and pollution.

Generally, however, the term economic efficiency is used in three different meanings, one related to Pareto improvement and the other two related to the

*Kaldor-Hicks criterion* or a *welfare function*, respectively.

(1) A Pareto improvement increases the utility of at least one individual without reducing the utility of any other individual. There is economic efficiency in the first sense if no Pareto improvements are possible. One might also speak of a Pareto improvement as constituting an increase in economic efficiency (towards the fully efficient state).

(2) A strategy is however often said to increase economic efficiency if the winners would be able to fully compensate the losers and still be winners. This is economic efficiency according to the Kaldor-Hicks criterion.

(3) If a welfare function has been specified, any increase in this function might also be said to improve economic efficiency. Unless the welfare function is utilitarian (giving equal weight to an euro more, regardless of who gets it), this usage of the word should be avoided.

### *Ecosystem*

An ecosystem consists of the living (plants and animals) and dead matter in a defined area, large or small. In its development, the ecosystem will tend to an ecological equilibrium.

### *Entropy*

This concept stems from thermodynamics. In transport analysis, increasing entropy means a tendency for choices between travel alternatives to be more evenly distributed among all alternatives and to be less dependent on travel costs.

### *Environment*

The environmental impacts of concern to transport include noise, atmospheric pollution, vibration, visual intrusion, severance, fear and intimidation, and the loss of flora and fauna, ancient monuments and historic buildings through the consumption of land. The environmental protection *objective* involves reducing the impact of transport facilities, and their use, on the environment of both users and non-users.

### *Environmental Impact Assessment*

Environmental Impact Assessment (EIA) is the study of the environmental impacts of single projects or at the level of policies, plans and programs (PPP). The aim of EIA is to ensure that the chosen options are environmentally sound, and to promote efforts to prevent environmental damage. The higher-order environmental assessment of proposed or existing PPP and their alternatives is called Strategic Environmental Assessment (SEA). SEA is supposed to be short and concise and to guide the subsequent EIA at lower-order decision levels.

Most countries require that EIA should be a part of the decision-making process at the project level, and more and more also at the strategic (PPP) level. A large field of research is concerned with EIA methods.

### *Equity*

The concept of equity may concern equal opportunities or equal outcomes. In our models, opportunities are unequal in so far as some individuals have lower income, more constrained choice sets or face higher costs. This will show up in unequal outcomes with respect to user benefits. The degree of inequality is measured by inequality indices. See Chapter 14.

### *Evaluation*

Evaluation is the process of finding out after implementation what the real impacts have been and how they compare to what we expected beforehand. See section 2.11. (Often, evaluation is taken to mean a process of assessing the relative merits of strategies *before* they are implemented. We use “appraisal” for this process).

### *External cost*

An externality exists if the utility function of some individual or the profit of some firm is affected by the level of consumption or production of somebody else. The impact may be positive or negative. If negative, the other agent's consumption or production is said to impose an external cost on the affected individual. The cost is the utility loss as measured in money. Primary examples are congestion, where each traveller increases the time costs of all other travellers, and noise and air pollution from traffic, where the amount of traffic reduces the environmental qualities of the adjacent properties. A part of accident costs is also external. Since the externality relation is technical, the only chance of removing an externality without some cost to the polluter is a change of technology. If this option does not exist, the issue might be to find some arrangement that maximises *economic efficiency*, given the externality. Economic efficiency is maximised when the marginal cost to the polluter of reducing the polluting activity equals the marginal benefit to the hurt part of this reduction. This could be achieved through Pigouvian taxes (letting the polluter pay the *social cost* of his activity, including the cost he confers on others), through creating a market in pollution rights, or through a merger of the two agents. The last option is obviously seldom possible.

### *Global warming*

By global warming we mean increasing annual mean temperature on earth, caused by human activity. According to IPCC (2001), global warming is taking place and will continue far into the future, but might eventually be stopped and reversed if emissions of CO<sub>2</sub> and other greenhouse gases are sufficiently reduced. Global warming causes economic harm through abrupt changes in ecosystems and probably more adverse weather.

### *Greenfield*

Greenfield locations are still in an undeveloped state and their environment is essentially not degraded. Agricultural land is also generally viewed as being greenfield even if it is not in its original, virgin, state.

### *Household disposable income*

A household consists of persons who live together and have their meals together or otherwise use their income together (income sharing) in private households. Its disposable income is income after tax and transfers.

Since the members of the household share their income, the household is the most relevant unit for equity analysis. The income concept to be used in equity analysis is household disposable income per consumption unit (see Chapter 14).

### *Hypothecation*

The requirement that income should be spent on specified items or areas of policy. For example, if revenue from road user charges were hypothecated to expenditure on public transport, expenditure of that revenue on relieving general taxation, or any other purpose other than public transport, would be forbidden.

### *Income*

An agent's income per period may be defined as the amount he can spend in the period without reducing his wealth. For households, this concept of income is *household disposable income*.

Income affects travel behaviour and other consumption choices. In our models, this takes place predominantly through car ownership and housing choices.

In consumer theory, the effect of income on consumption is captured by a budget constraint requiring total expenses to stay within available income. The possibility of saving is often abstracted from, so the income that constrains consumption must be taken as the amount available after saving.

*Indicator*

An item which, when measured, indicates the state or status of some aspect of a system. Thus the average speed of car journeys might be an indicator of congestion, the number of parts per million of carbon monoxide might be an indicator of pollution and the number of work destinations within a ten minute travel isochrone might be a measure of accessibility.

*Instrument*

See *policy instrument*.

*Intergenerational equity*

A fair distribution between present and future generations. See *sustainability, equity*.

*Irreversibility*

Anything that cannot be undone is irreversible.

Consider two polar cases. In the first case, we acquire some asset and incur costs now to get benefits later. In the second case, we consume some asset now and get benefits from it, but will have to pay the costs later. In both cases the future costs or benefits are uncertain.

In the first case, irreversibility means that if the benefits turn out to be smaller than we thought, we are not able to sell the asset and recover our costs. The costs are sunk.

In the second case, irreversibility means that if the costs turn out to be higher than we thought, we will not be able to do anything about it. We cannot acquire the asset again, and there is no other way of reducing the costs.

Irreversibility calls for caution. In the first case, we might consider postponing the investment until it becomes clearer what the benefits will be. So irreversibility makes us want a more thorough analysis before we commit to the investment, increases the minimum benefit/cost ratio required to go ahead, and in general makes us more inclined to turn down the investment.

In the second case, we will be more reluctant to consume the asset now and might want to stop consumption until the future cost have been more clearly identified. Only if the benefits are large will we go ahead.

This will be our thinking if the future costs or benefits are borne/reaped by our generation. If we think of a long-term future, the issue of intergenerational equity adds something to these considerations. In the first case, it may work against the cautionary principle and make us more willing to commit to the investment. In the second case, it reinforces the cautionary principle and makes us even more sceptical about consumption now. (This applies if the current generation is likely to be better off than future generations. If we know for certain that future generation will be better off than us, intergenerational equity will work the other way).

*Kaldor-Hicks criterion*

See *economic efficiency*.

*Lagrangian, Lagrangian multiplier*

Consider a function  $f$  of many variables  $\mathbf{x} = (x_1, \dots, x_n)$ . Suppose we want to maximise  $f(\mathbf{x})$  with respect to  $\mathbf{x}$  subject to a set of constraints

$$g_1(\mathbf{x}) \leq h_1, \dots, g_m(\mathbf{x}) \leq h_m.$$

To solve the problem, we form the Lagrangian

$$L(\mathbf{x}, \boldsymbol{\lambda}) = f(\mathbf{x}) - \sum_i \lambda_i (g_i(\mathbf{x}) - h_i),$$

where  $\boldsymbol{\lambda} = (\lambda_1, \dots, \lambda_m)$  are unknown *Lagrangian multipliers*. It turns out that to maximise  $L(\mathbf{x}, \boldsymbol{\lambda})$  with respect to  $\mathbf{x}$  and  $\boldsymbol{\lambda}$  is equivalent to solving the original problem, and more convenient. The solved Lagrangian multipliers have the following economic meaning:  $\lambda_i$  represents the marginal cost, in units of the

objective function  $f(\mathbf{x})$ , of keeping inside the constraint  $g_i(\mathbf{x}) \leq h_i$ . (This marginal cost is often called a *shadow cost*). Or equivalently, it represents the value of a marginal increase in the available resource  $h_i$ .

For instance, in the problem to maximise utility  $u(\mathbf{x})$  subject to a budget constraint  $\sum_i p_i x_i \leq R$ ,  $\lambda$  represents the marginal utility of income.

#### *Land use/transport system*

Except for simple theoretical models, the urban area is usually modelled as a set of zones. The transport system consists of the markets for trips between these zones (passenger and freight). The land use system consists of the markets for land in these zones and the market for housing and for production and service facilities on this land. To make the model complete, we will also have to include the labour market, since it determines the destination of work trips and the location of households, and the production of services, since it determines the destinations of other trips.

To account fully for freight, we need to include not only the markets for the inputs labour and land, but also the market for outputs from production. This is however not always done in LUTI models.

Finally, the land use system thus modelled gives rise to externalities (pollution, noise, accidents) that will also have to be included in the system.

#### *Landlord*

The owner of housing and production facilities or the land upon which these facilities stand. Landlords are the suppliers in these markets. They might or might not be identical to the property developers. Also, they might or might not be identical to the households and firms.

#### *Liberalisation*

See *deregulation*.

#### *Linear combination*

A linear combination of a set of variables  $\mathbf{x} = (x_1, \dots, x_n)$  is any function of the form  $f(\mathbf{x}) = a_0 + \sum_i a_i x_i$ , where  $a_0, a_1, \dots, a_n$  are constants.

A convex combination is a linear combination with  $a_0 = 0$  and  $\sum_i a_i = 1$ .

#### *Liveable streets and neighbourhoods*

Pleasant street and outdoor conditions in residential areas. It includes the positive external effects on social, cultural and recreational activity in neighbourhoods, freedom of movement on foot and bicycle, and reduced sense of danger for these modes. It is linked to, but separate from, the environmental and safety objectives.

#### *Management*

Management of the transport infrastructure is the provision of services to control and regulate the use of the infrastructure. It includes the provision of information to this end, traffic control, policing etc. Under this concept, we also include maintenance of the infrastructure (resurfacing, snow clearing etc.) and the provision of equipment and hardware (vehicles, cabling, data equipment, electricity) to perform these tasks.

The term management may be used more generally to denote the control of any system at the strategic, tactical or operational level.

#### *Metropolitan area*

A city of some size (say half a million) including its commuting region, or a cluster of such cities within commuting distance of each other.

#### *Model*

Usually, by a model we mean a formal mathematical description of a system. In



our context, a model of the transport or transport and land use system is often just called a model for short.

*Monitoring*

A continuous or regular programme of measuring changes and trends in the transport system. Monitoring conditions, using similar *indicators* to those for objective analysis, is also a way of identifying *problems*.

*Multi-criteria analysis*

*Appraisal* against more than one criterion or objective, using weights to express the relative importance of each of them and adding their weighted corresponding *indicators* to form an *objective function*. See section 3.4.4.

*Municipality*

The lowest level of government with its own elected governing body. (If even lower levels of government exist, they will be crucially dependent on the municipality for their budgets).

*Natural habitat*

A natural habitat of an animal or plant is a place where it can be found in its wild state.

*Natural capital*

The *stocks* of *natural resources*. Since this is a vector of extremely many dimensions and there is no agreed way to transform it into a one-dimensional measure, the concept of natural capital is for the most part misleadingly simple.

*Natural resource*

Anything from nature that is of use or gives utility to men, now or in the future, either as primary products or without being processed. Natural resources are classified into renewable and non-renewable (exhaustible). Non-renewable resources have a zero rate of regeneration, so any consumption or destruction means so much less for the future. Renewable resources have a positive rate of regeneration which may however depend on the level of use and the management of the resource and its surrounding ecosystems. The rate of regeneration as a function of the level of use might be highly non-linear and turn into negative beyond a certain threshold.

*Net present value*

See *cost benefit analysis, discounting*.

*Non-welfarist objective*

Society will have objectives going beyond the utility of individuals. This is for instance the case in wars. Also, the individuals may have objectives that are not reflected in their utility function, such as preferences on the allocation process, not only on the outcomes they themselves receive. All objectives that are not reflected in *welfare functions* (functions defined only over individual utilities) are called non-welfarist.

*Objective*

Objectives are broad statements of the improvements which a city is seeking in planning its land use and transport system. Objectives specify the directions for improvement, but not the means of achieving them.

*Objective function*

One or more *objectives* incorporated into a mathematic expression, used to appraise strategies or for optimisation. See Section 3.4.2 and chapter 7, respectively.

*Optimal*

An optimal strategy is one which achieves the maximum of the objective function. See Chapter 7 on optimisation.

*Optimisation*

The process of identifying the strategy that achieves the maximum of the objective function. See Chapter 7.

*Option*

A choice. In transport, usually meaning one possible strategy among several alternatives.

*Performance*

The degree to which an action is successful, or predicted to be successful; usually judged against one or more *objectives, indicators, thresholds* or *targets*.

*Performance matrix*

A performance matrix is the same as an appraisal framework, and is outlined in table 3.2. The columns of the matrix are the tested strategies and the rows are indicators, each reflecting goal achievement with respect to an objective.

*Policy instrument*

Policy instruments are the specific means by which policies are implemented (e.g. lower bus fares, road pricing). Other names for policy instruments are policies, measures and even projects. The latter term is mainly used for policy instruments of infrastructure provision. Appendix I provides a list of the policy instruments that we consider – see also section 2.7

For the purpose of strategic planning, policy instruments may be classified into strategic and supportive, or strategic and local (see section 7.1). The policy instruments considered there will be either discrete (applied or not applied) or continuous (applied at any level within a range).

In general, though, policy instruments have more than one dimension, and so the strategic viewpoint of section 7.1 is a simplification. The full complexity of each instrument is described in the Policy Guidebook.

*Present value*

See *discounting*.

*Present value of finance*

The annual value of finance of a strategy is the net result of the government budget (revenue minus payments). The present value of this (see *discounting*) is the present value of finance (PVF). In strategic planning, there will usually be a *constraint* on the present value of finance, stemming from the need to balance government budgets in the long run and the need to keep public expenditure on transport within certain bounds.

*Privatisation*

See *deregulation*.

*Producer surplus*

Producer surplus is a firm's revenue minus variable cost. In many of our strategies, the producer surplus of public transport operators will be negative. The deficit will be covered, in part or in full, by government subsidies and grants. As a rule, a *constraint* to the effect that producer surplus plus subsidies should be positive must be imposed, either explicitly or through making the "cost-plus" assumption that any deficit is to be covered by the government.

*Public transport service level*

This concept may have many dimensions and be defined in many ways. However, a useful definition for the public transport system as a whole is vehicle kilometres,

seat kilometres or capacity kilometres per period per square kilometre. Vehicle kilometres per square kilometre is less useful if some public transport modes use large vehicles and others use small. In that case, seat kilometres per square kilometre, in conjunction with average frequency, might be used. Indicators of overcrowding and average speed (compared to car) might be used as supplements.

*Regional*

A region in our circumstances might denote a *metropolitan area* (see this).

*Reliability*

For the road system, reliability means small daily variations in trip times. For the public transport system, it means that scheduled departures are running and arrive at all stops on schedule (punctuality).

*Rent*

Per period remuneration to *landlords* (see this). More generally, rent may mean remuneration to the factors of production in fixed or scarce supply. While factors of production that are fixed in the long run earn so-called 'economic rent', factors that are only fixed in the short run earn so-called 'quasi-rent'.

*Revenue*

Sales of firms or government income from taxes or charges.

*Risk premium*

Most people try to avoid risks (they are risk adverse). Consequently, their willingness to pay for an asset yielding 4% per annum with absolute certainty may be equal to their willingness to pay for an asset yielding 7% on average, but with big annual fluctuations. The difference – here, 3% – is the risk premium. Investors can eliminate some of the risk by diversifying their holdings, but some of the risk remains. The same, we assume, is true for a government considering to invest in transport and land use projects. Even if the government may diversify by investing in many projects, a risk premium remains and should be taken account of in setting the *discount rate*.

It may be argued that what is important for the risk premium is how the project contributes to reduce or increase the fluctuations of the yield on all national assets – the gross national product. See sections 3.6 and 8.3.

*Robust*

Likely to be successful in a wide range of future *scenarios*.

*Safety*

Safety to us is traffic safety. The traffic safety objective means to reduce the total traffic accident costs in the urban area. For each mode, accident costs are reduced by reducing the unsafe activity, by reducing the risk per unit of the activity (usually vehicle kilometres), or by reducing the average impact of an accident. See sections 12.1 and 12.4.

*Scenario*

Possible future development in terms of a range of factors such as economic growth, changes in population and household size, income and car ownership. See Section 2.5.

*Security*

Security is the subjective feeling of safety – safety from traffic accidents as well as other unpleasant or dangerous incidents. This feeling may be an important aspect of a sustainable land use and transport system, but one which we have not been able to take into account in our kind of planning.

*Sensitivity analysis*

Sensitivity analysis is a programme of tests of a strategy (usually the best performing strategy) or a set of strategies to find out how their performance changes with changes in the assumptions. These may be scenario assumptions (section 2.5), assumptions on unit values, weights and other parameters, or even assumptions on the relationships in the model. See section 3.6.

*Shadow cost, shadow price*

The marginal cost of keeping within a *constraint* (or the marginal benefit of being able to slacken the constraint). Such shadow prices depend on the formulation of society's *objective function* (the way we weight individual utilities together) and on the particular resource constraints that are seen to apply.

The term 'shadow price' is often used to denote the correct accounting price in a cost benefit analysis. We use 'social cost' to denote the same. The shadow prices of cost benefit analysis are ultimately identical to the shadow costs of an appropriately specified constrained optimisation problem. See *Lagrangian*.

*Social cost*

The social cost of a resource is the value it would have in its best alternative use. The implications of this are brought out in chapter 10. Very briefly, the value it would have in its best alternative use is what alternative users would have been willing to pay for it (on the margin), corrected for the costs imposed on non-users.

*Social exclusion*

To a varying extent, society excludes groups of people from the labour market, from public services and from normal social activities. Transport and land use strategies may not be the primary instruments to counteract social exclusion. But a car-based society is bound to create problems for those that cannot afford a car and those that cannot drive for other reasons. This is why we define social exclusion in our context as a low level of accessibility for those without a car and the mobility impaired. High housing rents and homelessness are also issues here, but are not covered at present.

*Social welfare function*

A social welfare function, or a welfare function for short, is defined in economics as a function of the individual utilities of all members of society. It is increasing in each argument, meaning that an increase in the utility of any individual is improving the welfare of society.

To be useful, a social welfare function should also reflect the importance of increasing the utility of one group of individuals relative to other groups – in brief, it should incorporate society's attitude towards distribution. However, since distributional objectives have many aspects, to measure welfare in this guidebook, we have settled for a utilitarian welfare function, modified to take account of intergenerational equity, and used in conjunction with explicit equity objectives and indicators. (A utilitarian welfare function assumes that an additional euro counts the same to society regardless of who gets it).

*Stakeholder*

All those people and organisations which have an interest in the transport system, whether as users or non-users.

*Stock*

Society's stocks at any point in time consist of its amounts of natural and produced resources. It is important to distinguish between stocks and flows. Flows are the changes in stocks per period – through production, consumption, natural regeneration etc.

*Strategy*

In this guidebook, a strategy is a combination of *policy instruments*, as they are applied over time.

*Sustainability*

Meeting the needs of the present without compromising the ability of future generations to meet their own needs. See Sections 2.3-2.4 and 3.5.

*Synergy*

Synergy between the policy instruments a and b exists if the application of a alone contributes A to the objective function, the application of b alone contributes B to the objective function, but the application of a and b together contributes  $C > A + B$ .

However, for various reasons this concept is not as simple as it seems. First, we may have targets for indicators that are not included in the objective function. There may be synergy with respect to the objective function, but quite the opposite with respect to a target. Second, the level of synergy depends on the level of use of the policy instruments, and may also depend on the scenario, the particular circumstances of a city etc.

*Target*

An aimed-for value of an *indicator*. See Section 3.4.1.

*Threshold*

The value of an *indicator* that should not be exceeded.

*Uncertainty*

Our analyses will be highly uncertain. There is uncertainty about which state of the world will apply in the future (scenario uncertainty), about what we ourselves will do in the future (endogenous uncertainty), about the objectives and norms on which we base our analysis and whether we have reflected them correctly, and about the relationships and mechanisms governing the land use and transport system and whether we have reflected them correctly in our models. See section 3.6.

*Urban sprawl*

Urban sprawl means the tendency for cities to spread out over wider areas with time, and for land use to become less dense.

*Vulnerable area*

A vulnerable area is one whose *ecosystems* are on the verge of breaking down or whose cultural values are about to get destroyed.

*Welfare function*

See *social welfare function*.

*Whitefield*

A location not zoned for any particular type of development.

*Willingness-to-pay*

An individual's willingness to pay for a change is the highest amount of money he is willing to pay to get the change. If, however, the change is for the worse, the monetary value to him must be expressed by his willingness to accept, which is the least amount of money he must have to accept the change.

All of this is based on the assumption that the changed situation is not his by right or by law. If it is, we should rather ask for his willingness to accept that the change is not made if it is a positive one, and his willingness to pay for reverting to the initial situation if the change was a negative one.

As willingness to accept gives higher values than willingness to pay, the latter concept is often used for economic valuation, regardless of rights.

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# Appendices



## **Appendix I**

# **Policy instruments**

## **The range of transport policy instruments**

The approach which has been adopted in the PROSPECTS guidebooks and KonSULT (<http://www.transportconnect.net/konsult/index.html>) has been to group policy instruments under the following six headings:

1. land use measures
2. attitudinal and behavioural measures
3. infrastructure provision
4. management of the infrastructure
5. information provision
6. pricing

This grouping focuses on the type of intervention rather than the mode of transport, since the same principles often apply whichever mode is used. However, we also distinguish, for the final four categories, between measures which:

- influence car use;
- influence public transport use;
- provide for cyclists and pedestrians;
- provide for freight.

## **The detailed list of instruments**

### **Land use measures**

The overall emphasis of these measures is to identify ways in which the demand for travel can be reduced, or modified to lessen its impact.

- Development densities, involving an increase in density of development throughout an area to reduce the need to travel;
- Development pattern, including transport corridor-based developments designed to encourage provision and use of public transport;
- Development mix in which homes, jobs and shops are placed close together, thus reducing the need to travel;
- Protection of certain sites from development;
- Parking standards for new development;
- Commuted payments, whereby developers can provide less parking, but pay for public space;
- Developer contributions to the financing of infrastructure;
- Value capture taxes, designed to reflect the windfall benefits to existing developments from improved accessibility;
- Other land-use taxes, including property taxes.

### **Attitudinal and behavioural measures**

- Public awareness campaigns, designed to encourage individuals to use alternatives which reduce overall travel, and travel by car;
- Flexible working hours;
- Telecommunications as an alternative to travel; and
- Company travel plans, in which firms set out ways in which they can reduce their demands on the transport system.

### **Infrastructure measures**

The measures listed under this heading involve additions or enhancements to the existing transport infrastructure. The main ones are:

#### *Measures to influence car use*

- New road construction;
- New off-street parking.

#### *Measures to influence public transport use*

- Upgrades to existing fixed infrastructure;
- Reopening closed rail lines;
- New rail stations;
- New rail lines;
- New rail services on existing lines;
- Light rail systems;
- Guided bus systems;
- Park and ride;
- Terminals and interchanges; and
- Enhancement of bus and rail vehicles.

#### *Provision for cyclists and pedestrians*

- Cycle routes;
- Pedestrian routes; and
- Pedestrian areas.

#### *Provision for freight*

- Lorry parks;
- Transshipment facilities.

### **Management measures**

The measures listed under this heading involve changing the way in which the existing transport infrastructure is used. They involve a wide range of approaches, including increases and reductions in road capacity, reallocations of that capacity, and changes in the operation of public transport.

#### *Measures to influence car use*

- Road maintenance;
- Conventional traffic management;
- Conventional speed controls and restrictions;
- Urban traffic control systems;
- Intelligent transport systems, which use new technology to improve the performance of the road network;
- Accident remedial measures;
- Traffic calming measures;
- Physical restrictions;
- Regulatory restrictions;
- Parking controls, including controls on duration, entry times and designated users
- Car sharing.

*Measures to influence public transport use*

- Maintenance of existing fixed infrastructure;
- New bus services;
- Bus priorities;
- High occupancy vehicle lanes;
- Changes in bus and rail frequencies;
- Timetabling strategies, such as regular "clock-face" departure times and simple (eg 10 minute headways);
- Bus service management measures designed to improve reliability;
- On-bus cameras for traffic regulation enforcement.

*Provision for cyclists and pedestrians*

- Cycle lanes and priorities;
- Cycle parking provision;
- Pedestrian crossing facilities; and
- Safe routes to school, including innovations such as "walking bus services" in which children walk together.

*Provision for freight*

- Lorry routes and bans; and
- Lorry parking and loading restrictions.

## **Information provision**

The measures listed under this heading involve improvements in the information available to transport users and operators. Some are traditional fixed information systems, others draw on real time applications of information technology. They include:

*Measures to influence car use*

- Conventional direction signing;

- Variable message signs;
- Real-time driver information systems and route guidance; and
- Parking guidance and information systems.

*Measures to influence public transport use*

- Conventional timetable and other service information;
- Real time passenger information;
- Trip planning systems which provide information on alternatives before the start of the journey;
- Operation information systems such as bus fleet management.

*Provisions for cyclists and pedestrians*

- Static direction signs;
- Tactile footways.

*Provision for freight*

- Static direction signs;
- Fleet management systems.

## **Pricing measures**

*Measures to influence car use*

- Parking charges;
- Charges for ownership of private parking space;
- Urban road charging, including area licensing and road pricing;
- Vehicle ownership taxes;
- Fuel taxes.

*Measures to influence public transport use*

- Fare levels;
- Fares structures, such as flat fares, zonal fares and monthly passes;
- Integrated ticketing systems; and
- Concessionary fares, which are lower for identified groups of users such as elderly people.

## Appendix II

## A full list of suggested indicators

This Appendix sets out a list of indicators at the three levels, and provide short definitions of each of them. Section 3.3.2 of the text contains a shorter list of the selection of these indicators that we think will be the preferred options in most cases.

These indicators cover the objectives

- economic efficiency
- protection of the environment
- liveable streets and neighbourhoods
- safety
- equity and social inclusion
- contribution to economic growth

The seventh objective, intergenerational equity, is covered by the weight we attach to net annual benefits at the end of the appraisal period, see Section 3.5.

The indicators are numbered in the following way: 10, 20, 30, 40, 50 and 60 represents our six objectives, while 11, 12 etc. represents different indicators covering the sub-objective 10. The level of the indicator (see Section 3.3.2) is indicated in a parenthesis, so 12(2) is a second level indicator. Where there are many alternative indicators at the same level, this will be marked by a star. Each indicator is tied to the sub-objective it is meant to reflect. Short definitions and references are provided.

The indicators of this list (except 5-12(1)) are meant to be annual values. Where relevant, these annual values will of course be discounted and added to form present values.

### 10 Economic efficiency

11(1) Economic efficiency

*Annual net benefits as measured by an ordinary CBA, see Chapter 8.*

12(2) Accessibility measures

13(2) Public expenditure

The indicators 12(2) and 13(2) are meant to be used together and form an alternative way of capturing the main impacts that are usually covered by a CBA, if for some reason one does not want to use CBA methods. These main impacts are of course the changes experienced by the users and the costs incurred by the government. A comprehensive and up-to-date survey of accessibility measures can be found in Geurs and Ritsema van Eck (2001). The

specification of indicator 12(2) can be made by using this or similar sources.

## **20 Protection of the environment**

### *2.1 Energy use and climatic change*

21(1) CO<sub>2</sub> cost *Emissions in tonnes weighted by shadow cost of national CO<sub>2</sub> target. May be presented by source. See Chapter 16.*

22(2) CO<sub>2</sub> emission *Emissions in tonnes*

### *2.2 Local and regional pollution*

23(1) Air pollution cost *Pollutants in tonnes weighted by unit costs. May be presented by substance and sources. See Sections 12.1 and 12.3.2.*

24(2) Emissions of air pollutants\* *Pollutants by substance in tonnes. May be presented by sources. See Sections 12.1 and 12.3.2.*

25(2) Air quality\* *Requires dispersion model. See Section 12.3.2.*

26(3) Local pollution index *As defined by answers to a questionnaire.*

### *2.3 Protection of valuable areas*

27(1) Green areas cost *Total cost of lost cultural heritage sites, natural habitats, green areas, agricultural land and recreational areas, each with their own shadow cost of not being developed. May be presented by type of land.*

28(2) Green area share *Types of land as in 27, measured as a percentage of built area.*

29(3) Green area index\* *As defined by answers to a questionnaire*



2-10(3) Green poster*	<i>A system of valuing valuable area changes, see PROSPECTS Deliverable 1 for reference.</i>
<i>2.4 Urban sprawl</i>	
2-11(2) Urban sprawl I	<i>Average trip distance.</i>
2-12(2) Urban sprawl II*	<i>Average distance of housing units to city centre (assuming there is only one centre).</i>
2-13(2) Main land uses*	<i>Area of land (a) not used, (b) built and (c) used for transport purposes in percent.</i>
<i>2.5 Fragmentation</i>	
2-14(3) Fragmentation index*	<i>As defined by results from a questionnaire</i>
2-15(3) Green poster fragmentation assessment*	<i>See PROSPECTS Deliverable 1 for reference to Green poster</i>
<i>2.6 Vulnerable areas</i>	
2-16(2) Vulnerable areas	<i>Percentage lost or damaged</i>
2-17(3) Conservation measures*	<i>Percentage subject to special conservation laws or measures.</i>
2-18(3) Green poster vulnerable areas assessment*	<i>See PROSPECTS Deliverable 1 for reference to Green poster</i>
<i>2.7 Noise</i>	
2-19(1) Noise cost	<i>Unit noise costs per vehicle kilometre in an area multiplied by vehicle kilometres of different classes of vehicle</i>
2-20(2) Noise	<i>Residents exposed to outdoor average noise level 60dbA (Leq or Leu) at home</i>

### **30 Liveable streets and neighbourhoods**

#### *3.1 Increased freedom of movement for vulnerable road users*

- 31(1) Vulnerable user accidents *Number of accidents involving pedestrians/-cyclists and a car multiplied by average cost. See Chapter 15.*
- 32(3) Safety and security score *As defined by results from a questionnaire.*

#### *3.2 Positive external effects on social, cultural and recreational activity*

- 33(2) Local activity index *Attractivity measure –see Chapter 15.*
- 34(3) Positive externalities score\* *As defined by results from a questionnaire.*

### **40 Reduce traffic accidents**

- 41(1) Accident costs *Number of accidents of average severity times unit cost of accidents of average severity. May be presented by modes involved and location/type of road. See Section 12.1 and 12.4.*
- 42(2) Accidents *Number of accidents of average severity. May be presented by modes involved and location/type of road.*
- 43(3) Danger & intimidation *As defined by results from a questionnaire.*

### **50 Equity and social inclusion**

#### *5.1 Accessibility for those without a car*

- 51(1) Accessibility for those without a car\* *A Kolm measure of inequality – see Section*

*14.2. Alternatively, consumer surplus per capita for those without a car as a proportion of overall consumer surplus per capita.*

52(2) Public transport performance\*

*Frequency and geographical coverage of the public transport supply.*

53(2) Proximity to services\*

*Index of mean distances from residential areas to green areas and basic services.*

54(3) Without car accessibility index

*As defined by the results of a questionnaire.*

The two level 2 indicators should preferably be used in conjunction. One possible way of specifying them is to use accessibility measures for the modes public transport and walking and cycling.

*5.2 Accessibility for the mobility impaired*

55(3) Quality of PT wrt mobility impaired\*

*Describe access/egress distances, how easy it is to board, how easy it is to get a seat and the systems of information*

56(3) Level of special services\*

*Describe special services*

57(3) Mobility impaired access index\*

*As defined by the results of a questionnaire.*

The indicators 55(3) and 56(3) should preferably be used in conjunction.

*5.3 Equity and compensation to losers*

58(1) Income inequality index

*A Theil  $S_0$  measure of the inequality of the distribution of generalised income. Might be decomposed. See Section 14.2.*

59(2) Equity impact tables

*Consumer benefits plus compensation displayed by group (Household income groups, household types, households by location). See Chapter 14.*

5-10(1) User benefit inequality

*A Kolm inequality index applied NOT to income groups but to household types, residents at different locations or any other differentiation. See Chapter 14.*

5-11(2) Benefits/accessibility by zone

*A map presentation of spatial distribution of benefits. See Chapter 14.*

An alternative way to specify indicator 5-10(1) would be to apply a scale invariant inequality measure to accessibility, since accessibility is positive in all strategies including the do minimum. See Section 14.2.

*5.4 Economise on taxpayers' money*

5-12(1) Taxpayers' money

*Net present value of finance as a percentage of total net benefits. See section 3.3.2 and Chapter 14.*

**60 Support economic growth**

61(1) Growth potential

*Sum of user benefits, producer surpluses and value of finance as defined in Chapter 8. See Section 3.3.2.*